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Integrating data of veterinarians’ practices in assessing the cost effectiveness of three components of the bovine tuberculosis surveillance system by intradermal tuberculin testing in French cattle farms through a scenario-tree approach

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ABSTRACT

Disease surveillance systems’ effectiveness relies on participants following prescribed practices. We developed a general method to improve a previous cost-effectiveness evaluation of three French screening program protocols for bovine tuberculosis (bTB) to account for the practices of participants by scenario tree modelling. This method relies on: 1) semi-directive interviews of participants to identify the variability of practices and potentially influential factors, and to understand the sociological context; 2) a quantitative survey, based on multiple-choice questions, to quantify various practices and identify significantly influential factors by multivariable regression analyses; 3) addition of the scenario-tree nodes corresponding to the practices and their influential factors and configuration of the new limbs according to the data of the quantitative survey.
We used this approach to integrate data concerning veterinary practices and identify some failures to conform to regulatory guidelines regarding intradermal cervical comparative tuberculin test (SICCT) (testing and notification of non-negative results). Such nonconformities appeared to be mainly caused by cattle restraint issues and the perception of veterinarians of the bTB control program. Indeed, their perception of that program significantly influenced veterinarians’ practices. We modelled the influence of the SICCT practices on the SICCT results. The incorporation of these data led to a major decrease of the herd sensitivity estimations relative to the previous assessments that did not incorporate data of practices (15% to 42% decrease). This result shows the important impact of veterinarians’ practices and their influencing factors (such as perception of the bTB control program) on the effectiveness of the surveillance system.

KEYWORDS: practices, scenario tree, bovine tuberculosis, sensitivity, surveillance, intradermal tuberculin test

INTRODUCTION

Quantitative evaluation methods to evaluate the effectiveness of animal surveillance systems are well established. Indeed, methods, such as scenario tree modelling, have been formally described (Martin et al., 2007) and used in many surveillance system evaluations (Hadorn et al., 2009; Christensen et al., 2011; Hénaux and Calavas, 2017). These methods usually use epidemiological and, for cost-effectiveness evaluations, economic data. In parallel to the development of these methods, the acceptability of surveillance systems and the corresponding practices by the participants has been studied. Indeed, the effectiveness of disease surveillance systems relies mostly on the willingness of their actors to participate and follow prescribed practices (Pfeiffer, 2006). This willingness depends in part on the epidemiological context of the considered disease and the perceived severity and consequences of it (Brennan et al., 2016). Thus, studies have evaluated the
willingness of actors to follow prescribed practices (Sayers et al., 2014; Delabouglise et al., 2017; Pham et al., 2017). In some of them that used participatory epidemiology, actors are directly implicated, allowing them to identify motivational levers and obstacles to the effectiveness of surveillance systems and to sometimes suggest means to improve them (Catley, 2006; Delabouglise et al., 2017). In the past few years, the increase of published studies investigating the influence of the practices and perceptions of veterinarians and farmers on the effectiveness of disease control programs shows the growing interest in these factors (O’Hagan et al., 2016; Schulz et al., 2016; Ciaravino et al., 2017; Rivière et al., 2018). Nevertheless, most of these studies were qualitative and even quantitative ones have never combined data concerning the practices of actors and associated influential factors with standard epidemiological and economic data in a global quantitative evaluation of disease control systems.

Here, we aimed to develop a method to integrate data concerning actor practices (in our example, the practice of SICCT and notification of non-negative results by veterinarians) within our research on bovine tuberculosis surveillance (bTB) in cattle and the factors that influence them in scenario-tree modelling, the quantitative method we used for the efficiency assessment. Indeed, we first evaluated the cost-effectiveness of periodic screening on French farms by scenario-tree modelling (Poirier et al., 2019). This first evaluation allowed us to identify the most efficient protocol for each type of herd (according to production type, herd size, and herd turnover) but accounted only for epidemiological and economic data. However, other factors, such as how the intradermal cervical comparative tuberculin test (SICCT) is practiced by the veterinarians or their willingness to notify authorities of non-negative results of the SICCT (which depends on his perception of bTB surveillance and control programs) could influence the effectiveness of bTB surveillance on French farms. The community of bTB researchers and surveillance managers empirically recognize the influence of such factors on bTB surveillance of cattle. In addition, the particular French context, in which private veterinarians are empowered by the State to perform regulatory controls on their own customers’ farms in a low bTB prevalence context, could potentially lead them to less frequently notify the authorities of non-
negative SICCT results. Indeed, they may want to avoid being responsible for negative sanitary and economic consequences for their customers’ farms, as false-positive results are currently frequent in the French epidemiological context and trigger serious restrictive measures, such as the ban of selling animals. In other European countries, researchers have begun to semi-quantitatively study veterinary SICCT practices (Humblet et al., 2011; Ciaravino et al., 2017). We also investigated these factors in France and strengthened the approach by integrating data concerning veterinary practices and the most influential field factors (determinants) in our quantitative evaluation of the bTB surveillance system component in cattle farms. Here, we describe the method we developed for integrating qualitative data concerning actor practices into scenario-tree modelling and its use in the evaluation of bTB surveillance by periodic screening of French farms. The use of this method will result in a more realistic estimation of the cost-effectiveness of the periodic screening component of the French bTB surveillance system to identify issues related to this component and suggest operational solutions for its improvement.

MATERIALS AND METHODS

1. The regulatory bTB surveillance protocols studied

In a previous study, we developed scenario-tree models to estimate the cost and sensitivity of the three regulatory French protocols of bTB surveillance in farms (Poirier et al., 2019): “strict”, “compliant quick-path”, and “compliant slow-path” protocols. These protocols all begin with the screening of cattle using the intradermal comparative cervical tuberculin test (SICCT). If at least one non-negative result is obtained in a herd, authorities consider the farm to be suspect and different protocols can be applied to investigate the suspicion.

In the strict and compliant quick-path protocols, non-negative animals are culled and laboratory tests (PCR, histology, and bacteriology) performed. If one of these tests detects *Mycobacterium tuberculosis*, *M. bovis*, or *M. caprae*, the herd is officially considered infected. Otherwise, in the
compliant quick-path protocol, the farm recovers its official bTB-free status, whereas in the strict protocol, a second negative SICCT on remaining animals in the herd is needed to recover the bTB-free status.

In the compliant slow-path protocol, cattle that are non-negative by the first SICCT (SICCT1) are tested with the interferon gamma test (IFNγ). The result of this test determines the next step of the protocol. If a cow obtains a positive result to the IFNγ test, it is culled and laboratory tests are performed, as for the two other protocols; otherwise cattle that were non-negative by SICCT1 are re-tested with the SICCT (SICCT2) six weeks later.

Scenario trees used to model these protocols were developed at the level of the individual animal. They accounted for herd type (production type, herd size, and herd turnover), age of the animal (younger or older than 24 months, which is the age limit at which they are tested with the SICCT), bTB status of the herd and that of the considered animal, and SICCT, IFNγ, and laboratory (PCR, histology and bacteriology) test results. Their implementation has been described in the corresponding published article (Poirier et al., 2019).

Here, we used these scenario trees as a starting point and integrated data concerning the veterinarians’ practices into them.

2. Method for integrating data about actor practices into scenario trees

2.1. A qualitative survey to identify potentially influential factors on veterinarians’ practices

The first step is to qualitatively investigate the participants’ practices and the sociological context. Such a qualitative investigation has several aims. First, it allows better knowledge of existing differences in practices to be estimated quantitatively afterwards. Second, it helps to identify factors that potentially influence such practices. This leads to hypotheses that guide the quantitative investigation by indicating the factors for which data must be collected and to help formulate
appropriate questions and pertinent suggested answers. Finally, it provides a better understanding of
the sociological context in which these practices are performed and of the actors’ difficulties and
concerns and thus highlights important information for the global discussion of the quantitative
results and the suggestion of improvements. This survey should be performed through semi-directive
interviews with the participants. The participants are chosen to maximally represent the diversity of
field practices and contexts. The aim is not to be representative of the population of all actors of
interest but to have a vision of all possible situations. In theory, the only rule deciding the size of the
sample is “theoretical saturation”: interviews stop when the interviewed actors express no more new
ideas (relative to the previous interviews).

For example, no study has yet been conducted in France concerning the factors that influence the
practice of the intradermal cervical tuberculin skin test (SICT) by veterinarians and/or their
perception of the bTB surveillance and control program. Hence, a qualitative study was first
conducted in collaboration with the French Ministry of Agriculture. Fifty-eight veterinarians with a
rural activity from seven administrative areas were interviewed (semi-directive interviews) (Guillon
et al., 2018; Gully and Hamelin, 2018). The seven administrative areas were selected to represent the
diversity of French cattle farming concerning three factors. First, bTB infection levels (bTB prevalence
between 2012 and 2016 and the existence of outbreaks after 2015) which could influence veterinary
practices due to its potential influence on their perception of the prevalence of bTB and the number
of SICTs performed by each veterinarian (because the level of bTB infection influences the
frequency of periodic screening of an area). Second, the main type of production (beef or dairy),
which could influence cattle restraint facilities and therefore the difficulty to perform SICTs. Third,
the screening frequency (annual, variable -some parts of the area are annually screened and others
less often or not all-, or every two, three, or four years), which influences the veterinarians’
experience of practicing SICTs, as it determines the number of SICTs performed. During these
semi-directive interviews, veterinarians were asked about the organisation of the periodic screening
for bTB in their clinic, how they perform SICTs in the field and what difficulties they encounter, how
they interact with the other actors of the surveillance program (farmers, authorities, cattle), and their views concerning the bTB surveillance and control program, its necessity, and difficulties. Data concerning their training, veterinary career, and demographic characteristics were also collected (appendix A).

The results of this qualitative study (presented in the “results” section) guided the design of the quantitative survey about the practices of veterinarians concerning SICCT and the collection of data about the factors that potentially influence these practices. In addition, qualitative data concerning the veterinarians’ perception of the bTB surveillance and control program helped in the formulation of the questions and suggested answers.

2.2. A survey to quantify practices and the variables that potentially influence them

The objective of this survey is to quantify the occurrence of each type of practice and the factors identified to potentially influence them. In our study, it was carried out by Crozet et al. (Crozet et al., 2019). They performed an online survey and asked veterinarians about their practices of SICT, notification habits, perception of the bTB surveillance and control program, and the characteristics of their customer’s farm (size, production type, restraining equipment, etc.). Data about the age, sex, training, number of SICCTs performed in the previous year, and the percentage of rural activity of the responding veterinarian were also collected. For the needs of our study, we only used the answers of veterinarians who performed at least one SICCT during 2017 in the context of programmed farm screening (115 of the 210 exploitable answers). Some of the raw results of the quantitative survey needed to be transformed into more manageable variables.

