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COST-EFFECTIVENESS OF SURVEILLANCE IN THE FARM PHASE IN THE NETHERLANDS AND GREAT BRITAIN

Contents

This meeting is part of the European Joint Programme One Health EJP.
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Summary

We explored a method to evaluate the cost-effectiveness of surveillance in the farm phase, focusing on *Salmonella* in pigs, and applying it to The Netherlands and Great Britain. The criterion is costs / DALYs evaded. Costs refer to the number of samples taken, and the costs of microbiological analysis per sample. To calculate DALYs evaded, it is assumed that pig meat from *Salmonella* test-positive farms does not reach the consumer. It is calculated as a decrease in *Salmonella* prevalence at animal level as a result of surveillance, which is carried through the slaughterhouse- and consumer phase to result in a reduction of DALYs.

It is shown that cost-effectiveness is independent of the number of farms sampled, and decreases with the number of samples taken per farm. Cost-effectiveness is more favorable (lower) for GB than for The Netherlands, 4.78E3 and 8.70E3 euros/DALY, respectively, for comparable scenarios. Both the costs and the DALYs evaded are higher for GB, being a larger country, but DALYs evaded with a higher factor than costs. It must be stressed, however, that the calculations have a high uncertainty.

Cost-effectiveness of sampling in the farm phase is much more favorable than in the (pre-)retail phase, being about 8.5E3 euro's/DALY vs 6.08E4 or 2.26E5 euro's/DALY (depending on sampling system)(Evers et al., 2020). The value of 8.5E3 euros/DALY is also lower than 4.6E4 euros/DALY, the standard value set by WHO for cost-effectiveness of an intervention (WHO Europe, 2014).

Additional data collection and conceptual model improvement will increase reliability of the calculation results.

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1. Introduction

The focus of the NOVA (Novel approaches) project is new methods, tools and data sources that can be used to improve the surveillance of foodborne pathogens and hazards in such a way that surveillance resources can be optimally allocated and human foodborne disease more efficiently prevented. In this report we focus on the cost-effectiveness of surveillance in the farm phase, to investigate whether money spent on surveillance could be well-spent in terms of public health. The costs refer to the money spent on the surveillance program. Effectiveness refers to improvement of public health as a result of surveillance. For this, it is assumed that raw meat from positively tested groups of animals does not reach the consumer, which can be achieved by pre-heating meat from these animals or leading it away altogether from human consumption.
This study will focus on *Salmonella* in pig meat as before, and on GB and The Netherlands. The effect of changing surveillance capacity, in terms of number of farms investigated or number of samples taken per farm, is also analyzed. The farm phase cost effectiveness obtained here can be compared with retail cost-effectiveness as calculated in another NOVA deliverable (Evers et al., 2020).

2. Methods

The cost-effectiveness of farm surveillance will be calculated as

$$\frac{Sampling\ costs}{DALYs\ evaded} \qquad \text{Eq. (1)}$$

Sampling costs are equal to the product of:

- Costs per sample
- No. of samples taken in a country in a year

To calculate the number of DALYs evaded for different farm/country scenarios, we make use of two models
(1) a farm model developed for this application, by Mark Arnold (APHA)
(2) the slaughterhouse and consumer part of a model developed previously for EFSA (VLA, DTU, RIVM, 2010; Swart & Pielaat, 2012).
Ad 1.
A model was developed to simulate pooled sampling on pig farms, immediately prior to sending animals to slaughter. A fixed number of farms were sampled using pooled samples, and the impact of removing farms that have pooled sample positives on the overall slaughter prevalence was calculated. The model inputs were: the number of farms sending animals to slaughter, the number of pooled samples taken per farm, and the national distribution of slaughter prevalence. The model output was the mean national slaughter prevalence at the end of the farm phase following removal of farms that have positive pools.
A key component of the model is the estimation of the national slaughter prevalence and the sensitivity of pooled sampling. This is performed by application of a Bayesian model (Arnold *et al*., 2005) to national surveillance data. Once these have been estimated, the model simulates the infection prevalence on each farm, simulates the number of pooled sample positives (which will depend on the infection prevalence in the farm, and the number of pools per farm, according to a binomial distribution), and removes farms that have positives from the slaughter population. The mean prevalence is then calculated over those farms that had no positives in the simulation.
Ad 2.
Using the user-friendly interface version of the EFSA model (Swart & Pielaat, 2012) the probability of illness per portion can be calculated for the three categories of products defined by this model: minced meat, fermented sausage and pork cuts. We determined empirical relationships between the prevalence at animal level at the end of the farm phase and the probability of illness per portion for these three products. Using this relationship, we could calculate probabilities of illness per portion for any animal prevalence indicated by the farm model.

