Rev Agric Food Environ Stud (2016) 97:215–223
DOI 10.1007/s41130-016-0022-5

Farm characteristics and perceptions regarding costs contribute to the adoption of biosecurity in Finnish pig and cattle farms

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Received: 30 January 2015 / Accepted: 11 January 2016 / Published online: 8 June 2016

Abstract The goal of this study was to estimate how the perceived costs of biosecurity measures and the characteristics of the farm and the producer influence the adoption of four biosecurity measures: (1) the use of protective clothing when entering an animal shelter and (2) the use of protective shoes when entering an animal shelter, (3) the verification of the health *status* of animals coming to the farm, and (4) the use of a carcass container to temporarily store dead animals at the farm. Questionnaire data from 852 Finnish livestock farms were analysed by a logistic regression model. The higher the producers perceived the cost of the biosecurity measure the less likely they were to adopt that measure. However, this response was inelastic. The results suggest that the use of biosecurity could be promoted by providing producers with economic incentives to follow stricter biosecurity policy. University education and the producer's activity to maintain his/her professional knowledge had a positive effect on the adoption of biosecurity measures. Also factors such as the producer's gender, farm size and production type contributed significantly to the adoption of biosecurity measures. The ongoing structural change in the livestock sector likely increases the use of biosecurity measures as larger farms were more likely to adopt biosecurity measures.

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Keywords Livestock · Biosecurity · Costs · Questionnaire · Logistic regression · Disease risk

JEL classifications Q12 · Q16 · Q19

Introduction

Contagious animal diseases can cause substantial economic losses to both livestock producers and society (Berentsen et al. 1992; Tisdell et al. 1999; Thompson et al. 2002; Bennett 2003; Mangen and Burrell 2003; Schoenbaum and Disney 2003; Neumann et al. 2005). Fortunately, studies (e.g. van Schaik 2000; Velthuis and Mourits 2007; Boklund et al. 2009) show that controlling risk factors can mitigate the risk of the disease.

Biosecurity can be regarded as the adoption of measures which can reduce the risk of contagious animal diseases, or more explicitly pathogenic agents (including zoonotic agents), from spreading. The measures can focus on preventing the spread of pathogens between farms (external biosecurity) or reducing the spread between animals located in the same farm (within farm spread, internal biosecurity). Pathogens can spread via different routes and the importance of routes can vary. Typically, biosecurity measures focus on eliminating either the pathogen (e.g. disinfection) or the realisation of route which can transmit the pathogen.

Several important routes for pathogen transmission exist. Pathogenic agents can spread via direct contact transmission which involves an animal being in physical contact with an infected animal, or infection upon reproduction. Hence, animal transports are considered as a major risk factor for contagious animal diseases. Besides direct transmission, pathogens can spread also via fomites such as contaminated clothes, booths, tools and other objects which enter in contact with the animal, and vehicles and even humans moving between farms; by oral transmission such as via contaminated feed or water or animal licking contaminated objects, faeces or urine; via aerosols such as contaminated air flowing between neighbour farms; and vectors such as arthropods or insects carrying the pathogen and being in contact with the animal (see e.g. Kahn and Line 2010). In this study, the main focus is on measures related to animal movements, visitors to the farm and disposal of dead animals.

Biosecurity measures are an option to reduce economic losses resulting from disease for the benefit of livestock producers and society. It is therefore important to ensure that producers have sufficient incentives to comply with the desired level of biosecurity. The industry plays a major role in the implementation of biosecurity measures, but due to the characteristics similar to a public good a government intervention may be needed to enforce the measures (e.g. Burrell 2002; Heikkilä 2010; Gramig and Horan 2011).

In economic terms, the relationship between costs and benefits determines the optimal use of biosecurity measures (see e.g. Gramig et al. 2009; Civic Consulting 2011). This requires that the decision maker has information on costs and benefits so that he/she can make an informed decision. Due to economic factors, different levels of biosecurity can arise (cf. Hennessy et al. 2005). Although studies indicate that the use of many biosecurity measures can be highly profitable (e.g. Fasina et al. 2012), the adoption of enhanced biosecurity requires that producers accept additional costs which may not always bring them enough direct benefits (e.g. Fraser et al. 2010). Technical innovations and frictions can encourage precautionary biosecurity actions or reduce society's welfare (Hennessy 2007).

