A COST-BENEFIT ASSESSMENT OF *SALMONELLA*-CONTROL STRATEGIES IN PIG HERDS WITHIN THE UNITED KINGDOM

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Introduction

Pork and pork products are considered to be a major source of human salmonellosis in the United Kingdom (UK). Despite a number of control programmes implemented within the UK, such as the Zoonoses National Control Programme (ZNCP), the prevalence of *Salmonella* in the UK slaughter pig population remains over 20% [1]. In particular, *S.* Typhimurium (including monophasic variants) continues to be a predominant serotype in humans, which is known to be most commonly found in pigs [2]. Therefore, to identify potential control measures that could reduce the number of human *Salmonella* cases it is necessary to understand the farm-to-consumption chain for pork and pork products. However, implementing control measures across the whole pig industry and food-chain would be a costly large scale project. It is therefore important to assess whether the benefit of implementing the control measures justifies the cost.

Cost-benefit analysis (CBA) is a standard method employed in a number of fields to assess whether a change in a process will produce a beneficial result and/or in a situation where a number of changes are proposed, to predict which change would produce the biggest benefit. CBAs are increasingly being employed in the field of epidemiology and food safety, for example to assess which control measures should be implemented within the food-to-consumption pathway. In these cases two main inputs are needed; a mathematical model to determine the effectiveness of the control measure (e.g. the reduction in number of cases of *Salmonella*) and an estimate of the costs, and savings made, of implementing the intervention. One of the most commonly used metrics to report results of a CBA is the ‘benefit-cost ratio’ (BCR), which gives an indication of how much benefit is obtained for each unit of cost, with a BCR>1 indicating that the benefits outweigh the costs.

Previous work has identified numerous risk factors as potential drivers of *Salmonella* transmission on pig farms; such as types of flooring, feed types and composition, and annual number of pig deliveries [3, 4]. However, results from previous CBA’s were not promising in terms of the overall cost-benefit to the European Union (EU) for *Salmonella* control at the stage of the live animal, whereby interventions produced BCRs considerably less than 1, both for the UK and worldwide [5-8]. One study estimated the BCR for the UK to be greater than one under a number of scenarios investigated [5]. While the positive cost-benefit appears to be due to the relatively high prevalence of *Salmonella* infection in UK pigs compared to the rest of the EU, it is worth investigating further.

The aim of this study was to conduct a cost-benefit analysis for *Salmonella* control measures on pig farms, utilising recent data from studies on UK pig farms to estimate whether any interventions would produce a positive cost-benefit to the industry and if not what would be the predicted change in cost to achieve it.

Materials and methods

To determine the cost-benefit of an intervention, *i*, a simple benefit-cost ratio, *BCR(i)* was used

$$BCR(i) = \frac{S(i) + B(i)}{C(i)}$$

where *C(i)* was the total cost of intervention *i* to the UK pig industry (£/year), *S(i)* the total saving (£/year) made from a reduction in human cases of *Salmonella* attributable to domestic pig meat consumption and *B(i)* the saving to the industry (£/year) from intervention *i*. It is clear from the equation, that if $S(i) + B(i) \geq C(i)$ then $BCR(i) \geq 1$, resulting in a net gain to the UK economy. The cost to the industry (*C(i)* £/year) for intervention *i* was given by $C(i)=c_{pp}(i)*N_T$, where $c_{pp}(i)$ is the cost per pig (£) for intervention *i* and N_T is the total number of pigs slaughtered in the UK per year, assumed to be 10.23 million. The total economic productivity saving as a result of implementing intervention *i*, *S(i)*, was given by $S(i)=c_H*H(i)$, where c_H is the cost (£) per human case of *Salmonella*, estimated to be £503.34, and *H(i)* is the annual number of human cases prevented by intervention *i*. The saving to the industry, *B(i)*, is given by $B(i)=b(i)*W(i)$, where *b(i)* is the savings per pig by preventing infection from intervention *i*, estimated to be £1.22, and *W(i)* the annual number of pig cases prevented by intervention *i*. By substituting these values into the BCR equation, rearranging and setting BCR(i)=1, we can obtain an equation for the cost per pig to get zero cost-benefit; $c_{pp0}(i)= (c_H H(i)+b(i)*W(i)) / N_T$.

Within this study, we assessed five interventions; vaccination, movement to an outdoor breeding unit, improved cleaning and disinfection practices, fermented liquid feed (wet feed) and use of organic acids in feed. Whenever there was uncertainty about parameterisation we erred towards a 'best-case scenario', so the results of the CBA are an upper estimate of how cost-effective we expect the interventions to be based on the available data. The model used here to obtain subsequent effectiveness estimates along the farm-to-consumption chain was a quantitative microbiological risk assessment (QMRA) previously developed for the European Food Safety Authority (EFSA) by a European consortium including APHA, RIVM and Food DTU [9, 10]. For each scenario tested, the QMRA is modified to simulate the effect of the intervention and estimates are obtained for the resulting percentage change in national pig prevalence at the point of leaving the farm, $p_w(i)$, and prevalence of human cases, $p_h(i)$. As such, the total number of prevented pig cases per intervention, is given by $W(i)= W_0*p_w(i)$, where W_0 is the number of pig cases predicted by the QMRA in the absence of the intervention. The number of prevented human cases per intervention is given by $H(i) =H_0*p_h(i)$, where H_0 is the total number of domestic pig meat-attributable human cases of *Salmonella*. Note that while $p_h(i)$ is estimated using the QMRA, H_0 is estimated from data according to the equation, $H_0=N_h*U_f*p_{sa}*p_{uk}$,, where N_h is the total number of reported UK human cases of *Salmonella*, U_f is the under-reporting factor, i.e. ratio of community to laboratory confirmed cases, p_{sa} is the proportion of human *Salmonella* cases attributed to pigs and p_{uk} is the proportion of UK-produced pig meat that enters the UK food chain, as opposed to being exported to another country. The costs were either provided by the companies conducting the intervention studies or estimated from the literature. The global parameter estimates are shown in Table1.

