A cost–benefit analysis of Salmonella-control strategies in Danish pork production

Stine Gissel Goldbach *, Lis Alban

Danish Meat Association, Axeltorv 3, DK-1609 Copenhagen V, Denmark

Received 12 January 2005; received in revised form 3 October 2005; accepted 28 October 2005

Abstract

In Denmark, it was agreed to lower the Salmonella prevalence in pork to 1.2% before the end of 2006. The current control did not seem to be sufficient to attain this goal. Therefore, four alternatives to the existing Danish control strategy for Salmonella in pork were compared in a cost–benefit analysis: (1) hot-water decontamination of all pigs at slaughter, (2) sanitary slaughter of pigs from herds with high levels of Salmonella, (3) use of home-mixed feed in herds with slaughter pigs and (4) use of acidified feed for slaughter pigs. The data originated from official statistics, published papers as well as expert opinion. The partial cost–benefit analysis was restricted to slaughterhouses affiliated with the Danish Meat Association and Danish human cases ascribable to pork from these slaughterhouses. Only hot-water decontamination was socio-economically profitable. Hot-water decontamination had a net present value over 15 years of €3.5 million. For sanitary slaughter the net present value was –€43.6 million, for home-mixed feed it was –€262.3 million and for acidified feed it was –€79.9 million. For all alternatives the costs were born solely by the pig sector, whereas primarily the consumers and public authorities received the benefits. The conclusions were robust in sensitivity analyses.

© 2006 Elsevier B.V. All rights reserved.

Keywords: Cost–benefit analysis; Salmonella; Pork; National surveillance; Human cases
1. Introduction

1.1. The decision-making context

During the early 1990s an increasing number of people in Denmark became ill from *Salmonella* in pork. This rising incidence prompted the initiation of the national control program for *Salmonella* in pigs and pork (Mousing et al., 1997). Since the start of the program in 1995, the number of *Salmonella*-infected pigs has dropped considerably—as has the number of human salmonellosis cases ascribable to pork. For example, in 1993 approximately 1100 human cases (Anon., 2004a) were ascribed to Danish pork whereas in 2003 the number had declined to 202 (Anon., 2004a).

In 2001 the Danish Meat Association (DMA) agreed with the Danish Veterinary and Food Administration to attain a *Salmonella* prevalence in pork of maximum 1.2% before the end of 2006. Because the current control did not seem to be sufficient to attain this goal, the DMA considered alternative measures to further reduce the *Salmonella* prevalence in pigs and people.

The role of economics in analysis of food safety can be one of three. Firstly, the aim could be to evaluate a chosen policy. Such an analysis has recently been conducted by Andersen and Christensen (2004) who evaluated the current Danish *Salmonella* surveillance and control programs. Secondly, if the goal is defined, then an economic analysis can be used to identify the most cost-effective measures to attain the goal. Thirdly, economic analysis can be used to prioritize between different goals and measures. Our analysis is of the second kind: an evaluation of the socio-economic profitability of different control strategies along the stable to table chain.

1.2. The present Danish control program

The present surveillance consists of two major parts: a herd-monitoring program based on serology and bacteriological follow-up (Alban et al., 2002) and post-chill monitoring of carcasses based on bacteriology (Nielsen et al., 2001). Each month, herds are assigned to one of three *Salmonella* levels based on the proportion of sero-positive meat juice samples taken over the previous 3 months. Herds with <40% reactors are assigned to level 1, herds with 40–70% reactors are assigned to level 2, and herds with >70% reactors are assigned to level 3 (Alban et al., 2002). By the end of 2003, 96.7% of the herds fell within level 1, 2.7% within level 2, and 0.6% within level 3 (Anon., 2004a). Pigs from level-3 herds are sanitary slaughtered, which as a minimum includes no splitting of head, and offal either condemned or subjected to heat treatment or curing. Sanitary slaughter is performed at selected slaughterhouses and takes place at the end of the day to prevent cross-contamination to other carcasses (Nielsen et al., 2001). In addition, herds in levels 2 and 3 are subject to mandatory bacteriological follow-up based on a collection of pen faecal samples to clarify the distribution and type of the *Salmonella* infection in the herd. Furthermore, DMA slaughterhouses employ a financial penalty-system to encourage implementation of *Salmonella*-controlling measures in level-2 and level-3 herds (Nielsen et al., 2001).

Monitoring of *Salmonella* in pork is based on swab samples taken from the carcass after chilling (Nielsen et al., 2001). The overall *Salmonella* prevalence in pork from
slaughterhouses affiliated with DMA in 2003 was estimated to be 1.6% while for the remaining (privately owned) slaughterhouses it was 1.1% (G. Sandø, personal communication, 2004).

The Danish Zoonosis Centre applies a mathematical model to estimate the origin of the human cases of salmonellosis. The model is based on a comparison of the number of human cases caused by different Salmonella sero- and phage types with the prevalence of the Salmonella types isolated from the various animal food sources, weighted by the amount of food source consumed (Anon., 2004a; Hald et al., 2004). In 2003, 202 registered cases of human salmonellosis in Denmark were ascribed to Danish pork (Anon., 2004a). These 202 cases originated either from DMA slaughterhouses (with approximately 67% market share, DMA Marketing Department) or privately owned slaughterhouses (representing the remaining approximately 33% of the market). When the higher Salmonella prevalence in DMA pork is weighted with the market share of 67%, this pork is assumed to have contributed with \((0.67 \times 0.016)/ (0.67 \times 0.016 + 0.33 \times 0.011) = 75\%\)—corresponding to 151 registered cases of human salmonellosis in Denmark in 2003.