Previously, Fraser et al. (2010) have found that an increase in pig farmers' willingness to adopt biosecurity measures to control food-borne zoonoses on farms was related to a decrease in the estimated cost of disease. Valeeva et al. (2011) noticed that producer's perceived benefits of biosecurity measures, producer's risk attitude on farming choices, and his/her self-protection behaviour (such as tendency to wear a seatbelt) contributed to the decisions to adopt a biosecurity measure. In their structural equation model, a farm's internal risk exposure and probability of disease occurrence were counted as factors affecting first the impact of disease on farm business, which then further affected perceived benefits of biosecurity measures. Toma et al. (2013) developed a structural equation model and found that producers' perceived importance regarding specific biosecurity policy influence the decision to apply biosecurity measures. Stott and Gunn (2008) analysed the management of bovine viral diarrhoea in suckler beef herds and found that vaccination and biosecurity were generally complements, rather than substitutes, for one another. Hence, producers investing in the herd may be more willing to invest in multiple biosecurity measures to protect the herd.

Besides economic parameters, farm characteristics and previous experiences affect the adoption of biosecurity. Casal et al. (2007) noticed that Spanish producers adopted measures to reduce the risks of contamination from people and animals other than pigs, but measures related to replacement stock were applied less frequently. They noticed that the perception regarding a measure was strongly influenced by measures actually applied on the farm. Understanding the relationship between perceptions and measures taken was seen important in developing effective biosecurity strategies on pig farms (Casal et al. 2007). In Belgium, Ribbens et al. (2008) identified three groups of biosecurity adopters among pig farms and noticed that the level of biosecurity improved with farm size. Brandt et al. (2008) also noticed that the adoption of biosecurity can vary by farm type.

Information about perceived benefits and costs of biosecurity and farm characteristics is needed to identify how different factors affect producers' decision to take biosecurity measures into practice, and how measures to promote the adoption of biosecurity could be targeted. The goal of this study is to estimate how the perceived costs of biosecurity measures and the characteristics of the farm and the producer influence the adoption of measures. This study does not focus on any specific disease because a biosecurity measure can mitigate several diseases. Rather our focus is on measures which can be used to prevent infectious animal diseases agents from spreading. This paper contributes to the previous knowledge by illustrating with survey data how cost perceptions and farm-specific factors can influence the adoption of biosecurity. Our main focus is on cattle farms since dairy and beef cattle are present in the clear majority of farms in our sample.

2 Methods

2.1 Questionnaire

A questionnaire to collect information about biosecurity and hygiene practices on Finnish cattle and pig farms was mailed in March 2011 to 3000 cattle and 1000 pig farmers, representing 18 and 43 % of these farms in Finland in 2009, respectively. The farms receiving the questionnaire were randomly selected except that farms defined as the largest farms (representing 10 % of farms) received the questionnaire more frequently than smaller farms. All of the largest pig farms, and 45 % of the largest cattle farms received the questionnaire. Sampling was based on farm size which is defined here as the number of animals (cows and heifers older than 6 months, sows and finishers older than 3 months) on the farm. The selection of large farms was justified because there is a tendency towards larger farm size whereas smaller farms tend to discontinue their production (Pyykkönen et al. 2013). A reminder was mailed 4 weeks later. It was possible to answer on the Internet. The survey is further described by Sahlström et al. (2014).

In the questionnaire demographic background of the respondent (such as age, gender, education and experience in animal husbandry), characteristics of the farm (such as production type and the type of buildings) and different on-farm biosecurity measures and hygienic precautions were surveyed. Respondents were asked to indicate whether different biosecurity measures were applied on their farm. For example, whether the health status of animals purchased for the farm was verified prior to their arrival at the farm or whether farm workers and visitors entering the animal shelter were using protective shoes or protective clothing. These measures were assumed be targeted to mitigate all relevant diseases rather than a single disease. In this article, we will focus on variables which were found meaningful in the statistical analysis. The questionnaire was pretested in an expert group of veterinarians working with biosecurity.