Results

The results of the CBA analysis (Table 1) suggest that none of the on-farm interventions were predicted to achieve a net gain to the UK economy (i.e. BCR >1). The intervention with the highest BCR was the addition of organic acids to pig feed. Analysis of what the cost per pig would need to be in order to achieve a BCR=1, suggests that all interventions would need to be considerably cheaper; e.g. the cost of the vaccine would need to reduce from £0.60 to £0.39 per pig.

Table 1. Cost-benefit results, showing QMRA results of % reduction in slaughter pig prevalence and reduction in human cases, estimates of the intervention cost per pig and financial savings to pig productivity and human illness, along with the resulting BCR and the estimated cost per pig necessary to achieve a BCR equal to 1.

Intervention	CBA Model Inputs						Results	
	Reduction in national slaughter pig prevalence (%), $p_w(i)$	**Cost per pig, £ per year, $c_{pp}(i)$**	**Cost of nationwide implementation, £'000 per year, *C(i)***	**Benefit to pig productivity, £'000 per year, *B(i)***	**Reduction in human cases per year, *H(i)***	**Human illness savings, £'000 per year, *S(i)***	**Benefit-Cost Ratio, BCR(i)**	**Cost per pig to achieve BCR =1, £ per year $c_{pp0}(i)$**
Wet feed	58.8*	£1.16	£9,645k	£1,260k	6,086	£3,063k	0.448	£0.423
Organic acids	94.6*	£0.80	£8,184k	£2,502k	9,171	£4,616k	0.870	£0.696
Vaccination	48.8	£0.60	£6,179k	£1,290k	5,321	£2,678k	0.642	£0.388
Cleaning & disinfection	28.9	£5.21	£53,298k	£764k	3,244	£1,633k	0.0450	£0.2343
Movement to outdoor breeding unit	40.1	£0.75	£7,673k	£1,059k	4,745	£2,388k	0.449	£0.337

*These reductions are a result of the APHA QMRA farm model, rather than extrapolated from an experimental study.

Discussion

There are large uncertainties associated with how representative the experimental intervention studies are if implemented on a national level, not least because of the relatively small sample size. For example, the organic acids intervention, which assumes that pigs will not shed more than 10^4 cfu/g, gives a high reduction in national slaughter pig prevalence, but is very much a best case estimate and would benefit from further UK studies that could demonstrate a product can achieve this in practice. Also, while there are clearly costs associated with outdoor units, it is possible that the land may be used for other sources of income (e.g. sugar beet or cereal crops), which would in turn lower the costs calculated previously. If further investigation can prove that there is a link between *Salmonella* infection and Key Performance Indicators then this will impact the BCR by increasing the financial benefit to the farmer by preventing cases of *Salmonella*. There are around 10,000 pig farms in the UK, although the vast majority of production comes from a much smaller number of large scale industrial farms. Thus, another possible way to improve the benefit-cost ratio of interventions would be to make them risk-based, e.g. to target intervention measures at a sub-set of farms, thus reducing the scale (and cost) of the operation required by the UK pig industry to reduce human risk. Such a risk-based approach could target larger farms or use *Salmonella* monitoring data to target farms with a high prevalence of infection, which could also act as an incentive for improvement. Consequently, the investigation of a risk-based intervention programme on human Salmonellosis due to the consumption of pork/pork products would be beneficial.

There are other factors not considered in this analysis that may provide additional benefits, such as the interventions being effective against other foodborne and pig diseases and the effect of combining multiple interventions. Intervention measures further down the farm-to-consumption chain, e.g. slaughterhouse interventions such as anal bunging, more thorough scalding, double singeing or improved slaughter hygiene to reduce cross-contamination, might incur a lower cost as there are fewer slaughterhouses than pig farms to implement interventions and less opportunities further down the chain for re-contamination or cross-contamination of carcasses to occur. However, such interventions would have no benefit to pig productivity so could well be less cost-effective.

Conclusion

Even under the best case scenarios (full implementation of effective intervention across the UK), the estimated cost of implementing all interventions exceeds the estimated financial benefit to pig productivity and human health. However, there are factors other than simple cost, e.g. Government targets to reduce foodborne illness, trade, societal pressure due to fear of contaminated meat products, which may encourage the desire for implementation of control measures. The analysis here would help in the determination of which interventions would be the most beneficial.

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