2.3. From the raw quantitative results to usable quantitative variables

2.3.1. The SICCT practice index

The quantitative online survey contained questions to investigate each step of SICCT practices, in the form of multiple choice questions in which the possible answers were determined according to the deviance of SICCT practices from the regulatory protocol reported in the qualitative study for each
step of the test. For each of the eight steps (Table 1), zero points were attributed to veterinarians if they followed the regulatory protocol or if their practice of the test was considered to be “acceptable”, i.e. if the differences from the regulatory protocol were thought to have little impact on the sensitivity of the SICCT and therefore tolerated by the health authorities. One point was attributed if the veterinarian’s practice of the test could negatively influence test sensitivity. For example, for the injection site, zero points were attributed if they performed the injection on the neck for all animals or for all calm animals. One point was attributed if they did not inject anything or if they injected at other sites (which decreases the sensitivity of an SICT performed with the bovine PPD antigen dose used in France (25,000 UI/ml) (Casal et al., 2015)).

Humblet et al. (Humblet et al., 2011) estimated the relative proportion of each step in influencing the risk of obtaining a false negative result with a panel of bTB experts. Indeed, each step of the SICCT has a specific influence on the characteristics of the SICCT (sensitivity, specificity). We thus attributed a weight for each evaluated step based on their results. The attributed weights are presented in Table 1. The final index for a veterinarian was the weighted sum of the points obtained for each step and ranged from zero to eleven: the higher the index, the more the practice of the SICCT deviated from the regulatory protocol.

2.3.2. The perception index

We used the same perception index as Crozet et al. (Crozet et al., 2019) to represent the global perception of the bTB surveillance and control program by the veterinarians. This index was calculated from the answers of veterinarians to four themes: their major concern when they obtain a non-negative result to an SICCT, their perception of the SICCT, the difficulties that prevent the eradication of bTB, and their perception of the bTB surveillance and control program. The possible answers to these questions were determined from analysis of the qualitative survey results. The answers and corresponding attributed scores are presented in Table 2. For each answer, zero points
were attributed if it reflected a positive perception and one point for a negative perception of the bTB surveillance and control program.

The final index was calculated by summing the points for each theme divided by the maximum possible sum. We thus obtained an index between zero and one: The higher the perception index, the worse the veterinarian's perception of the bTB surveillance and control program.

2.3.3. The notification index

The habit of veterinarians concerning the notification of non-negative results was evaluated using a corresponding question in the quantitative survey. Zero points were attributed if they answered that they did not systematically notify the authorities of all non-negative results obtained for the SICCT and one point if they always did it.

2.4. The determination of major influential variables

Once the indexes described above were created, linear and/or logistic regressions (depending on the type of the variable) of the results from the quantitative survey were performed to identify variables that significantly influence the practice of interest (in our example, the SICCT practice index and the notification index). For each variable, simple linear regression models were first used to select predictor variables to include in a multivariable model (variable with p value ≤ 0.25). The selected variables were then used in a primary multivariable model. The estimate of variance inflation factor (VIF) for each predictor variable of this model allowed us to identify collinear variables. The collinearity of two variables was investigated and their eventual removal (of one) was considered for variables with a VIF > 3. Then, a Bayesian information criterion (BIC) based stepwise selection procedure was used to simplify and optimise the multivariable model (R function “stepAIC” from the MASS package (Venables and Ripley, 2002)). We added to the scenario trees only variables with a significant impact on the practices of interest and which selection into the multivariable model had the less probability to be due to chance, to retain high selectivity and avoid over complicating them, we thus used a threshold of 0.01 for the p-value. The conditions of application of the model used
(linear or logistic regression) were verified. In our example, all linear regression models built for this study had residuals with a normal distribution. The homoscedasticity of the residuals were graphically checked. In addition, all logistic regressions had at least five to ten events by explicative variables and ROC analysis was performed to evaluate their classification ability that seemed satisfying. We thus considered the models to be valid.

2.5. Integrating factors that influence practices in the scenario trees

First, to account for the practice of a test, its influence on the sensitivity and specificity of the test must be modelled. We modelled the link between the SICCT practice index and characteristics (sensitivity and specificity) of the SICCT. The SICCT practice index accounted for the influence of each step of the SICCT on the probability of obtaining false negative results, i.e. on sensitivity (paragraph 2.3.1). A null SICCT practice index means that veterinarians follow the recommended procedures of the SICCT or that their practices are acceptable. In the literature on estimations of the characteristics of the SICCT, in particular for French estimates, sensitivity and specificity are based on the results of protocols monitored by the authorities, for which the veterinarian was committed to following the rules for performing the SICCT. We hypothesised that their practices concerning the SICCT were at least acceptable. In our scenarios trees, we therefore attributed sensitivity and specificity values published in the literature to a null SICCT practice index. If the index is maximal (equal to 11), all SICCT steps are inconsistent with regulatory prescriptions: we therefore hypothesised that in this case, SICCT sensitivity is null and, consequently, SICCT specificity is perfect. Between these two extremes, there was a large range of possible combination of practices for each step, each combination having a potentially different effect on the SICCT characteristics. The true impact of each of these combinations of practices is unknown and experts consider themselves incapable of precisely estimating it (Humblet et al., 2011; experts of the French working group on bovine tuberculosis). We therefore modelled this impact in our scenario trees by splitting the range of SICCT practices index values into three equally sized categories to distinguish low SICCT index values from...
average and high ones. We then assumed there to be decreasing sensitivity and increasing specificity of the SICCT as we pass from one category (with the lowest value) to the next, i.e. if practices are less acceptable, as described in Table 3.

If the practice of interest concerns case notification, a node, “notification”, with at least two branches (“yes”, “no”) must be added to the tree. The probability of occurrence of each branch will be modelled according to the results of the quantitative survey. It is possible to include other types of practices. The way to model their influence on the effectiveness of the surveillance system should then be individually developed according to the context.

Then, nodes corresponding to the factors for which a significant influence on practices was identified in the previous step of the method must be added to the scenario tree. The probability of occurrence of each new branch generated by this addition of a node will be modelled according to the results obtained in the quantitative survey by either a fixed probability (if there is no incertitude and no variation in the probability of occurrence) or an appropriate distribution law (for example, Normal distribution laws to model uncertainty and variability and parameters were chosen according to the results of the multivariable analyses).

2.6. Simulations with scenario trees

Finally, the developed scenario trees were used to estimate the mean herd sensitivity (probability of detection of at least one infected animal in an infected herd) and cost of each studied protocol and their 95% confidence interval (CI) for a one-year period (bTB is a chronic disease and screening in farms occurs every year) from 10,000 simulated values for each herd type. The scenario trees were implemented in R (version 3.4.2).

First, the model calculated the probability of occurrence of each path by multiplying the probabilities of occurrence of the corresponding limb. Then, it estimated the individual sensitivity for each type of herd (Se_k) by adding the probability of occurrence of every path beginning with the nodes corresponding to the herd type k (k corresponds to one of 12 possible categories of herd defined by
production type, herd size, and herd turnover) with a positive outcome. The initial hypothesis used in the creation of the scenario trees was that the specificity of the combination of analyses performed by the national reference laboratory for bTB was 100% (Poirier et al., 2019). Thus, individual specificity was equal to one in the scenario trees used. Finally, the sensitivity for each herd type (CSe<sub>k</sub>) was calculated according to formula (1).

\[
CSe_k = 1 - (1 - Se_k) \times \text{herd size} \times \text{intra-herd prevalence}
\]

The estimated herd sensitivities by herd type were then compared to the estimated herd sensitivities without accounting for the veterinarian’s practices of our previous study (Poirier et al., 2019), modelled from the scenario tree presented in figures 1 to 3, without the nodes “Help for cattle restraint”, “veterinarian’s age”, “perception index” and “Notification”, corresponding to the node added to account for the veterinarians’ practices.

3. Analyses of the results of the evaluation of bTB surveillance system on French farms

All analyses were performed using R (version 3.4.2). The accepted α risk of error was set to 1%. The means were compared using Student’s t test, corrected for multiple comparisons by the Bonferroni correction method.

We evaluated which model input most influenced outcome uncertainty and variability by performing a sensitivity analysis for each scenario tree. As some inputs were interdependent, we could not use the AOT method and instead used the McKay method (McKay, 1995), which can be used for dependant inputs (Jacques et al., 2006), with 20 replications of Latin hypercube samples. We used the R package “sensitivity dependent” (Jacques, 2014).

RESULTS
1. Results of the qualitative survey on veterinarians’ SICCT practices and their perception of the bTB surveillance and control program

The qualitative study showed that regulatory protocols for the practice of SICCT were not systematically followed in ways that may highly influence test sensitivity and specificity. It also showed that veterinarians do not always notify the authorities of non-negative results. This confirmed the interest of assessing veterinarians’ practices in our quantitative evaluation of the bTB surveillance component in cattle. This study provided veterinarians the opportunity to freely express their difficulties in performing bTB surveillance in the field, allowing us to formulate hypotheses concerning the factors that influence their practices in bTB surveillance. The constraints and motivations for SICCT screening expressed by veterinarians varied, depending on herd type, screening frequency, and prevalence of bTB. For example, SICCT practices appeared to better conform to regulatory protocols in administrative areas with a higher prevalence of bTB, perhaps because veterinarians are well informed about these protocols and have more training in their application. Veterinarians justified their adaptations of regulatory SICCT protocols because of the difficulty of restraining cattle associated with the danger of performing the SICCT along with its time-consuming nature. They justified the non-notification of some non-negative results to the authorities because of their lack of confidence in the results. Indeed, the prevalence of bTB in France is very low and non-negative results are therefore often false-positive results due to the lack of specificity of the test. In addition, the economic consequences of the notification of such results are substantial for the farmer, as their herd becomes suspect of carrying bTB and they can no longer sell any animals during all the investigation process, which can be very long (more than six weeks when the herd must be screened a second time with the SICCT). Some veterinarians therefore hesitate to notify the authorities of a non-negative result because they do not trust a positive result of the SICCT and do not want to negatively (and sometimes unjustifiably) affect the farmer, who is also their customer. Veterinarians appeared to have a different perception of the bTB surveillance system depending on the prevalence bTB in the area and screening frequency. Indeed, the perception of veterinarians...
appeared to be better in areas more highly affected by bTB (higher bTB prevalence, higher frequency of screening), i.e. they seemed to be more convinced of the importance and utility of the bTB control program.

The results of this first qualitative study allowed us to identify the factors that potentially influence the practice of the SICCT and notification of non-negative SICCT results: prevalence of bTB in the area, screening frequency, herd type, restraining devices, trust in the SICCT results, and veterinarians’ perception of the bTB surveillance system.