The measures investigated in our analysis were (dichotomous variables):

(1) The health status of animals coming to the farm is verified prior to their arrival at the farm.
(2) Protective clothing is used by visitors entering the animal shelter.
(3) Protective shoes are used by visitors entering the animal shelter.
(4) A leak-proof carcass container is used to store dead animals at the farm temporarily, until they are collected by carcass rendering vehicle.

These measures can help prevent the spread of an infectious animal disease agent to the farm. In addition, some measures such as the use of a carcass container can be important in reducing the risk of pathogens spreading within the farm and from the farm to other livestock farms. Table 1 describes variables used in the analysis. Table 2 represents descriptive information regarding categorical variables in the data.

A total of 2242 responses were received, resulting in a response rate of 45 %. However, all respondents did not answer all the questions. For instance, the respondents may have considered individual questions irrelevant for their farm type. For example, approximately 19 % of the farms were pig farms and some of the questions which were relevant for pig farms may not be relevant for dairy farms. In addition, a respondent was required to provide information on all variables included in the estimation before it could be included in the data. Due to missing information on one or more variables, the number of observations included in the estimation varies by equation and it ranges from 584 to 852 farms.

The adoption rate of biosecurity measures varied among farms. According to the raw data, almost 10 % of the respondents had adopted one of four measures, 28 % had adopted two measures, 26 % three measures and 7 % four measures. However, 30 % did not adopt any of the four measures. Table 3 represents the adoption rates of four biosecurity measures among farms which have applied another specific measure. The table shows that more than 95 % of farms which used protective clothes used also protective shoes whereas 88 % of farms using protective shoes used also protective clothes. Farms using carcass container also often used protective clothing and shoes. These farms were mainly pig farms as the use of carcass container was much more common among pig than cattle farms. More than 80 % of farms verifying health status of incoming animals also used protective clothing or shoes, whereas less than one fourth of these farms used carcass container. There can be different ways to implement measures in practice. For instance, the health of new animals can be verified by requiring a health certificate or the buyer can inspect them him/herself.

Continuous variables are also included in the data. The data on the costs of biosecurity measures represent respondents' perceptions regarding the costs, and the ranking of respondents is done with respect to cost perception rather than true costs of a measure. The median perceived costs for using protective clothing and for using protective shoes were €100 per farm per year (the 95 % confidence intervals being €10–€550 and €10–€500, with a mean of €169 and €137, respectively). The median costs of using a carcass container were estimated at €2000 (95 % confidence interval of €100–€10, 000, with a mean of €3367) per year. The costs of verifying the health of animals were indicated on average at €100 per farm per year (95 % confidence interval of €0–€2000, with a mean of €763). As these data suggest, the distributions had long tails and the responses were not normally distributed before taking the logarithmic transformation. The perceived costs varied little between production types. A natural logarithm transformation was performed for the perceived cost variables and then values were standardised within the farm type.

The average age of respondents' newest animal shelter (by year built or renovated) was 2.4 years (95 % confidence interval of 1.1–3.6, standard deviation of 0.7). Although the farms in our data had quite new production facilities, most farms had other older buildings whose average age was 19 years (by the age of the oldest animal shelter at the farm). The average number of dairy cows, if any cows were present, on the farm was 31 (95 % confidence interval of 2–81, standard deviation of 22), the average number of other cattle if any of them was present on the farm was 67 (95 % confidence interval of 6–295, standard deviation of 107), the average number of sows if any sows were present on the farm was 121 (95 % confidence interval of 13–366, standard deviation of 127) and the average number of finishing pigs if any finishing pigs were present on the farm was 535 (95 % confidence interval of 4–2122, standard deviation of 656).