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The total number of cases for any scenario could then be obtained for each product group by multiplying the number of portions consumed with the probability of illness per portion, and then adding up over the product groups. For each scenario, this total number of cases is then divided by the total number of cases for 0 farms sampled (which effectively is the present situation; surveillance results have presently no consequence for positively tested farms). Multiplying this quotient with the no. DALYS for the present situation, and subtracting the result from this same number, gives the number of DALYs evaded.

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3. Results

3.1 General

Slaughterhouse and consumer model

For the empirical relationship between animal prevalence at the end of the farm phase and the probability of illness per portion, we considered polynomial relationships through the origin. It proved that a simple linear relationship gave little or no difference with a 2nd grade polynomial, and therefore we chose for a linear relationship. The slopes (probability of illness per portion / animal prevalence end of farm phase) found were 1,55E-4 (minced meat), 9,43E-4 (fermented sausage) and 1,27E-4 (pork cuts).

3.2 The Netherlands

Scenarios -NL

Next to the base scenario (0 farms sampled), scenarios considered were 112, 225 and 450 farms sampled. Sampling per farm consists of 5 pooled samples which each consist of feces sampled from 12 places in the farm.

Farm model - NL

Data used were based on a Dutch report on a surveillance performed in 2013 (Zomer et al, 2014). At that time there were 1681 registered pig farms with 500 pigs or more. In the surveillance, 54 of 184 farms were found to be positive. The distribution of the no. of positive pooled samples (10 g feces) per farm was as follows:

0 positive of 5: 129
0 positive of 4: 1
1 positive of 5: 29
2 positive of 5: 16
3 positive of 5: 5
4 positive of 5: 4
5 positive of 5: 0

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A previously developed model of the sensitivity of pooled sampling, originally applied to UK farms (Arnold *et al*., 2005), was fitted to the pooled sampling data from NL to estimate pooled sample sensitivity and national slaughter prevalence. Specifically, the model assumed that the sensitivity of a pooled faecal sample, Se_p, was given by (Arnold et al., 2005):

$$Se_p(i) = 1 - \exp\left(-wC\pi_i(1 - \exp\left(\frac{\rho}{w}\right)\right)$$

Where *w* is the sample weight in grammes (= 10 g), *C* is the number of Salmonella clusters per gramme of faeces, π_i is the infection prevalence in farm *i*, and *ρ* relates the probability of a successful diagnostic test to the concentration of *Salmonella* clusters in the sample.

The farm level prevalence was assumed to follow a beta distribution as follows:
$\pi_i \sim beta(a, b)$ with probability τ
$\pi_i = 0$ with probability 1- τ
where τ represented the proportion of farms infected.

As the model was Bayesian, it allowed for priors for the parameters. Two different models, with different priors, were fitted:

1. *Non-informative priors for prevalence of infection* (given by beta distribution with both parameters equal to 1, which is uniform over the range 0-1)
    - parameters determining the sensitivity of pooled sampling were fixed and given by previous studies in the UK (Arnold *et al*., 2005, Arnold and Cook, 2009). This resulted in an overall infection prevalence of 8.5% at slaughter, with 32.6% of farms infected and the within herd prevalence following a beta distribution: beta(2.73, 7.86).
2. *Prior for the prevalence of infection taken from the 2006/07 EU baseline survey*
    - In this survey, lymph nodes were used to sample pigs at slaughter and an 8% apparent prevalence was found. It was assumed that lymph node sensitivity was similar to that found by a latent class model applied to EU baseline survey data for the UK, where a 42% sensitivity of testing lymph nodes to detect *Salmonella* was found. This resulted in a prior prevalence of 20% (95% credible interval 15-25%) for the infection prevalence in NL pigs. The Bayesian model also included priors for the pooled sample senstivity, taken from a previous UK based study (Arnold and Cook, 2009). This resulted in an estimated 55% of farms being infected, and a within herd prevalence given by beta(0.72, 1.53). With these results, the mean slaughter prevalence in pigs in NL is 17.6%.