2. Factors that influence the practice of SICCT from the quantitative survey results

First, we sought explicative variables for the SICCT practice index based on the analysis of the quantitative survey results carried out by Crozet et al. (Crozet et al., 2019). Results of the simple linear regression are shown in Appendix B. Variables representing the help in restraining cattle and the screening rhythm in the area in which the veterinarian works were forced into the primary multivariable model because they appeared to influence the practice of the SICCT, according to the preliminary qualitative study. All VIFs were ≤ 2 and we found no collinear variables that could introduce a bias in the estimation of the model parameters. Results of the final model obtained after the automatic selection process are shown in Table 4. The only variable significantly associated (p < 0.01) with the SICCT practice index was the perception index: veterinarians with a better perception of the bTB surveillance and control program had a better SICCT practice index. We therefore fitted a model explaining the SICCT practice index with the perception index, which is presented in Table 5.

Having determined that the perception index was the only variable significantly associated with the SICCT practice index, we wanted to determine which variables could influence the perception index. We used the same method as for the SICCT practice index: the results of the simple linear regressions are summarized in appendix C and those of the final multivariable regression in Table 6. The age of the veterinarian, the number of people from the farm usually present to help for animal restraint
during screening, and the frequency of headlocks were the only variables significantly associated with the perception index. Veterinarians over 50 years of age tended to have a more positive perception of bTB control, probably because they were already practicing before France obtained its bTB-free status, when the prevalence of bTB was much higher, and they therefore have a better awareness of the importance of bTB surveillance and control. Veterinarians who usually received appropriate help for animal restraint (at least two people of the farm) when carrying out the SICCT and veterinarians working in farms in which headlocks were frequent had a more positive perception of the bTB surveillance and control program, probably because it is easier for them to perform the SICCT. A regression model explaining the perception index by these three major variables was fitted (Appendix D).

We carried out similar analyses to explain the number of people usually helping in animal restraint (by logistic regressions) and the frequency of headlocks. Results of these analyses are presented in appendices E, F and G. None of the variables were significantly associated neither with the number of people usually present to help the veterinarian during his visits nor with the frequency of headlocks.

Finally, we determined which variables were significantly associated with notification practices using the same method. Results of the multivariable analysis are shown in Table 7. The perception index was the only variable associated with the notification of non-negative results with a p-value close to 0.01 (p-value=0.03) and had an important influence on this variable in the logistic regression (high estimated coefficient). In addition, a real influence of veterinarian’s perception of bTB on the notification of non-negative results seemed logical and was consistent with the qualitative study findings. Therefore, we chose to account for it in our scenario tree modelling.

3. Awareness of veterinarians’ practices in the scenario trees modelling bTB surveillance in farms

We next added nodes corresponding to variables with a significant influence to the scenario trees identified by the previous multivariable analyses. We thus added the nodes “help in cattle restraint”
(less than two people or at least two people), “veterinarian’s age” (under or over 50 years), “headlocks frequency” (prevalent or less prevalent) and “notification of non-negative SICCT results” (yes or no). The final scenario trees obtained for each protocol are shown in Figures 1 to 3.

The probability of occurrence of each of the new limbs was modelled by beta distribution laws. The probability of the veterinarian to receive help in restraining the cattle from at least two people from the farm was modelled by a beta distribution law with parameters set to best fit the real distribution observed in the quantitative results of the survey: $\beta(49, 64.9)$. The probability of the veterinarian being under or over 50 years old was set according to the French national data from the demographic atlas of veterinarians from 2018 from the National Observatory demographics of the veterinary profession. Veterinarians thus had a fixed probability of 33% of being over 50 years old.

The age of the veterinarian, number of people usually present to help for cattle handling in a herd and the frequency of headlocks have an influence on the value of the perception index to be used in the scenario trees. Indeed, in the models, a perception index was simulated for each iteration using a beta distribution law. The parameters of these distributions were set, depending on the limb, according to the results of the survey, as described in Table 8.

Finally, for each iteration of the model, the value of the perception index shaped the SICCT practice index, which influences the sensitivity and specificity of the SICCT and the probability of the veterinarian notifying the authorities of a non-negative SICCT result.

As the results of the multivariable model explaining the SICCT practice index showed that the perception index was the only variable that significantly influenced the practice of the SICCT, we modelled the SICCT practice index according to the perception index, using the results of the multivariable model. In the scenario trees, the SICCT practice index was therefore calculated according to formula (2).

\[
\text{SICCT practice index} = c \times \text{perception index} + \varepsilon
\]
Where $c$ followed a normal distribution law $N(\text{mean} = 4.37, \text{sd} = 1.20)$, for which the parameters were set according to the result of the multivariable analysis explaining the SICCT practice index (Table 5); and $\varepsilon$, the residue of the multivariable regression, followed a normal distribution law $N(\text{mean} = 1.80, \text{sd} = 0.39)$ and was included between $-c*\text{perception index}$ and $11-c*\text{perception index}$.

The probability of the authorities being notified of a non-negative result was modelled by beta distribution laws with parameters set according to the quantitative survey and is shown in Table 9.

For protocols with a second SICCT (strict protocol and compliant slow-path protocol), we hypothesized that the veterinarians would systematically notify the authorities of non-negative results of the second SICCT because they performed these test in a suspected herd attentively monitored by the authorities and for which misidentification of a suspect animal could have important consequences.

4. Results of the evaluation of bTB surveillance by screening of French farms

4.1. Herd sensitivity

Table 10 summarizes the mean and 5th and 95th percentiles of the output distribution for the herd sensitivity for each protocol by herd type. Mean herd sensitivity ranged from 12.7% for the compliant quick-path protocol (in big beef-cattle farms with a high turnover) to 46.2% for the strict protocol (in big mixed farms with a low turnover).

4.2. Impact of the incorporation of data on SICCT and notification practices

Integrating data on SICCT and non-negative result notification practices resulted in a major decrease (the value of the percentage of decrease was between 15% and 42% depending on herd type) of the initial herd sensitivity estimations without practices data, regardless of herd type and protocol (Table 11). For a given protocol, the decrease in the estimated herd sensitivity was significantly lower for big
herds than small herds (of the same production type and herd turnover) and for big mixed herds than other big herds. For a given herd type, the difference in the decrease of the estimated herd sensitivity was not significant between the compliant slow-path and compliant quick-path protocols, whereas it was significantly smaller for the strict protocol than the compliant slow-path and compliant quick-path protocols.

4.3. Sensitivity analyses

Mc Klay indices of inputs $> 10\%$ by herd type for each protocol are shown in Figure 4. This index estimates the proportion of variation of the output caused by the variability and uncertainty of the inputs. SICCT sensitivity had the greatest influence on variations of herd sensitivity for small herds and big dairy herds, for the compliant slow-path protocol. In other big herds and for the two other protocols, SICCT sensitivity, within-herd prevalence, and herd size significantly influenced this variation.

DISCUSSION

1. Method

The method we developed has the advantage of combining data from diverse sources, including qualitative field data collected using a sociological methodology among actors and quantitative data with variability and uncertainty. The main setback of this approach is the large amount of time and human and financial resources needed to perform it.

The method of semi-directive interviews also requires knowledge and skills in sociology. This interdisciplinarity is highly rewarding but brings the risk of misusing the method if it is insufficiently mastered. A collaboration with sociologists could therefore be very useful, as they would ensure the quality of the qualitative study and would provide a better understanding of the field in a sociological
context. The results of this qualitative study should not be set aside once the quantitative survey is launched as they would be a rich source of information, possibly leading to field recommendations.

For this qualitative study, we interviewed veterinarians from chosen administrative areas. However, each area has a unique distribution of the type of cattle production and its own sanitary authority unit, in which the interactions between actors vary. We therefore may have overlooked certain issues specific to the context of a particular area. Nevertheless, the aim of this study was to globally evaluate the impact of veterinarians’ SICCT practices on the effectiveness of surveillance and the selected areas were representative of the diversity of French areas for global context indicators (type of production, prevalence of bTB and context, and periodic screening frequency). Thus, it likely allowed us to obtain a good picture of the predominant practices and influential factors at the national level.

All semi-directive interviews can lead to biases caused by the interviewer/interviewee interaction, as they each have their own socio-economic background, which may affect their relationship and thus the interviewee’s discourse. Although such bias cannot be completely avoided, it can be minimised by the attitude of the interviewer. In our case, he could potentially have been perceived as an “officer” who could report irregular practices to authorities, as the interview concerned regulatory practices. Nevertheless, the careful presentation of the interviewer and objectives of the study appears to have limited such bias, as many of the interviewees reported practices differing from regulatory guidelines.

Any bias in our quantitative survey is well described by Crozet et al. (Crozet et al., 2019). Veterinarians of our sample had demographic characteristics similar to the ones of Crozet et al.’s study; selecting a subset of their sample did not seem to have introduced additional selection bias. Concerning the perception index, it may be presumptuous to believe that this index truly measures the veterinarians’ perception. Indeed, “veterinarians’ perception” is more a sociological concept than a physical variable (unlike the SICCT practice index, for example). In sociology, quantifying a concept
through several measurable variables is normal but requires the development of a measurement tool according to the paradigm of Churchill (Churchill, 1979), summarised in Appendix H. Our approach of perception measurement was less subtle and could be improved by following this paradigm to ensure that it is reliable and “measures what it is supposed to measure” (Bollen, 1989). This could be a full research project in itself, more suited to a sociologist, what underlines the interest of a multidisciplinary collaboration.

Our modelling of the impact of SICCT practices on the SICCT characteristics is very simplified, partly as there was no detailed data on it and also because the scenario trees, being themselves simplifications of reality, would not have accounted for all the diversity of possible practice combinations. This simplification may have led us to amplify the negative effects of adapted SICCT practices and thus to underestimate the herd sensitivity of the protocols. Indeed, a veterinarian could, for example, be assigned an SICCT index of one, leading to a 25% decrease of the SICCT sensitivity in the model, because the person reading the test result is occasionally another veterinarian; thus, we would systematically consider that the test sensitivity is 25% lower, whereas the veterinarian sometimes reads the test result himself or herself. In addition, the percentage of the decrease in sensitivity is purely theoretical and may have been over-estimated. Nevertheless, the direction of the influence on the SICCT characteristics we modelled is logical. It therefore seems legitimate to consider that the direction of the estimated influence of sociological data on herd sensitivity reflects the true direction of this influence. However, the limitation caused by this simplification must be kept in mind when considering the quantitative estimation of the influence of practices on herd sensitivity. We estimated that with a linear impact decreased of 50%, SICCT practices impact on protocols’ sensitivity will still be significant, causing a decrease of protocols sensitivity of 16% to 21% compared to sensitivities estimated without accounting for veterinarian’s practices. Further investigations are necessary to verify our assumption to collect additional data about veterinarians’ practices, the results of the tests they performed and the infection status of the corresponding animals estimated through laboratory analysis. Unfortunately, French centralised data
of the results of SICCT and of suspicions’ investigations are not yet sufficiently detailed and collecting them at a local scale will be very time-consuming.