Table 1 Description of variables used in the study to estimate four models describing the likelihood of adoption of biosecurity measure i

Variable	Description	Type	Options
i	Biosecurity measure taken into practice	Nominal	1 = Health status of incoming animals are verified. 2 = Visitors entering the animal shelter have to wear protective clothes. 3 = Visitors entering the animal shelter have to wear protective shoes. 4 = Dead animals are temporarily stored in a carcass container.
p_i	Probability for biosecurity measure i	Scale	0…1
β_0	Intercept	Scale	–∞…∞
$\beta_{1,i}\ldots\beta_{15,i}$	Coefficients of explanatory variables for measure i	Scale	–∞…∞
x_1	Respondent is female	Nominal	0 = no, 1 = yes
x_2	Respondent has university level education	Nominal	0 = no, 1 = yes
x_3	Continuous training: the respondent updates or maintains his/her professional knowledge	Nominal	0 = no, 1 = yes
x_4	Farming is the primary source of income	Nominal	0 = no, 1 = yes
x_5	Farm size, standardised number of animals	Scale	0…∞
x_6	Animal shelter age in years	Scale	0…∞
x_7	Respondent has plans to expand farm	Nominal	0 = no, 1 = yes
x_8	Farm was included in animal health classification register in 2011	Nominal	0 = no, 1 = yes
x_9	Farm has a production contract	Nominal	0 = no, 1 = yes
x_{10}	Type of production is suckler cow farm	Nominal	0 = no, 1 = yes
x_{11}	Type of production is other cattle	Nominal	0 = no, 1 = yes
x_{12}	Type of production is farrowing farm	Nominal	0 = no, 1 = yes
x_{13}	Type of production is farrowing-to-finishing farm	Nominal	0 = no, 1 = yes
x_{14}	Type of production is finishing farm	Nominal	0 = no, 1 = yes
x_{15}	Perception of costs (€ per year) caused by the adoption of biosecurity measure	Scale	0…∞, separately for each i
ε_i	Error term for measure i	Scale	0…∞

The parameters are applied in the following logit regression model: $\ln\frac{p_i}{1-p_i} = \beta_0 + \beta_1 x_{1,i} + \cdots + \beta_{15} x_{15,i} + \varepsilon_i$

2.2 Logistic regression

Our hypothesis is that the producer's perceptions regarding the costs, the producer's educational level, demographic and farm-specific factors influence the decision to use a biosecurity measure either directly or through their association with other factors (a proxy). A logistic regression model was used to estimate how farm's and producer's characteristics and producer's perceptions about biosecurity were related to the stated choice to take biosecurity measures into practice. The model was:

$$\mathrm{logit}\left(\mathrm{E}\left[Y_i \middle| x_{1,i}, \ldots, x_{m,i}\right]\right) = \mathrm{logit}(p_i) = \ln\frac{p_i}{1-p_i}$$
$$= \beta_0 + \beta_1 x_{1,i} + \cdots + \beta_m x_{m,i} + \varepsilon_i = \mathbf{bX_i} + \varepsilon_i \qquad (1)$$

where p_i represents the likelihood to adopt biosecurity measure i; $i = 1,..,4$ indicates whether (1) the measure to verify the health status of animals coming to the farm, (2) the use of protective clothing by visitors entering the animal shelter, (3) the use of protective shoes when entering the animal shelter, and (4) the use of carcass container to temporarily store dead animals, is examined by the equation; β_m and $x_{m,i}$ ($m = 1, \ldots, 15$) are as explained in Table 1; E is expectations operator, Y_i is the observation of whether i is adopted; ε_i is estimation error; and $\mathbf{b}$ and $\mathbf{X_i}$ represent the estimated parameters and explanatory variables in the vector format. Since the model was estimated separately for each measure i, the values of estimated parameters (β_m) vary by measure. Farm size index and the age of the animal shelter were standardised prior to the analysis. The explanatory variables were selected based on suggestions obtained from the literature and our hypotheses. Explanatory variables were expected to describe exogenous or predetermined characteristics of the producer or the farm which can contribute to the biosecurity decisions.