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The second model was used. The results of the model, in terms of the prevalence at animal level at the end of the farm phase, are as follows:

Number of farms sampled	animal level prevalence (%)
0	17.6
112	17.0
225	16.5
450	15.2

Slaughterhouse and consumer model - NL

The number of portions consumed per year can be obtained from Appendix 2A from Evers et al. (2020), using Appendix 1 and 2A. The 10 product group categories defined there are reduced to the three product categories of the EFSA model:

Product group Evers et al. (2020)	**Product group EFSA model (VLA, DTU, RIVM, 2010)**	**Number of portions consumed per year per country**
1	minced meat	6.44E+06
2	minced meat	1.89E+08
3	fermented sausage	6.92E+08
4	minced meat	1.00E+08
5	minced meat	5.78E+08
6	pork cuts	2.41E+07
7	pork cuts	3.74E+08
8	pork cuts	2.81E+07
9	pork cuts	1.26E+08
10	pork cuts	9.85E+07

DALY estimate - NL

The number of DALYs per year due to Salmonella in consumed pork is estimated at 88 (Appendix 2A of Evers et al., 2020).

Surveillance costs - NL

The costs per sample is taken as the mean value from Appendix 2A of Evers et al. (2020) and is equal to 43.65 euro per sample.

Cost-effectiveness of surveillance - NL

The results of cost-effectiveness in terms of costs/DALYs evaded are as follows:

Number of farms sampled	Costs (euros)	DALYs evaded	Costs/DALYs evaded
112	2.44E4	2.95	8.29E3
225	4.91E4	5.64	8.70E3
450	9.82E4	12.0	8.21E3

3.3 Great Britain

Scenarios -GB

The base scenario is 0 farms sampled. For the number of farms sampled in case of sampling we take the same percentage of farms sampled as in the Netherlands, which is 225/1681 = 13.4%. Taking 13.4% of the total number of pig farms in GB (2367), gives 317 farms. Scenarios considered were taking 2, 5, or 10 pooled samples per farm, where each pooled sample consists of feces sampled from 12 places in the farm.

Farm model – GB

The distribution of the prevalence of infection in GB farms was estimated using serological data collected as part of a national surveillance programme known as the Zoonoses Action Plan (ZAP), which consisted of routine sampling of pigs sent to slaughter (Snary et al., 2010). The serology data was from 2009, and it was assumed there were no significant changes in infection prevalence in GB since that time. Analysis was restricted to farms which had at least 50 pigs sampled within the year, leading to 120 farms included in the analysis. Pigs were assumed positive if they had a signal to positive (S/P) ratio of 0.25 or greater from the serological test (a meat juice (MJ) ELISA).

A zero inflated Poisson model was fitted to the serological data from each farm, in order to estimate the proportion of farms infected and the distribution of within-herd prevalence. In order to do this, it was necessary to obtain estimates for the sensitivity and specificity of MJ ELISA for *Salmonella*. The sensitivity and specificity of the MJ ELISA were obtained from applying a latent class model to data from the 2006 EU baseline survey for slaughter pigs in the UK, which gave an estimate of sensitivity of 46% and specificity of 89%. The number of positive samples in each farm is then assumed to follow a binomial distribution with the probability of a positive on each farm given by

$\pi_i Se + (1 - \pi_i)(1 - Sp)$,

where π_i is the infection prevalence on farm *I*, and *Se* and *Sp* are the sensitivity and specificity of MJ ELISA respectively.

The zero-inflation arises from allowing the within-farm prevalence to be 0, where the model infers the possibility that there are no infected pigs on the farm. To aid model identifiability, the proportion of farms infected was given an informative prior, with an expected proportion of farms infected to equal 99%, and 95% certain that it is greater than 95%, resulting in beta (88.3, 1.88). This model estimated that 91% of farms in GB were infected, and that the within herd prevalence followed a beta distribution, beta (0.86, 0.51), leading to an overall estimate of 57.2% of pigs infected.

There were 2 possible options for the assumption of pooled sample sensitivity (see Fig. 1):

- Pooled sample sensitivity as estimated in Arnold et al. (2005) (high sensitivity), or
- Pooled sample sensitivity estimated from analysis of pooled sample data from The Netherlands (low sensitivity)

We choose to assume the same pooled sample sensitivity in The Netherlands and the UK. In case of The Netherlands we chose to use an informative prior baseline survey prevalence which results in a low sensitivity estimate for pooled sampling. Therefore we chose low pooled sample sensitivity for GB

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for consistency in the analysis between the 2 countries, but the uncertainty in the sensitivity of pooled sampling should be noted.
For GB, we also explored the impact of amending the number of pooled samples per farm, also looking at taking 2 or 10 samples per farm in addition to the scenario looking at 5 pooled samples per farm.