The general trend of the influence of altered SICCT practices on the test characteristics was easy to evaluate using existing published studies (Doherty et al., 1995; Humblet et al., 2011; Benet et al., 2012; Casal et al., 2015). This modelling may be less obvious to perform for the tests used in other disease surveillance systems.

2. Results

Some potentially influential factors identified in the qualitative study, such as the relationship between veterinarians and sanitary authorities and between veterinarians and farmers, were difficult to assess quantitatively and were therefore not directly accounted for in our scenario trees. These factors should nevertheless not be underestimated and all actions improving these relationships should be enhanced.

In the quantitative study results, there were no differences in practices between French administrative areas. We assumed that there is some heterogeneity between these areas (this was a hypothesis based on the qualitative survey), in particular depending on the bTB prevalence and the historical context. The quantitative survey may have not confirmed this hypothesis because of a lack of statistical power due to the limited number of responding veterinarians (115/1,084). Thus, the input parameters were set according to aggregated data from all of the targeted areas. We thus obtained an effectiveness estimation of the protocols in the global sociological context of the investigated areas. However, the practice of SICCT in certain French areas, where veterinarians were particularly well trained for SICCT and well informed about bTB, is known to be better than others, closer to recommendations (personal communication from the French national referent of bTB surveillance Fabrice Chevalier). It appears to be validated by the decreasing prevalence of bTB in these areas (Direction Générale de l’Alimentation, 2010). We can therefore expect herd sensitivity of
the protocols in these areas to be higher than our estimations and closer to the first estimation we made (Poirier et al., 2019).

The creation of an index to represent SICCT practices was necessary to allow analysis of the results but it simplified the true complexity of practicing SICCT in the field. Indeed, altered practices at each step of performing the test led to an increase in the SICCT practice index. However, some steps are more essential than others and some practice adaptations may not lead to a decrease in SICCT sensitivity. We tried to account for this complexity by attributing a weight to each step of the test, accounting for their varying impact on the probability of obtaining false negative results, and “tolerating” certain adapted practices that probably have no consequences on the SICCT characteristics. Nevertheless, it is still an imperfect simplification and therefore, a high SICCT practice index is not the exact equivalent of reduced test effectiveness in the field.

In the analysis of their results, Crozet et al. (2019) found the same influence of the veterinarians’ perception of bTB surveillance and control on the SICCT practice index. However, they found two variables which were more influential (with a smaller effect than the veterinarians’ perception): the number of years in large animal practice and the number of performed SICCTs during the last year. The influence of these two variables was not significant in our analyses. This is not surprising given that we only analysed the responses of veterinarians that practice SICCT in a periodic screening context (veterinarians practicing SICCT only on cattle to sell or to investigate epidemiological links with outbreak were excluded) as they were the only ones pertinent to our scenario-tree modelling. We therefore had less data (115 answers instead of 210), probably resulting in a lack of power.

Veterinarians with a better perception of the bTB surveillance and control program had a better SICCT practice index. This is probably explained by a better understanding of the importance of bTB control: veterinarians convinced that controlling bTB is useful and necessary will certainly more carefully follow regulatory recommendations, despite the constraints, than veterinarians thinking it is useless (Brennan et al., 2016).
We assumed that veterinarians notified all non-negative results for a second SICCT (SICCT2) because SICCT2 are performed in suspect herds monitored by authorities and in which veterinarians have notified of non-negative results to the first SICCT. It is thus likely that they will notify of it for SICCT2. However, this hypothesis may have been optimistic and may have slightly overestimated the number of notifications and therefore herd sensitivity. On the other hand, we accounted for the impact of SICCT practices on the SICCT2 characteristics. Yet, it is possible that some veterinarians that did not follow the regulations for SICCT1 will follow regulatory practices for SICCT2, given the context: in this case, we may have slightly underestimated herd sensitivity of strict and compliant slow-path protocols.

Veterinarians that declared that they did not systematically report non-negative results were considered in the model as if they never notified authorities of any non-negative SICCT1 results. This lacks nuance as the qualitative survey showed that some of them do their own personal risk analysis to decide whether to notify the authorities or not. Such behaviour is indeed detrimental for the effectiveness of the protocol, but it is not as detrimental as systematic non-notification. Therefore, we certainly overestimated non-declaration and thus slightly underestimated true herd sensitivity. Nevertheless, such behaviour is inconsistent with the effective control of bTB, that is why we chose to account for these veterinarians as if they never notified the authorities of any SICCT non-negative results. In addition, this type of approach, based on declarations concerning regulatory practices, could have led to some veterinarians under-declaring altered practices.

The herd sensitivity estimations based on scenario trees were therefore imprecise but allowed us to show the important influence of the practice parameters of the actors on herd sensitivity for the different protocols. It highlights the importance of optimising SICCT practices and the notification of non-negative results of bTB surveillance and underlines the importance of accounting for data concerning these practices in surveillance system evaluations. Interestingly, the adaptations of practices made by veterinarians, certainly to decrease the cost to farmers, probably has the desired
impact on protocol cost, with the unfortunate collateral damage of decreasing herd sensitivity. Such adaptations of practices decrease the effectiveness of the protocols and negatively affect the long-term cost of the surveillance program, as it slows down and perhaps prevents the eradication of bTB. According to the qualitative survey, these adaptations are a reaction to the restrictive regulations of the European Union, which prescribes a selling ban for all suspect herds (for example for at least six weeks in the strict protocol). In addition, in the context of very low prevalence and given the characteristics of the SICT, the confidence veterinarians have in a non-negative SICCT is low. Combining these two considerations, some veterinarians perform their own risk analysis and may decide, for example, to overlook certain non-negative results. It is probable that these adaptations of practices may differ, depending on the bTB history in the area, its prevalence, and the production type of the herd (because a selling ban could have greater economic consequences for a beef herd than a dairy herd). Such adaptations of practices can probably be found in other European countries subject to the same regulations with similar historical and epidemiological contexts.

Our herd sensitivity estimations suggest that periodic screening using the SICCT may not be very effective for the detection of infected herds. However, our herd sensitivity estimations only reflect the effectiveness of a single screening campaign, whereas such campaigns are regularly performed in France (up to one every year), which improves the probability of eventually detecting an infected herd. In addition, periodic screening is not the only surveillance system in place in France and its association with the screening of transported cattle, slaughterhouse surveillance, and the investigation of farms linked to outbreaks guarantees more effective detection of infected herds. According to the sensitivity analyses, SICCT sensitivity and within-herd prevalence were the main influential variables. This is not surprising, given the uncertainty we had concerning their values and major role in disease detection. Inputs concerning practices were not the most influential variable on outcome variability but they contributed approximately 1% to 10% to it, depending on the herd type. 
The percentage of the decrease of estimated herd sensitivity caused by incorporating SICCT and notification practices of veterinarians was lower in the strict protocol (regardless of herd type), in big herds (for a fixed production type and herd turnover, regardless of the protocol), and in mixed herds (for a fixed herd size and herd turnover). For the strict protocol, this difference can be explained by the fact that the test is used twice in parallel, which led to the smallest percentage decrease relative to protocols in which the test is used only once or serially (Appendix I). For big and mixed herds, it was due to the higher number of infected animals tested (Appendix I). Indeed, as there is a large number of animals in such herds with a same within-herd prevalence, in the model, large and mixed infected herds will have a higher number of infected animals that will be tested, leading to higher herd sensitivity, which may compensate for the decrease in herd sensitivity due to altered practices. This difference decreases with a decrease of the modelled impact of SICCT practice on SICCT characteristics. In addition, the high number of iterations used lead to narrow confidence intervals but with less iterations, many of the differences between herd types are not significant.

3. Field recommendations

According to our study, improving veterinarians’ perception of the bTB surveillance and control program could enhance the effectiveness of the surveillance system by improving their SICCT practices. This is consistent with several qualitative studies (Pfeiffer, 2006; Brennan et al., 2016). This could be achieved by addressing cattle-handling issues, which could be dealt with through (1) technical and financial help for farmers towards adapted handling devices, such as head-lockers (Crozet et al., 2019) and (2) training for farmers to make them aware of the need of having several people to help in restraining the cattle. The veterinarians’ perception of the bTB surveillance and control program can also be improved by training to convince them of the utility of control and
reassure them of its feasibility. It is likely that the training needs in France will be heterogeneous, depending, for example, on the bTB prevalence in the area (Crozet et al. 2019).

Finally, an additional possibility to improve veterinarians’ and farmers’ perception of the bTB surveillance and control program could be an improvement of the protocol. For example, the second SICCT test could be replaced by an IFNγ test, leading to potentially better cost-effectiveness and a shorter duration of the protocol, such as by decreasing the time between the first and second SICCT, during which farmers cannot sell any animals. Such protocols could positively influence veterinarians’ perception and reduce their reluctance to declare non-negative results, leading to an improvement of bTB surveillance on farms, as they would be less penalizing for the farmers. In addition, the IFNγ test is easier to perform for the veterinarian, as only one blood sample is required, causing fewer cattle-restraint issues, and interpretation of the result is performed in a laboratory. Nevertheless, changing these protocols will require modification of the European regulatory protocols.

CONCLUSION

In this study, we developed a method to integrate practices data into scenario tree modelling and used it to evaluate the impact of the SICCT practices on French bTB surveillance system. Further studies have yet to be done to improve the modelling of the impact of SICCT practices on its sensitivity and specificity. However, our study highlighted the importance of the veterinarians’ involvement and the need to convince them of the utility of controlling bTB and of the necessity to perform the tests according to regulatory recommendations. Authorities could provide technical and financial support to help them in practicing the SICCT, in particular for animal restraint and for an awareness program of the utility of controlling bTB.

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The authors want to thank the French Ministry of Agriculture and the French Agency for Food, Environmental, and Occupational Health and Safety for providing access to the SIGAL and BDNI data. We also thank all the veterinarians that answered the qualitative or quantitative surveys. Finally, we thank William Hempel from Alex Edelman and Associates for English proofreading of the manuscript.

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Appendix A. Guide used for the semi-directive interviews of the qualitative study (translated from the work of Gully S. and Hamelin E., 2018)

First part: characteristics of the veterinarian

In a few words, describe your career

Anticipated data: Education and training, age, sex, work experience, status in the clinic (employee or private practitioner)

Second part: organisation of bTB screening in the clinic

- What is the proportion of rural activities of the clinic?

Anticipated data: size of the structure, proportion of rural activity of the overall activity of the clinic, distribution of work between veterinarians of the clinic, position of the interviewee in the general organisation of the clinic. Competitive context of the clinic.