Table 2 Descriptive statistics representing the percentage of farms which have specific characteristics (percent among farms which have responded yes to the question and are included in the data)

Variable	%
Verify health status of incoming animals	44.7
Visitors entering the animal shelter have to wear protective clothes	47.7
Visitors entering the animal shelter have to wear protective shoes	33.5
Dead animals are stored temporarily in a carcass container	11.3
Female respondent	23.1
Respondent has a university level education	17.2
Respondent is updating or maintaining his/her professional knowledge	94.6
Farming is the primary source of income	71.7
Respondent has plans to expand farm	77.4
Farm was included in animal health classification register in 2011	67.8
Farm has a production contract	58.8
Type of production is dairy	56.5
Type of production is suckler cow farm	9.4
Type of production is other cattle	18.5
Type of production is farrowing farm	4.7
Type of production is farrowing-to-finishing pig farm	6.7
Type of production is finishing pig farm	7.9

In the final model only variables which were tested statistically significant at 5 % risk level were included.

The analysis was performed by using logistic regression of Matlab econometrics toolbox (LeSage 2005). We estimated four different models. Each estimated equation explained the use of one of four biosecurity measures represented in the previous section. Different model specifications were tested, including specifications utilising extra variables collected by the questionnaire. However, more variables and interactions between some variables were considered in the preliminary data analysis. The selection of these variables was carried out by stepwise elimination, by testing the impact of the elimination of the variable with the smallest statistical significance one at the time from the model. The goodness of fit of different specifications was evaluated primarily by the model's capacity to classify adopters and non-adopters of biosecurity measures correctly.

Table 3 Percentage of farms applying at least two biosecurity measures simultaneously

	Measure that is applied by all farms in the column			
	Protective clothes	Protective shoes	Carcass container	Health status
All farms (%)				
Protective clothes	100.0	88.3	88.9	80.8
Protective shoes	96.9	100.0	90.1	88.5
Carcass container	24.2	22.3	100.0	22.6
Health status	43.8	43.7	45.0	100.0
Cattle farms (%)				
Protective clothes	100.0	84.9	75.0	75.8
Protective shoes	96.2	100.0	79.2	86.3
Carcass container	2.8	2.6	100.0	4.0
Health status	44.1	44.3	62.5	100.0
Pig farms (%)				
Protective clothes	100.0	96.5	92.4	93.6
Protective shoes	98.5	100.0	92.0	93.6
Carcass container	66.1	64.4	100.0	67.5
Health status	44.1	43.2	44.5	100.0

Numbers in each row represent percentage of farms applying a biosecurity measure among those farms that apply another measure mentioned in the top column. The numbers are based on the raw data. Due to missing observations for other variables, not all observations in the raw data could be used in the logit model

3. Results

3.1 Verification of health of animals coming to the farms

Table 4 presents the regression results for all four models. The model identified correctly 63.1 % of farms regarding their verification of the health status of incoming animals. Hence, 36.9 % of farms in the sample were classified incorrectly. The model categorised non-adopters better than adopters, because 74 % of non-adopters but only 50 % of adopters were categorised correctly.

As the verification of animal health was not concerned about an individual disease, results (estimated parameters) reflect the preferences of livestock producers given their perceptions regarding the health status of pigs and cattle in Finland. Results suggest that when the costs perceived by the respondent due to verifying the health status of animals increased by one standard deviation, the likelihood to take this measure decreased by about 16 %. Hence, a perceived cost increase reduced the use of this measure. In our data, the coefficient of variation of log costs ranged from 26 % (dairy) to 52 % (farrowing farms). Hence, a 26 to 52 % increase in perceived costs of verifying the health of animals coming to the farm decreased the likelihood of verification by 16 %.