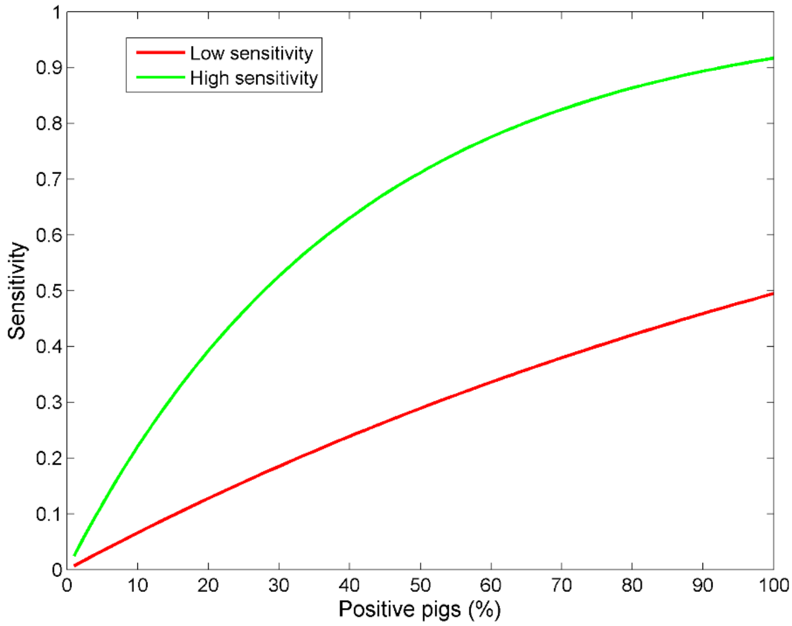

Figure 1. Sensitivity of pooled sampling for detection of Salmonella in pigs for two scenarios, (i) low sensitivity, based on posterior density from analysis of data from The Netherlands, assuming prior prevalence from EU baseline survey data, and (ii) high sensitivity, based on published data from the UK.

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The results of the farm model, in terms of the prevalence at animal level at the end of the farm phase, are as follows:

Number of pooled samples per farm	animal level prevalence (%)
0	57.2
2	55.93
5	55.66
10	55.85

Slaughterhouse and consumer model – GB

The number of portions consumed per year can be obtained from Appendix 2C from Evers et al. (2020), using Appendix 1 and 2C. The values obtained there must be corrected for the fact that they represent UK, whereas we do calculations now for GB. The number of inhabitants of Northern Ireland and UK are 1.89E6 and 66.65E6, respectively, giving a multiplication factor of (66.65-1.89)/66.65 = 0.972. The 6 product group categories reported for the UK (GB) are reduced to two product categories of the EFSA model:

Product group Evers et al. (2020)	**Product group EFSA model (VLA, DTU, RIVM, 2010)**	**Number of portions consumed per year per country**
2	minced meat	3.95E+09
5	minced meat	5.48E+07
6	pork cuts	2.36E+08
7	pork cuts	3.00E+08
8	pork cuts	5.41E+09
10	pork cuts	1.46E+08

DALY estimate – GB

The number of DALYs per year due to Salmonella in consumed pork is estimated at 969. This is the product of the value (997) given in Appendix 2C of Evers et al. (2020) multiplied by 0.972 (the UK->GB conversion factor).

Surveillance costs – GB

The costs per sample is taken as the mean value from Appendix 2C of Evers et al. (2020) and is equal to 78.60 euro per sample.

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Cost-effectiveness of surveillance - GB

The results of cost-effectiveness in terms of costs/DALYs evaded are as follows:

Number of pooled samples per farm	**Costs (euros)**	**DALYs evaded**	**Costs/DALYs evaded**
2	4.98E4	21.5	2.32E3
5	1.25E5	26.1	4.78E3
10	2.49E5	22.9	1.09E4

4. Discussion

Variation of the number of sampled farms (The Netherlands)

Variation of the number of sampled farms has only a small effect on the cost-effectiveness of surveillance, an effect that is possibly a numerical effect of the farm phase simulation model. Clearly, costs will increase linearly with the number of sampled farms, but this is also found for the number of evaded DALYs. This can probably be explained by the fact that an increase of the number of farms sampled will on average give a linear increase of the number of farms that are found positive. Meat originating from these farms will not reach humans, which leads to an associated linear increase of DALYs evaded, as the slaughterhouse and consumer model is a linear function as well.