- Who performs bTB screenings in the clinic?

- For your rural activity, what is the context of the area you cover? What type of cattle are there and what type of interventions do you usually perform?

Anticipated data: economical context of the farmers, relationship with the farmers, type of herds (dairy vs beef, type of cattle housing), size of herds

Third part: training/experience

- How and when were you educated about bovine tuberculosis (bTB)? (Education about the characteristics of the bacteria and bTB issues, training to perform the intradermal cervical tuberculin test (SICT), education about the characteristics of the SICT)
- Do you perform SICT?

- What type of SICT (SSICT (single intradermal cervical tuberculin test) or SICCT (intradermal cervical comparative tuberculin test)) do you perform more often?

- What is your experience concerning bTB

Anticipated data: the veterinarian knew about bTB before the bTB-free status of France or he never worked in bTB infected areas. In which context does he perform SICT (screening, in herds with an epidemiological link to an outbreak, for purchased animals)? Frequently/rarely?

Fourth part: field practice

- How well does bTB screening go in the field? How do you proceed?

Anticipated data: SSICT or SICCT, description of the procedure, preparation of the injection site, first measurement of skin thickness, how it is measured, injection quality check and reinjection if necessary, time of reading, type of reading (measurement of skin thickness?), difference between SSICT and SICCT.

- How do you manage the restraint of cattle?

Anticipated data: differences depending on the herd, cattle type (race, age...)? Difficulties?

Frequency of difficulties?

- What difficulties do you encounter?

Anticipated data: cattle restraint, relationship with the farmer, relationship with health authorities, the SICT itself (training, management, etc.)

- What do you think about the fees for the SICT?
Anticipated data: How and how much are you paid for a SSICT? for an SICCT? What is the financial profitability of each one of these tests for the clinic?

- Have you ever detected cattle with a small reaction to SICT? with a big one?
  Anticipated data: collect information about their management of doubtful results and under-notification.

- Have you ever had a non-negative case? Could you tell me how it happened and what you did? Do you always manage a non-negative case the same way?

- Have you ever had to manage a complex case (use the veterinarian’s lexical field)? Could you tell me how it went? What did you do? Do you always manage a non-negative case the same way?
  Anticipated data: succession of decisions and actions; if several cases, ask the veterinarian to talk about each one and ask whether there were differences in the reactions? If there were, why? Finish by a question summarizing: What did you learn from this experience? If you had to do it again, would you do some things differently? Why?

- Have your practices changed since your first participation in a bTB screening campaign?
  What did you change? Why?

- Has your management of complex cases changed since your first case? Why?

- How is it with the other veterinarians of the clinic: do you sometimes discuss bTB screening? About which facet in particular?
  Anticipated data: When you detected a non-negative result for an SICT, did you talk about it
in the clinic? If you did, what did you discuss? (We want to understand whether veterinarians share experiences and whether they try to standardize their practices within the clinic.

- How is it with the other stakeholders of the bTB control program?
  - With the farmers? Are they your usual customers? How does the collaboration work? How do you react to the refusal of a farmer?
  - With the animals? What do you do when it is difficult to restrain the animals? Potentially, if the veterinarian talks about certain types of cattle or a race in particular: Are there some animals for which you proceeded differently? Why?
  - With the health authorities of the area? How does information circulate? How available are the health authorities? Who is your representative? Have you participated in meetings with the local health authorities?
  - What is the role of the GDS(1) (health defence group, group of farmers)?
  - With the GTV (veterinary technician group)

Fifth part: veterinarian’s perception of the bTB surveillance and control program

Finally, what do you think about the bTB surveillance and control program? What works and what doesn’t? What are the main difficulties? What should be changed? Why do you think health authorities continue with the program? What do you foresee in the next 5 years?
Appendix B. Results of simple linear regressions explaining the SICCT practice index ($n = 115$)

<table>
<thead>
<tr>
<th>Predictor variable</th>
<th>p-value</th>
<th>Comment on the predictor variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perception index</td>
<td>0.00043**</td>
<td>Continuous</td>
</tr>
<tr>
<td>Veterinarian’s sex</td>
<td>0.525</td>
<td>Binary (Man/Woman)</td>
</tr>
<tr>
<td>Veterinarian’s age</td>
<td>0.358</td>
<td>Categorical ($\leq 30$ years, 31-40, 41-50, 51-60, $&gt; 60$)</td>
</tr>
<tr>
<td></td>
<td>0.439f</td>
<td>Categorical ($&lt; 50$ years, $\geq 50$ years)</td>
</tr>
<tr>
<td>Number of years of rural practice (in years)</td>
<td>0.813</td>
<td>Continue</td>
</tr>
<tr>
<td>Veterinary school</td>
<td>0.03566*</td>
<td>Categorical (Abroad, Nantes¹, Toulouse¹, Lyon¹, Alfort¹)</td>
</tr>
<tr>
<td>Veterinarian’s status</td>
<td>0.50</td>
<td>Categorical (self-employed/employee)</td>
</tr>
<tr>
<td>Number of SICCTs performed in 2017</td>
<td>0.882</td>
<td>Continuous</td>
</tr>
<tr>
<td>Proportion of SSICTs among the SICTs performed by the</td>
<td>0.0151*</td>
<td>Continuous</td>
</tr>
<tr>
<td>veterinarian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of rural practice</td>
<td>0.2827</td>
<td>Categorical ($\leq 20%$, 20-40, 40-60, 60-80, 80-100)</td>
</tr>
<tr>
<td>Prevalence of headlocks on the veterinarian’s customer’s farms</td>
<td>0.0494*</td>
<td>Categorical (prevalent ($n = 40$)/ less prevalent ($n = 75$))</td>
</tr>
<tr>
<td>Prevalence of restraining corridors on the veterinarian’s</td>
<td>0.011*</td>
<td>Categorical (prevalent ($n = 62$) / less prevalent ($n = 53$))</td>
</tr>
<tr>
<td>customer’s farms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Help during cattle handling</td>
<td>0.379f</td>
<td>Categorical ($&lt; 2$ people, $\geq 2$ people)</td>
</tr>
<tr>
<td>Production type</td>
<td>0.107*</td>
<td>Categorical (dairy/beef/mixed)</td>
</tr>
<tr>
<td>Herd size</td>
<td>0.856</td>
<td>Continuous</td>
</tr>
<tr>
<td>Maximal screening rhythm in the areas where the veterinarian works</td>
<td>0.312 f</td>
<td>Categorical (annual, biennial or triennial, stopped or zoned)</td>
</tr>
<tr>
<td>Prevalence of bTB in the areas where the veterinarian works</td>
<td>0.581</td>
<td>Categorical (bTB free or 1 to 5 breakouts more than 5 years ago, infected (1 to 10 breakouts in the last 5 years), highly infected (more)</td>
</tr>
</tbody>
</table>
than 10 breakouts in the last 5 years)

**significant with \( \alpha = 0.01 \), included in the multivariable analysis

*non-significant, but \( p < 0.25 \), so included in the multivariable analysis

\(^\circ\) Variables forced into the primary multivariable model

\(^1\) The four French veterinary schools

SSICT: single intradermal tuberculin cervical test

SICCT: intradermal cervical comparative tuberculin test

SICT: intradermal cervical tuberculin test (it can be an SSICT or an SICCT)
### Appendix C. Results of simple linear regressions explaining the perception index

<table>
<thead>
<tr>
<th>Predictor variable</th>
<th>p-value</th>
<th>Comment on the predictor variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>SICCT index</td>
<td>0.00043**</td>
<td>Continuous</td>
</tr>
<tr>
<td>Veterinarian’s sex</td>
<td>0.229*</td>
<td>Binary (Man/Woman)</td>
</tr>
<tr>
<td>Veterinarian’s age</td>
<td>0.024*</td>
<td>Categorical (&lt; 50 years, ≥ 50 years)</td>
</tr>
<tr>
<td>Number of years of rural practice (in years)</td>
<td>0.103*</td>
<td>Continuous</td>
</tr>
<tr>
<td>Training school</td>
<td>0.187*</td>
<td>Categorical (Abroad, Nantes¹, Toulouse¹, Lyon¹, Alfort¹)</td>
</tr>
<tr>
<td>Veterinarian’s status</td>
<td>0.329</td>
<td>Categorical (self-employed/employee)</td>
</tr>
<tr>
<td>Proportion of SSICTs among the SICTs performed by the veterinarian</td>
<td>0.12*</td>
<td>Continuous</td>
</tr>
<tr>
<td>Number of SICCTs performed in 2017</td>
<td>0.523</td>
<td>Continuous</td>
</tr>
<tr>
<td>Proportion of rural practice</td>
<td>0.078*</td>
<td>Categorical (≤20%, 20-40, 40-60, 60-80, 0-100)</td>
</tr>
<tr>
<td>Restraining help</td>
<td>0.00081**</td>
<td>Categorical (&lt; 2 people, ≥ 2 people)</td>
</tr>
<tr>
<td>Prevalence of headlocks on the veterinarian’s customer’s farms</td>
<td>0.017*</td>
<td>Categorical (prevalent (n =4 0)/less prevalent (n = 75))</td>
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<tr>
<td>Prevalence of restraining corridors on the veterinarian’s customer’s farms</td>
<td>0.997</td>
<td>Categorical (prevalent (n =6 2)/less prevalent (n = 53))</td>
</tr>
<tr>
<td>Herd size</td>
<td>0.277</td>
<td>Continuous</td>
</tr>
<tr>
<td>Maximal screening rhythm in the areas were the veterinarian works</td>
<td>0.2029*</td>
<td>Categorical (annual, biennial or triennial, stopped or zoned)</td>
</tr>
<tr>
<td>Prevalence of bTB in the areas were the veterinarian works</td>
<td>0.522</td>
<td>Categorical (bTB free or 1 to 5 breakouts more than 5 years ago, infected (1 to 10 breakouts in the last 5 years), highly infected (more than 10 breakouts in the last 5 years)</td>
</tr>
<tr>
<td>Production type</td>
<td>0.1413*</td>
<td>Categorical (dairy/beef/mixed)</td>
</tr>
</tbody>
</table>

**significant with α = 0.01, included in the multivariable analysis**
*non-significant but p < 0.25, so included in the multivariable analysis

¹ The four French veterinary schools

SSICT: single intradermal tuberculin cervical test
SICCT: intradermal cervical comparative tuberculin test
SICT: intradermal cervical tuberculin test (it can be an SSICT or an SICCT).
Appendix D. Results of the multivariate logistic regressions explaining the perception index with veterinarian’s age, the number of people from the farm usually present to help for animal restraint during screening, and the frequency of headlocks