Besides the cost perception, other factors affected the likelihood to verify the health of animals coming to the farm. An average-sized farm which did not have any of the characteristics (i.e. their effects on logit were set at zero) included in the final logit model reported in Table 2 had a likelihood of 0.30 to verify the health status of incoming animals. This was used as the benchmark. Female respondents were 34 % more likely (the likelihood was 0.40) to verify the health status of incoming animals than the benchmark male respondents having otherwise similar characteristics. Respondents with an academic education or with the stated attention to continuous training

Table 4 Results of the four logit regression models explaining the use of biosecurity measures with respondent's and farm's characteristics and perceptions about the costs of respective measure

Equation	Protective clothes		Protective shoes		Carcass container		Verify health	
	β	sd	β	sd	β	sd	β	sd
Intercept	−1.174	0.223			−4.737	0.549	−0.870	0.169
Female respondent (1 = yes, 0 = no)	0.463	0.196	0.790	0.209			0.450	0.207
University education (1 = yes, 0 = no)			0.568	0.261			0.548	0.230
Continuous training (1 = no, 0 = yes)							−1.076	0.468
Full-time farmer (1 = yes, 0 = no)	0.824	0.207						
Health classified farm (1 = yes, 0 = no)					−1.395	0.554		
Farm size (index)	0.667	0.103	0.674	0.102	1.319	0.228		
Plans to expand (1 = yes, 0 = no)			0.553	0.201			0.514	0.192
Production contract (1 = yes, 0 = no)	0.431	0.168	0.658	0.131			0.453	0.182
Suckler cow farm (1 = yes, 0 = no)	−0.690	0.302					0.720	0.298
Other non-dairy cattle farm (1 = yes, 0 = no)			−0.521	0.247				
Farrowing farm (1 = yes, 0 = no)	2.700	0.499			5.712	0.617		
Farrowing to finishing farm (1 = yes, 0 = no)	1.620	0.396			6.008	0.639		
Finishing farm (1 = yes, 0 = no)	1.282	0.330			6.258	0.621		
Costs of perception (index)	−0.217	0.083	−0.200	0.089	−0.499	0.161	−0.247	0.095
Model performance								
Number of observations	790		758		852		591	
McFadden R^2	0.18		0.14		0.56		0.07	
Zeros, % observations	47.7		33.5		88.7		44.7	
Ones, % observations	52.3		66.5		11.3		55.3	
Model fit, correctly classified observations								
Zeros, % observations	67.1		44.9		96.8		74.0	
Ones, % observations	73.4		89.5		70.8		49.6	
Total, % observations	70.4		74.5		93.9		63.1	

The four regressions correspond to (1) visitors' use of protective clothes when entering the animal shelter, (2) visitors' use of protective shoes when entering the animal shelter, (3) using a carcass container to temporarily store dead animals and (4) verification of the health of animal prior their arrival at the farm. β represents estimated coefficients and sd represents standard deviation of estimated β. The models included only parameters which were statistically significant at 5 % significance level. The goodness of fit is represented for each model in the lower part of the table as 'Model performance' and updating of their professional knowledge were more likely to take the measure than respondents without the characteristic. Farms having a production contract or planning to expand production were also more likely to verify the health of incoming animals.

3.2. The use of protective clothing or shoes by visitors entering an animal shelter

The use of (1) protective clothing by visitors entering an animal shelter or (2) protective shoes (typically rubber boots or shoe covers) by visitors entering an animal shelter is two measures which can be adopted quite easily by all producers. These measures are examined here simultaneously due to the ease of representation. Both measures were adopted by more than half of respondents in the sample. Estimated models categorised correctly 70–75 % of all respondents. Non-adopters and adopters of protective clothing were categorised almost equally well. Almost 90 % of adopters of protective shoes were assigned a correct category whereas a false category was estimated for more than half of non-users of protective shoes.

When the costs perceived by the respondent due to the use of protective clothing or shoes increased by one standard deviation, the likelihood to take these measures decreased by about 16 and 10 %, respectively. Hence, the effect of perceived costs was quite similar as in the event of verifying the health status of animals. The impact was slightly smaller than the corresponding percentage increase in the costs (17 % on finishing pig farms and 20 % on farrowing-to-finishing farms). Other factors that were associated with an increase in the likelihood of using protective clothing and protective shoes included farms with a female respondent, full-time farmers and farms that have a production contract, and farms engaged in pig production (as opposed to cattle farms). Production type (pigs vs. cattle) and full-time farming activity (yes vs. no) were the main differences between these two measures. When farm size increased by one standard deviation, the likelihood of using protective clothing and shoes increased by 59 and 32 %, respectively.