Variation of the number of pooled samples per farm (Great Britain)

Variation in the number of pooled samples per farm shows that cost-effectiveness of surveillance becomes less favorable when this number is increased. Costs are assumed to increase linearly with the number of pooled samples per farm, whereas the number of DALYs evaded shows only a small variation. This small variation will be due to the fact that when the number of pooled samples per farm increases, there are two phenomena acting in conflict:

- Lower prevalence in the sampled farms that "pass" the sampling i.e. have no pooled sample positives – this acts to reduce the overall slaughter prevalence (including the non-sampled farms)
- Fewer farms that do "pass" – this acts to increase the overall slaughter prevalence, as a higher proportion of the overall slaughter population will come from the non-sampled farms

This leads to small variation in animal prevalence at the end of the farm phase, and due to the slaughterhouse and consumer model being a linear function, also in DALYs and DALYs evaded.

Comparison of The Netherlands and Great Britain

A comparison can be made between Netherlands and Great Britain, taking the 225 farms scenario for NL and the 5 pooled samples per farm scenario for GB. The Table below summarizes the cost-effectiveness results for these scenarios.

Country	**Costs (euros)**	**DALYs evaded**	**Costs/DALYs evaded**
NL	4.91E4	5.64	8.70E3
GB	1.25E5	26.1	4.78E3

It proves that cost-effectiveness is a factor of 1.8 more favorable (smaller) for GB than for NL, but it must be stressed that the calculations have a large uncertainty. Both the costs and the DALYs evaded are higher for GB, being a larger country, but DALYs evaded with a higher factor than costs.

Costs are a factor of 2.5 higher for GB. This consist of the product of the number of samples (which is a factor 1.4 (317/225) higher for GB) and the costs per sample (which is a factor 1.8 (78.6/43.65) higher for GB). DALYs evaded are a factor 4.6 higher for GB. Analyzing the calculation of DALYs evaded gives the insight that it is only determined by the product of 1) the fraction decrease of animal level prevalence at the end of the farm phase due to surveillance and 2) the DALY estimate for Salmonella in consumed pork. As for 1), this is a factor 0.42 lower for GB. For GB, it is 0.0269 ((0.572-0.5566)/0.572); For NL, it is 0.0641 ((0.1762-0.1649)/0.1762). As for 2), this is a factor 11.0 (969/88) higher for GB.

Cost-effectiveness is more favorable for farm- than for (pre-)retail phase sampling
The results for The Netherlands indicate that cost-effectiveness of sampling in the farm phase is much more effective than in the (pre-)retail phase. For the farm phase we find here about 8.5E3 euros/DALY, whereas in Evers *et al*. (2020) we found for the (pre-)retail phase 6.08E4 and 2.26E5 euros/DALY for sampling by meat industry and Food Inspectorate, respectively. This gives a relatively strong indication that it is more cost-effective to intervene in the farm phase than in the (pre-)retail phase. In addition, the value of 8.5E3 euros/DALY is lower than 4.6E4 euros/DALY, the standard value set by WHO for cost-effectiveness of an intervention (WHO Europe, 2014). So following WHO, surveillance in the farm phase coupled with an intervention is an efficient option in terms of cost-effectiveness.

Future improvement of the calculations
To increase reliability of the calculations we might have to consider a number of secondary effects that could possibly occur in the present approach of a surveillance combined with meat from positive farms not reaching the consumer. Only in the case that as a response to this approach pig production is increased in order to meet demand, but still meat from positive farms does not reach the consumer, then our model calculations are conceptually correct. Secondary effects to be considered are:

- When pigs from positive farms are diverted from the human consumption chain, there will overall be less pig meat available, leading to less consumption and total DALYs to be considered.
- When pigs from positive farms are diverted from the human consumption chain, there will be import of pigs or pig meat from foreign countries, and these can be infected/contaminated at a lower/higher level than for national production which will decrease/increase DALYs.
- Pig meat from positive farms could be heated and yet be brought on the market. This will give an additional decrease in the number of DALYs.

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