Adjusted $R^2 = 0.1587$

F statistic = 8.171

Model’s p-value < 0.001

Residual standard error = 0.1105 (degrees of freedom = 111)

<table>
<thead>
<tr>
<th>Estimated coefficient</th>
<th>Standard error</th>
<th>p-value</th>
<th>Reference category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.38</td>
<td>0.019</td>
<td>$&lt; 2 \times 10^{-16}^{**}$</td>
</tr>
<tr>
<td>Veterinarian’s age (&lt; 50, ≥ 50)</td>
<td>-0.049</td>
<td>0.021</td>
<td>0.019*</td>
</tr>
<tr>
<td>Headlock frequency (prevalent/less prevalent)</td>
<td>-0.057</td>
<td>0.022</td>
<td>0.0098**</td>
</tr>
<tr>
<td>Restraining help (&lt;2 people / ≥2 people)</td>
<td>-0.069</td>
<td>0.021</td>
<td>0.0013**</td>
</tr>
</tbody>
</table>

**p ≤ 0.01, significant association

*p < 0.05
Appendix E. Results of the simple logistic regressions explaining the restraining help variable

<table>
<thead>
<tr>
<th>Predictor variable</th>
<th>p-value</th>
<th>Comment on the predictor variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Veterinarian’s sex</td>
<td>0.169*</td>
<td>Binary (Man/Woman)</td>
</tr>
<tr>
<td>Veterinarian’s age</td>
<td>0.4144</td>
<td>Categorical (&lt; 50 years, ≥ 50 years)</td>
</tr>
<tr>
<td>Number of years of rural practice (in years)</td>
<td>0.851</td>
<td>Continuous</td>
</tr>
<tr>
<td>Veterinary school</td>
<td>0.274</td>
<td>Categorical (Abroad, Nantes¹, Toulouse¹, Lyon¹, Alfort¹)</td>
</tr>
<tr>
<td>Veterinarian’s status</td>
<td>0.812</td>
<td>Categorical (self-employed/employee)</td>
</tr>
<tr>
<td>Number of SICTs performed in 2017</td>
<td>0.939</td>
<td>Continuous</td>
</tr>
<tr>
<td>Proportion of SSICTs among the SICTs performed by the veterinarian</td>
<td>0.0446*</td>
<td>Continuous</td>
</tr>
<tr>
<td>Proportion of rural practice</td>
<td>0.851</td>
<td>Categorical (≤ 20%, 0-40, 40-60, 60-80, 80-100)</td>
</tr>
<tr>
<td>Prevalence of headlocks on the veterinarian’s customer’s farms</td>
<td>0.705</td>
<td>Categorical (prevalent (n = 40)/ less prevalent (n = 75))</td>
</tr>
<tr>
<td>Prevalence of restraining corridors on the veterinarian’s customer’s farms</td>
<td>0.0846*</td>
<td>Categorical (prevalent (n = 62) / less prevalent (n = 53))</td>
</tr>
<tr>
<td>Production type</td>
<td>0.9493</td>
<td>Categorical (dairy/beef/mixed)</td>
</tr>
<tr>
<td>Herd size</td>
<td>0.913</td>
<td>Continuous</td>
</tr>
<tr>
<td>Maximal screening rhythm in the areas were the veterinarian works</td>
<td>0.1232*</td>
<td>Categorical (annual, biennial or triennial, stopped or zoned)</td>
</tr>
<tr>
<td>Prevalence of bTB in the areas were the veterinarian works</td>
<td>0.0388*</td>
<td>Categorical (bTB free or 1 to 5 breakouts more than 5 years ago, infected (1 to 10 breakouts in the last 5 years), highly infected (more than 10 breakouts in the last 5 years))</td>
</tr>
</tbody>
</table>

**significant with α = 0.01, included in the multivariable analysis

*non-significant, but p < 0.25, so included in the multivariable analysis

Variables forced into the primary multivariable model

SSICT: single intradermal tuberculin cervical test
SICCT: intradermal cervical comparative tuberculin test

SICT: intradermal cervical tuberculin test (it can be an SSICT or an SICCT)
Appendix F. Results of the multivariable logistic regression explaining the restraining help variable

AUC of ROC analysis: 0.6976 [0.6014-0.7938]_{CI95%}

<table>
<thead>
<tr>
<th>Predictor variable</th>
<th>Estimated coefficient</th>
<th>Standard error</th>
<th>p-value</th>
<th>Reference category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-0.979</td>
<td>0.915</td>
<td>0.228</td>
<td>/</td>
</tr>
<tr>
<td>Veterinarian’s sex</td>
<td>0.868</td>
<td>0.523</td>
<td>0.0970</td>
<td>Woman</td>
</tr>
<tr>
<td>Proportion of SICTs among the ICTs performed by the veterinarian</td>
<td>-0.0120</td>
<td>0.00639</td>
<td>0.0608</td>
<td>/</td>
</tr>
<tr>
<td>Prevalence of restraining corridors in the vet. customers’ farms (prevalent/less prevalent)</td>
<td>0.929</td>
<td>0.432</td>
<td>0.0314*</td>
<td>Less prevalent</td>
</tr>
<tr>
<td>Screening rhythm in the area</td>
<td>Biennial or triennial</td>
<td>-1.00</td>
<td>1.17</td>
<td>0.0993</td>
</tr>
<tr>
<td>Stopped</td>
<td>-0.825</td>
<td>0.949</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zoning (1)</td>
<td>0.284</td>
<td>0.848</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < 0.05, significant association.

(1) Zones are defined around outbreaks in which annual screening is performed regardless of the screening rhythm in the rest of the area.

Appendix G. Results of the simple logistic regressions explaining the frequency of headlocks

<table>
<thead>
<tr>
<th>Predictor variable</th>
<th>p-value</th>
<th>Comment on the predictor variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main production type among the veterinarian’s customer’s farms</td>
<td>0.63</td>
<td>Categorical (dairy/beef/mixed)</td>
</tr>
<tr>
<td>Herd size</td>
<td>0.50</td>
<td>Continuous</td>
</tr>
<tr>
<td>Maximal screening rhythm in the areas were the veterinarian works</td>
<td>0.86</td>
<td>Categorical (annual, biennial or triennial, stopped or zoned)</td>
</tr>
<tr>
<td>Prevalence of bTB in the areas were the veterinarian works</td>
<td>0.58</td>
<td>Categorical (bTB free or 1 to 5 breakouts more than 5 years ago, infected (1 to 10 breakouts in the last 5 years), highly infected (more than 10 breakouts in the last 5 years)</td>
</tr>
</tbody>
</table>

**significant with α = 0.01, included in the multivariable analysis

*non-significant, but p < 0.25, so included in the multivariable analysis
**Appendix H. Summary of Churchill's paradigm for developing a measurement tool in social science (Churchill, 1979)**

<table>
<thead>
<tr>
<th>Steps of the development process</th>
<th>Coefficients or evaluation technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Define the studied concept</td>
<td>Literature review, free interviews</td>
</tr>
<tr>
<td>2- Generate a sample of variables potentially usable to measure this concept</td>
<td>Literature, introspection, individual semi-directive interviews, etc.</td>
</tr>
<tr>
<td>3- Primary data collection</td>
<td>N &gt; 30, on a sample with characteristics close to those of the population of interest</td>
</tr>
<tr>
<td>4- “Purification” of the measure: suppress the variables that digress from the subject</td>
<td>Cronbach’s Alpha coefficient(^{(1)}), Split-half(^{(2)}), principal component analysis</td>
</tr>
<tr>
<td>5- Data collection</td>
<td>N &gt; 200</td>
</tr>
<tr>
<td>6- Assess the reliability of the measure</td>
<td>Cronbach’s Alpha coefficient(^{(1)}), Split-half(^{(2)})</td>
</tr>
<tr>
<td>7- Assess the validity of the measure</td>
<td>Discriminant(^{(3)}) and convergent(^{(4)}) validity procedure and nomological(^{(5)}) validation</td>
</tr>
</tbody>
</table>

\[ \alpha = \frac{k}{k-1} \left( 1 - \frac{1}{k+2} \sum_{i<j} r_{ij} \right) \]

1. \( \alpha = \frac{k}{k-1} \left( 1 - \frac{1}{k+2} \sum_{i<j} r_{ij} \right) \) in which \( k \) is the number of variables, \( n \) the sample size and \( r_{ij} \) the correlation coefficient between the variables \( i \) et \( j \) (Cronbach, 1951). Alpha is between zero and one. If \( \alpha = 0 \), the correlations between variables are null and therefore the measurement tool is not reliable because there is no internal coherence. On the contrary, if \( \alpha = 1 \), the measure is perfectly reliable. Reliability is considered satisfying if \( \alpha > 0.7 \) (Nunnally, 1967).

2. The sample is randomly divided into two sufficiently large parts, the results of the measurements obtained for the two samples and the global sample must be very close.
(3) Two measures of two different and independent concepts must produce uncorrelated results.

(4) Two measures of the same concept must produce convergent (highly correlated) results.

(5) The two measures of two different but theoretically linked concepts must recapitulate both the direction and the intensity of this link.

Appendix I. Evolution of the percentage of the decrease of herd sensitivity of two protocols: one using a unique test and the other using parallel testing, with the number of infected animals tested using a test with an initial sensitivity of 80% that has decreased to 60%.

Formulas (1) and (2) were used to calculate the percentage of the decrease (D) of herd sensitivity for the unique test protocol and parallel testing, respectively for which $Se = \text{an initial test sensitivity of } 80\%$ and $Se' = \text{a decreased sensitivity of } 60\%$, with $n$ the number of infected animals tested.

\[
D_{\text{unique}} = \frac{(1-(1-Se)^n)-(1-(1-Se')^n)}{1-(1-Se)^n}
\]
(2) \[ D_{\text{parallel}} = \frac{(1-(1-Se)^{2n})-(1-(1-Se')^{2n})}{1-(1-Se)^{2n}} \]
Figure 1. Scenario tree incorporating factors related to veterinarians’ SICCT and notification practices used to model the strict regulatory protocol.
Figure 2. Scenario tree incorporating factors related to veterinarians’ SICCT and notification practices used to model the compliant quick-path regulatory protocol.
Figure 3. Scenario tree incorporating factors related to veterinarians’ SICCT and notification practices used to model the compliant slow-path regulatory protocol.
Figure 4. Sensitivity analysis index above 10% (Mc Kay method) for the output "herd sensitivity" by herd type for each protocol

Legend:

Bbinf: big beef farm with a turnover < 40%, Bbsup: big beef farm with a turnover > 40%, Bsinf: small beef farm with a turnover < 40%, Bssup: small beef farm with a turnover > 40%, Dbinf: big dairy farm with a turnover < 40%, Dbsup: big dairy farm with a turnover > 40%, Dsinf: small dairy farm with a turnover < 40%, Dssup: small dairy farm with a turnover > 40%, Mbinf: big mixed farm with a turnover < 40%, Mbsup: big mixed farm with a turnover > 40%, Msinf: small mixed farm with a turnover < 40%, Mssup: small mixed farm with a turnover > 40%.