3.3 Carcass container

A leak-proof carcass container to temporarily store dead animals at the farm was used by 11 % of respondents in the sample. The model identified quite well farms that were or were not using a carcass container because, in total, 93.9 % of farms were correctly categorised by the model. The accuracy was better regarding non-adopters than adopters, which is probably due to the strong impact of production type, i.e. due to the fact that carcass container was used predominantly by pig farms. When the perceived costs of the use of carcass container increased by one standard deviation, the likelihood of taking this measure decreased by 39 %. As the container requires an investment, it can be quite costly to adopt. The high cost of an investment can also be seen in the estimated parameter which has a larger impact on the likelihood of use than parameter estimates reported in the previous sections.

Demographic factors such as respondent's gender, university education or a full-time vs. a part-time employment at the farm did not have a statistically significant impact on the adoption of a carcass container. By contrast, the likelihood of using a carcass container was mainly determined by production type, since the containers are mainly used by pig farms, and by farm size, as larger farms were more likely to use a container.

4 Discussion

We have analysed how livestock producers' and farms' characteristics and perceived costs of biosecurity are related to the adoption of four biosecurity measures in Finland. Our results suggest that a livestock producer's perceptions about the cost of biosecurity are important for the adoption of these measures. If the perceived costs are excessive, producers may prefer not to take the measures into action. This is in line with Casal et al. (2007) who found that perceptions about the measures and the use of biosecurity measures were related to each other. The results are also in accordance with studies such as Valeeva et al. (2011), Toma et al. (2013) and Fraser et al. (2010) who found that the costs and benefits of biosecurity contribute to the adoption of biosecurity measures. Similar to our results, Toma et al. (2013) found evidence about the contribution of economic factors and that factors other than economic may have a larger impact on biosecurity.

The likelihood of adopting biosecurity increased inelastically when the perceived costs of biosecurity decreased. This means that the relative (percentage) change in biosecurity adoption is smaller than the relative change in the assumed cost. Moreover, the result shows that if the producer receives information about a low-cost biosecurity technology that is available, this increases the adoption rate of biosecurity. Regarding biosecurity measures that we investigated, the main focus was on measures which were highly relevant for reducing contamination due to people and animals coming to the farm. While the verification of animal health status clearly focused on incoming animals, three other measures, especially the use of carcass container, were relevant also for internal biosecurity as they can reduce the spread of pathogens also between different parts of the farm and are part of the overall hygiene.

Our explanatory variables reflect producers' perceptions regarding the costs of biosecurity measures. It is not known whether perceptions regarding the costs are correct. Moreover, factors other than cost perception contribute to the adoption of biosecurity. These factors include education and training. As adopters tend to perceive the costs of biosecurity lower than non-adopters, merely providing accurate information about the true costs and benefits of biosecurity (assuming that non-adopters have too pessimistic view) could improve biosecurity in some farms. Hence, the adoption of biosecurity could also be promoted by sharing positive but realistic information about experiences and costs of biosecurity and by increased training and education. As our study did not explore potential benefits of biosecurity measures in monetary terms, further studies are needed to examine how much a producer can benefit from adopting biosecurity measures.

Producers' characteristics and attitudes may have a smaller impact on the adoption of measures which do not require substantial investments than they have on the adoption of measures which require substantial investments. Estimated parameters suggest that livestock producers are likely to pay more attention to the profitability of measures which require large effort and which may have uncertain benefits. In addition, they may not be fully aware of cost implications associated with biosecurity measure. In the poultry sector, for instance, Siekkinen et al. (2012) identified a long list of items which contribute to the costs of biosecurity. Hence, information dissemination could highlight the benefits and costs of measures.