Coefperception: perception index
SICCT Se: sensitivity of the intradermal cervical comparative tuberculin test,
SICCT Sp: specificity of the intradermal cervical comparative tuberculin test,
pr_intra: within-herd prevalence of bovine tuberculosis,
Size: herd size.
Table 1. Points attributed to the veterinarians, according to their answers to the quantitative online survey, to develop the ICCT practice index (adapted from Crozet et al. in press)

Legend: $0 = \text{in agreement with recommendations or acceptable practices}, 1 = \text{unacceptable practices}$

<table>
<thead>
<tr>
<th>Injection site</th>
<th>Score</th>
<th>Relative contribution towards the risk of obtaining a false negative result for the ICCT (Humblet, 2011)</th>
<th>Weight*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Always on the neck</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck only for non-nervous cattle, no skin test for others</td>
<td>0</td>
<td>7.0%</td>
<td>1</td>
</tr>
<tr>
<td>Neck only for non-nervous cattle, other injection site (e.g. caudal fold) for others</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No skin test if nervous cattle are present</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other injection site (e.g. caudal fold) for all animals</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Preparation of the injection site</th>
<th>Score</th>
<th>Relative contribution towards the risk of obtaining a false negative result for the ICCT (Humblet, 2011)</th>
<th>Weight*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scissors</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clipper</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Razor</td>
<td>0</td>
<td>6.0%</td>
<td>0.5</td>
</tr>
<tr>
<td>Marking without cutting hair (e.g. marker)</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No preparation</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Injection tool</th>
<th>Score</th>
<th>Relative contribution towards the risk of obtaining a false negative result for the ICCT (Humblet, 2011)</th>
<th>Weight*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syringe and needle</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>McLintock™</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muto™</td>
<td>0</td>
<td>3.0%</td>
<td>0.5</td>
</tr>
<tr>
<td>Synthena™</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dermojet™</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Injection quality check</th>
<th>Score</th>
<th>Relative contribution towards the risk of obtaining a false negative result for the ICCT (Humblet, 2011)</th>
<th>Weight*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systematic check of tuberculin release and reinjection, if present, with a quantity adjusted to the estimated release</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systematic check of tuberculin release and reinjection if present with a full tuberculin dose</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systematic check of tuberculin release but no reinjection, if present (because of drudgery)</td>
<td>1</td>
<td>10.2%</td>
<td>1</td>
</tr>
<tr>
<td>No check of tuberculin release</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systematic check of tuberculin release but no reinjection, if present (because of fear of a false-positive reaction)</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Person performing reading of the skin test results</th>
<th>Score</th>
<th>Relative contribution towards the risk of obtaining a false negative result for the ICCT (Humblet, 2011)</th>
<th>Weight*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Always the same veterinarian as the one who injected</td>
<td>0</td>
<td>7.9%</td>
<td>1</td>
</tr>
<tr>
<td>Occasionally a different veterinarian from the one who injected</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reading time</th>
<th>Score</th>
<th>Relative contribution towards the risk of obtaining a false negative result for the ICCT (Humblet, 2011)</th>
<th>Weight*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postponed to the day after if impossible at Day 3</td>
<td>0</td>
<td>7.9%</td>
<td>1</td>
</tr>
<tr>
<td>Performed earlier if impossible at Day 3</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reading method in case of difficulties in handling the cattle</th>
<th>Score</th>
<th>Relative contribution towards the risk of obtaining a false negative result for the ICCT (Humblet, 2011)</th>
<th>Weight*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Following regulatory recommendations</td>
<td>0</td>
<td>19.4%</td>
<td>2</td>
</tr>
<tr>
<td>Visual examination only</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reading method</th>
<th>Score</th>
<th>Relative contribution towards the risk of obtaining a false negative result for the ICCT (Humblet, 2011)</th>
<th>Weight*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement of skin folds at the 2 injection sites before injection and comparison with the 2 measurements performed at Day 3</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measurement of skin fold at only one site before injection and comparison with measurements performed at the 2 injection sites at Day 3</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measurement of skin folds at the 2 injection sites before injection and comparison with the 2 measurements performed at Day 3 only if there is a palpable reaction</td>
<td>0</td>
<td>19.4%</td>
<td>2</td>
</tr>
<tr>
<td>No measurement before injection, 3 measurements at Day 3: 2 at the injection sites compared to a measurement of a non-injected site</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Category of the influence of the risk to obtain a false negative result for the ICCT during performance of the test (Humblet, 2011) (in %) and associated weight: $[0\%-7\%] \Rightarrow weight = 0.5, [7\%-15\%] \Rightarrow weight = 1, [15\%-22\%] \Rightarrow weight = 2.$

Note: this table was extracted from Crozet et al. 2019 and adapted for our study. The second and last columns were modified.
Table 2. Points attributed to the veterinarians, according to their answers to the quantitative online survey, to develop the perception index representing their perception of the bTB surveillance and control program

Legend:
0: answer associated with a positive perception; 1: answer associated with a negative perception.
Points were summed and rescaled to range from 0 to 1.

<table>
<thead>
<tr>
<th>Score</th>
<th>Major consideration in case of non-negative result obtained for skin testing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thinks of a potential outbreak of a zoonotic disease</td>
</tr>
<tr>
<td></td>
<td>Thinks of a potential outbreak with major economic impact for the farmer</td>
</tr>
<tr>
<td></td>
<td>Thinks of potential temporary and useless blocking of the farm (false-positive result)</td>
</tr>
<tr>
<td></td>
<td>Has no specific consideration</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Concerning intradermal skin tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Has necessary information from sanitary authorities</td>
</tr>
<tr>
<td>Perceives him/herself as able to properly perform skin tests</td>
</tr>
<tr>
<td>Thinks a knowledge update on skin tests is necessary</td>
</tr>
<tr>
<td>Thinks intradermal skin tests are the best available screening tests</td>
</tr>
<tr>
<td>Thinks the interpretation of skin tests is too subjective</td>
</tr>
<tr>
<td>Thinks it is necessary to re-evaluate the administrative part associated with skins tests during screenings (reporting of measurements, transmission of results, etc.)</td>
</tr>
<tr>
<td>Thinks it is necessary to adapt regulatory recommendations to realities of the field</td>
</tr>
<tr>
<td>Thinks it is necessary to stop blocking herds for 6 weeks in case of a non-negative result</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Concerning hurdles to eradicating bovine tuberculosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highlights limitations of single intradermal skin tests</td>
</tr>
<tr>
<td>Highlights limitations of single intradermal comparative cervical skin tests</td>
</tr>
<tr>
<td>Highlights possible role of wildlife reservoir</td>
</tr>
<tr>
<td>Highlights a lack of consideration from sanitary authorities</td>
</tr>
<tr>
<td>Highlights the low fees paid for skin tests</td>
</tr>
<tr>
<td>Highlights the danger of performing skin tests</td>
</tr>
<tr>
<td>Highlights the dual role of private practitioner and sanitary veterinarian *</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Concerning the bovine tuberculosis control program</th>
</tr>
</thead>
<tbody>
<tr>
<td>Essential because it is a major zoonotic infection</td>
</tr>
<tr>
<td>Essential to keep an official tuberculosis-free status</td>
</tr>
<tr>
<td>Essential to prevent the circulation of infectious agents in cattle herds</td>
</tr>
<tr>
<td>Essential to end the eradication effort initiated decades ago</td>
</tr>
<tr>
<td>Useless, because the bovine tuberculosis situation is favourable</td>
</tr>
<tr>
<td>Useless, because such a program will never have good results</td>
</tr>
</tbody>
</table>
In France, private veterinarians are empowered by the State to perform regulatory testing and investigations on the farms in which they usually work. Therefore, veterinarians have a dual role: one as a private veterinarian and another as a State agent.
Table 3. Method used to calculate the sensitivity and specificity of the SICCT in the scenario trees depending on the SICCT practice index value

<table>
<thead>
<tr>
<th>ICCT practice index</th>
<th>0</th>
<th>[0-3]</th>
<th>[3-6]</th>
<th>[6-10]</th>
<th>&gt; 10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sensitivity</strong></td>
<td>literature: Se</td>
<td>0.75*Se</td>
<td>0.5*Se</td>
<td>0.25*Se</td>
<td>0</td>
</tr>
<tr>
<td><strong>Specificity</strong></td>
<td>literature: Sp</td>
<td>Sp+(1-Sp)*0.25</td>
<td>Sp+(1-Sp)*0.5</td>
<td>Sp+(1-Sp)*0.75</td>
<td>1</td>
</tr>
</tbody>
</table>

For the first screening SICCT, Se was modelled using a normal asymmetric distribution law, with a mean of 74%, and 95% of the values between 43% and 95%. Sp was modelled using a normal asymmetric distribution law, with a mean of 99%, and 95% of the values between 80% and 100% (Poirier et al., 2019).
Table 4. Results of the multivariate linear regression explaining the SICCT practice index

<table>
<thead>
<tr>
<th>Estimated coefficient</th>
<th>Standard error</th>
<th>p-value</th>
<th>Reference category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.97</td>
<td>0.490</td>
<td>0.05*</td>
</tr>
<tr>
<td>Perception index</td>
<td>4.47</td>
<td>1.188</td>
<td>2.85.10***</td>
</tr>
<tr>
<td>Veterinarian’s age (&lt;50, ≥ 50 years)</td>
<td>0.573</td>
<td>0.293</td>
<td>0.054</td>
</tr>
<tr>
<td>Production type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dairy</td>
<td>-0.1467</td>
<td>0.398</td>
<td>0.0766</td>
</tr>
<tr>
<td>Mixed</td>
<td>-0.805</td>
<td>0.351</td>
<td></td>
</tr>
<tr>
<td>Prevalence of restraining corridors in the vet. customers’ farms (prevalent/less prevalent)</td>
<td>0.698</td>
<td>0.283</td>
<td>0.0155*</td>
</tr>
<tr>
<td>Proportion of SSICTs among the SICTs performed by the veterinarian</td>
<td>0.0082</td>
<td>0.004354</td>
<td>0.0626</td>
</tr>
</tbody>
</table>

**p < 0.01, significant association
*p < 0.05

SSICT: single intradermal tuberculin cervical test; SICCT: intradermal tuberculin cervical comparative test; SICT: intradermal cervical tuberculin test
Table 5. Results of the univariate linear regression explaining the SICCT practice index by the perception index

Adjusted $R^2 = 0.1063$
F statistic = 13.25
Model’s p-value < 0.001
Residual standard error = 1.526 (degrees of freedom = 102)

<table>
<thead>
<tr>
<th>Estimated coefficient</th>
<th>Standard error</th>
<th>p-value</th>
<th>Reference category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1.7963</td>
<td>0.3933</td>
<td>$1.38 \times 10^{-5}$**</td>
</tr>
<tr>
<td>Perception index</td>
<td>4.3708</td>
<td>1.208</td>
<td>$4.3 \times 10^{-4}$***</td>
</tr>
</tbody>
</table>

**p < 0.01, significant association

SICCT: intradermal cervical comparative tuberculin test
Table 6. Results of the multivariate linear regression explaining the perception index

Adjusted $R^2 = 0.2142$
$F$ statistic = 6.181
Model’s $p$-value = 1.34*10^{-5}
Residual standard error = 0.1068 (degrees of freedom = 108)

<table>
<thead>
<tr>
<th></th>
<th>Estimated coefficient</th>
<th>Standard error</th>
<th>p-value</th>
<th>Reference category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.4086</td>
<td>0.0214</td>
<td>&lt; 2.10^{-16}**</td>
<td>/</td>
</tr>
<tr>
<td>Veterinarian’s age (&lt; 50, ≥ 50)</td>
<td>-0.07047</td>
<td>0.0223</td>
<td>0.00206**</td>
<td>&lt; 50 years</td>
</tr>
<tr>
<td>Veterinarian’s status (employee/self-employed)</td>
<td>-0.05977</td>
<td>0.0288</td>
<td>0.0406*</td>
<td>Self-employed</td>
</tr>
<tr>
<td>Headlock frequency (prevalent/less prevalent)</td>
<td>-0.06543</td>
<td>0.0212</td>
<td>0.00252**</td>
<td>Less prevalent</td>
</tr>
<tr>
<td>Restraining help (&lt;2 people / ≥2 people)</td>
<td>-0.06583</td>
<td>0.0203</td>
<td>0.00156**</td>
<td>&lt; 2 people</td>
</tr>
<tr>
<td>Production type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dairy</td>
<td>-0.05730</td>
<td>0.0279</td>
<td>0.0566</td>
<td>Beef</td>
</tr>
<tr>
<td>mixed</td>
<td>0.01928</td>
<td>0.0256</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**$p \leq 0.01$, significant association
*p < 0.05
### Table 7. Results of the multivariate logistic regression explaining the notification of non-negative results.

AUC of ROC analysis: 0.849 [0.77-0.92]_{95%}

<table>
<thead>
<tr>
<th></th>
<th>Estimated coefficient</th>
<th>Standard error</th>
<th>p-value</th>
<th>Reference category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>5.03</td>
<td>1.7</td>
<td>1.8.10^{-5}</td>
<td>/</td>
</tr>
<tr>
<td>Perception index</td>
<td>-9.03</td>
<td>-1.94</td>
<td>0.03*</td>
<td>/</td>
</tr>
<tr>
<td>bTB cumulative incidence for 1000 herds between 2012 and 2016 in the areas where the veterinarian works</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 0.1</td>
<td>18.08</td>
<td>1888.62</td>
<td>0.76</td>
<td>0.1</td>
</tr>
<tr>
<td>0.1-10</td>
<td>0.76</td>
<td>0.73</td>
<td>1.769</td>
<td>[0.1,1]</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>1.769</td>
<td>1.40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < 0.05, significant association.
Table 8. Mean and standard deviation of the perception index in the database, according to the veterinarian’s age, number of people usually helping to restrain the cattle during the ICCT and headlocks frequency; and parameters of the corresponding beta laws used to model the perception index of veterinarians

<table>
<thead>
<tr>
<th>Veterinarian’s age</th>
<th>Help during cattle handling</th>
<th>Headlocks frequency</th>
<th>Mean</th>
<th>sd</th>
<th>Beta law’s parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>a</td>
</tr>
<tr>
<td>&lt; 50 years</td>
<td>&lt; 2 people</td>
<td>Less prevalent</td>
<td>0.37</td>
<td>0.14</td>
<td>4.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>prevalent</td>
<td>0.32</td>
<td>0.13</td>
<td>3.80</td>
</tr>
<tr>
<td></td>
<td>≥ 2 people</td>
<td>Less prevalent</td>
<td>0.31</td>
<td>0.14</td>
<td>3.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td>prevalent</td>
<td>0.25</td>
<td>0.09</td>
<td>5.54</td>
</tr>
<tr>
<td>≥ 50 years</td>
<td>&lt; 2 people</td>
<td>Less prevalent</td>
<td>0.33</td>
<td>0.10</td>
<td>6.97</td>
</tr>
<tr>
<td></td>
<td></td>
<td>prevalent</td>
<td>0.27</td>
<td>0.08</td>
<td>8.05</td>
</tr>
<tr>
<td></td>
<td>≥ 2 people</td>
<td>Less prevalent</td>
<td>0.26</td>
<td>0.08</td>
<td>7.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>prevalent</td>
<td>0.22</td>
<td>0.12</td>
<td>2.40</td>
</tr>
</tbody>
</table>
Table 9. Parameters of the beta distribution law used for the probability that the veterinarian notifies a non-negative result for an ICCT according to perception index category

<table>
<thead>
<tr>
<th>Perception index(^{(1)})</th>
<th>Notification of ICCT non-negative results</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.30</td>
<td>Yes</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complementary to 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 0.30</td>
<td>Yes</td>
<td>49</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complementary to 1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{(1)}\) The categories were defined according to the mean perception index of 0.303 observed in our data.
Table 10. Herd sensitivity estimation (in %) for each protocol by herd type

<table>
<thead>
<tr>
<th>Herd production type</th>
<th>Herd size category</th>
<th>Herd turnover</th>
<th>Compliant slow-path protocol</th>
<th>Compliant quick-path protocol</th>
<th>Strict protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean 95% CI</td>
<td>Mean 95% CI</td>
<td>Mean 95% CI</td>
</tr>
<tr>
<td>Dairy farm</td>
<td>small (&lt; 74 adults)</td>
<td>&lt; 40%</td>
<td>25.2 25.1-25.3</td>
<td>25.7 25.6-25.9</td>
<td>32.3 32.2-32.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 40%</td>
<td>18.5 18.4-18.5</td>
<td>18.4 18.3-18.4</td>
<td>24.3 24.2-24.4</td>
</tr>
<tr>
<td></td>
<td>big (≥ 74 adults)</td>
<td>&lt; 40%</td>
<td>32.0 31.8-32.2</td>
<td>33.2 33.0-33.5</td>
<td>36.6 36.3-36.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 40%</td>
<td>24.8 24.7-25.0</td>
<td>25.4 25.3-25.6</td>
<td>29.8 29.7-29.9</td>
</tr>
<tr>
<td>Beef farm</td>
<td>small (&lt; 66 adults)</td>
<td>&lt; 40%</td>
<td>22.3 22.2-22.4</td>
<td>22.5 22.4-22.6</td>
<td>29.2 29.1-29.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 40%</td>
<td>19.1 19.0-19.2</td>
<td>19.1 19.0-19.2</td>
<td>25.3 25.2-25.4</td>
</tr>
<tr>
<td></td>
<td>big (≥ 66 adults)</td>
<td>&lt; 40%</td>
<td>30.5 30.3-30.8</td>
<td>31.6 31.3-31.8</td>
<td>35.1 34.9-35.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 40%</td>
<td>13.8 13.7-13.9</td>
<td>12.7 12.6-12.8</td>
<td>18.4 18.2-18.5</td>
</tr>
<tr>
<td>Mixed farm</td>
<td>small (&lt; 124 adults)</td>
<td>&lt; 40%</td>
<td>26.4 26.3-26.6</td>
<td>27.2 27.0-27.4</td>
<td>31.9 31.7-32.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 40%</td>
<td>22.9 22.8-23.0</td>
<td>23.3 23.2-23.4</td>
<td>28.8 28.6-28.9</td>
</tr>
<tr>
<td></td>
<td>big (≥ 124 adults)</td>
<td>&lt; 40%</td>
<td>46.2 45.8-46.5</td>
<td>48.6 48.2-48.9</td>
<td>50.8 50.4-51.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 40%</td>
<td>41.7 41.4-42.0</td>
<td>43.7 43.4-44.1</td>
<td>46.2 45.9-46.6</td>
</tr>
<tr>
<td>Herd production type</td>
<td>Herd size category</td>
<td>Herd turnover</td>
<td>Compliant slow-path protocol</td>
<td>Compliant quick-path protocol</td>
<td>Strict protocol</td>
</tr>
<tr>
<td>----------------------</td>
<td>-------------------</td>
<td>---------------</td>
<td>-----------------------------</td>
<td>------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Socio - (%) (1)</td>
<td>Socio + (%)</td>
<td>Decrease of herd sensitivity (%) (2)</td>
</tr>
<tr>
<td>Dairy farm</td>
<td>small (&lt; 74 adults)</td>
<td>&lt; 40%</td>
<td>42.7</td>
<td>25.2</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 40%</td>
<td>30.8</td>
<td>18.5</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>big (≥ 74 adults)</td>
<td>&lt; 40%</td>
<td>49</td>
<td>32.0</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 40%</td>
<td>40.4</td>
<td>24.8</td>
<td>39</td>
</tr>
<tr>
<td>Beef farm</td>
<td>small (&lt; 66 adults)</td>
<td>&lt; 40%</td>
<td>37.5</td>
<td>22.3</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 40%</td>
<td>32</td>
<td>19.1</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>big (≥ 66 adults)</td>
<td>&lt; 40%</td>
<td>46</td>
<td>30.5</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 40%</td>
<td>40.2</td>
<td>13.8</td>
<td>32</td>
</tr>
<tr>
<td>Mixed farm</td>
<td>small (&lt; 124 adults)</td>
<td>&lt; 40%</td>
<td>43</td>
<td>26.4</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 40%</td>
<td>37.7</td>
<td>22.9</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>big (≥ 124 adults)</td>
<td>&lt; 40%</td>
<td>61</td>
<td>46.2</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 40%</td>
<td>56.8</td>
<td>41.7</td>
<td>27</td>
</tr>
</tbody>
</table>

Legend: Socio -: estimation by scenario-tree modelling without accounting for the sociological data concerning the intradermal cervical comparative tuberculin test (ICCT) and non-negative ICCT result notification; Socio + : estimation by scenario-tree modelling accounting for the sociological data concerning the intradermal cervical comparative tuberculin test (ICCT) and non-negative ICCT result notifications.

(1) Poirier et al. 2019, under review

(2) Proportion of sensitivity estimation decrease resulting from the incorporation of data concerning ICCT and notification practices.