The models we estimated showed quite low coefficients of determination (McFadden R^2). However, in logistic regression models, it is often the case that the coefficient of determination is low even when the model classifies the observations properly. In this respect, classification tables (or confusion matrices) can provide useful data concerning the predictive performance of the model. Regarding the use of protective clothing, the models categorise adopters better than non-adopters, whereas regarding the verification of the health status of incoming animals and the use of a carcass container, non-adopters are better identified than adopters. This can also be useful information. From the viewpoint of improving biosecurity at livestock farms, it is more important to identify non-adopters than adopters because outreach campaigns and other actions to improve biosecurity are targeted mainly at non-adopters.

There are substantially more cattle farms than pig farms both in Finland and in our sample. Hence, one caution regarding the current analysis is that the number of pig farms in the sample is small compared to the cattle farms. In that sense, the results mainly reflect the views of cattle farms, and in particular dairy farms. Taking into account interactions between production type and other factors, they might alter the results as for instance the impact of farm size could differ by production type. Some interactions were tested during the preliminary data analysis, but the dataset did not allow testing all the interactions simultaneously. Production type and farm size had a large impact on some measures. For instance, carcass containers are frequently used by pig farms but are seldom used by cattle farms. The reasons may be that there are more animals dying in pig farms than cattle farms and hence a higher need to store dead animals and that the size of animals is smaller so that the costs of storing does not require as large investments in pig farms than in cattle farms. Besides farm type, farm location might also affect the use of this measure because rendering requirements to some extent vary between Northern and Southern Finland.

In our data, production type and some other farm characteristics are highly significant factors. Some measures can be implemented more easily on pig farms, or they are more important in large farms. Hence, pig farms and large farms for instance have stronger incentives to adopt some biosecurity measures than cattle farms or smaller farms. Such differences may be due to organisational structures and the nature of production organisation in the sector. The importance of taking production type or farm size into account has also been identified by previous studies (e.g. Ribbens et al. 2008; Brandt et al. 2008; Boklund et al. 2009). The relevance of production type may partly explain why some measures are beneficial to adopt as noted by Fasina et al. (2012).

Farms committed to their business partners with a contract seem to be more likely to adopt biosecurity measures. This is possibly due to standards set to production practices, which may require that a farm adopts certain biosecurity practices. Responses regarding the production contract perhaps signal the awareness of the rules and the way they are respected rather than real differences in contracting practices, because the majority of livestock farms in Finland have a production contract but the producers may not always consciously think that they have such a commitment. As the average size of farms is increasing and the farms are operated more increasingly like any other business, conditions required to meet contractual obligations could be an important tool to improve biosecurity in the future. Moreover, vertically integrated livestock sector could benefit from technological innovations at different parts of the chain. For instance, contract farms may have easier adoption of innovations or better access to innovations and information held by a dairy company or slaughterhouse than non-contract farms.

The number of large livestock farms has been increasing during recent years, although the total number of farms has been decreasing simultaneously. For instance, most dairy farm investments currently occur in facilities with a capacity of over 50 or 100 dairy cows (Pyykkönen et al. 2013). Small farms, which do not expand their operation, typically exit the industry whereas large farms typically continue in the business (Niemi et al. 2012). Due to increasing farm size, biosecurity is likely to receive more attention in the future and the level of biosecurity may improve. Attention is required for instance when purchasing a newly built empty facility which needs to be populated quickly. Then, a lot of animals may need to be purchased and they can originate from several different sources, thus exposing the farm to a disease risk unless the purchase of animals is planned properly in advance.

Attention to biosecurity issues when planning an investment is also warranted because it is probably easiest to improve biosecurity during the enlargement stage. Examining the efficiency and costs of biosecurity measures and related investment decisions in large farms which are expanding their production would be an interesting future line of research.

5 Conclusion

In conclusion, producers' perceptions about the cost of biosecurity measures contribute to the adoption of the measures. The lower the cost is perceived, the more likely the producer is to adopt the measure. However, the response between adoption and costs seems to be inelastic. Although the costs are important, other factors may be more critical to the adoption of biosecurity measures, because demographic factors, such as gender and education, and farm characteristics, such as production type and farm size, are very important determinants of adoption. The results suggest that biosecurity measures could be also promoted through sharing information about their possible benefits for each farm type and by advisory services providing practical advice on how to improve biosecurity cost-effectively.

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