1.3. Ways to mitigate the risk of Salmonella

Several measures to reduce the prevalence of Salmonella exist, depending on how widespread it is and which initiatives have already been put in place. Initiatives can either be taken pre-harvest (in the herd) or post-harvest (at the slaughterhouse) or by a combination of the two. In Denmark, almost all pigs are housed indoors, and Salmonella has been combated for >10 years. This implies that experience has been gained and several initiatives have already been put in place in most herds like limited commingling of piglets as well as rodent control. The official policy has been to combat Salmonella at its source. Therefore, focus has been on pre-harvest initiatives. Acidified (Jørgensen et al., 2001) or home-mixed feed (Kranker et al., 2001) have documented effects on Salmonella in the individual herd. To obtain a further reduction in the national prevalence of Salmonella in pigs, mandatory use of these measures would be needed.

Despite the continued effort pre-harvest, the Salmonella prevalence in Danish pigs and pork remained more or less unchanged since year 2000. Therefore, focus in DMA has changed toward post-harvest initiatives (Alban and Goldbach, 2005); what can be done at the abattoir to effectively mitigate the risk of Salmonella? Sanitary slaughter of a larger proportion of finishers than today would lower the national prevalence of Salmonella in pork. Hot-water decontamination is a promising alternative; a large-scale Danish study has demonstrated that Salmonella prevalence on pig carcasses is reduced 2 log units when the pig carcass is showered with 80 °C hot water for 14–16 s (Jensen and Christensen, 2000). Decontamination of carcasses by use of organic acids is not allowed in the European Union (Anon., 2004b). Several other initiatives like improved disinfection of tools and enclosure of the rectum with a plastic bag have already been put in place.

In summary, if both pre- and post-harvest Salmonella-control measures were to be considered, we judged the following alternatives to be the most relevant for Danish pig production:
hot-water decontamination of all pigs at slaughter;
- sanitary slaughter of pigs from herds with higher levels of Salmonella (levels 2 and 3);
- use of home-mixed feed in all herds with slaughter pigs;
- use of acidified feed for all slaughter pigs.

In summary, the alternatives chosen reflect control measures with a documented mitigating effect on Salmonella in live pigs or on pig carcasses.

2. Materials and methods

2.1. Methods

To ease the understanding of the analysis, we chose to describe the methods before the materials.

The strategy for controlling for Salmonella in pigs and pork in Denmark is partly a political issue and measures regarding Salmonella control need to be negotiated with political decision makers. This means that an evaluation of control strategies for Salmonella in pigs and pork – when directed towards the political decision-making level – should include costs and benefits to society in general. Hence, we analysed the alternative Salmonella-control measures within the framework of a socio-economic cost–benefit analysis (CBA), in which, generally, all costs and benefits for the different stakeholders are described and assessed. In our case the stakeholders were the consumers, the pig industry (farmers and slaughterhouses) and the public budget (i.e. taxpayers). The primary costs and benefits to the public budget were related to health-sector expenses and the national production loss associated with absence from work due to illness.

We compared each of the four alternatives to the current program and determined incremental costs and benefits occurring within the chosen time period. In the analysis of the four alternatives, we made the following assumptions.

Danish politicians are mainly interested in the food safety of domestic residents and therefore we only considered effects on Danish consumers. Even if we wanted to include effects on export markets we would not be able to because of lack of data (on e.g. use of imported meat, market shares, Salmonella prevalence in pork, and health-sector costs in all countries that import Danish pork).

Due to the dynamics of the slaughter process, a 10% decrease in the Salmonella burden of pigs would lead to a <10% reduction in the Salmonella burden in pork (Alban and Stärk, 2002). The exact correlation is unknown; and therefore we used three different values for this parameter (0.25; 0.5; 0.75)—and in the base scenario we used the value 0.25. Additionally, we assumed that a given decrease in the amount of Salmonella-infected pork would lead to proportional reductions in the number of human salmonellosis cases of different severities.

In accordance with Schwartz (1999) we assumed that there is no productivity loss associated with subclinical Salmonella infection in a swine herd.
We assumed that there would be full effect on *Salmonella* after 6 months of using hot-water decontamination, sanitary slaughter or acidified feed. For home-mixed feed we assumed a 5-year implementation period, and the effect on *Salmonella* was assumed to increase linearly from years 1 to 5.

The penalty scheme might be seen as a transfer payment, that is, a payment for which no good or service is obtained in return—money is merely redistributed within the economy. Although penalty payments would not affect the total net present value of a given strategy, they were included (as a cost to the one party and a benefit to the other) when data were available—to show the effect on the different stakeholders (in this case farmers and slaughterhouses).

The distribution of costs and benefits over time is not similar for the different alternatives, because some of them involve an initial investment. We set the time period to 15 years to reflect the assumed life span of home-mix feeding equipment. The expected life span of hot-water decontamination facilities is around 7 years (H. Christensen, personal communication, 2004), so we assumed that reinvestments would take place in year 8 after the first round of investments. Furthermore, the depreciation period for investments in buildings is 20 years; therefore we included the scrap value of such investments made in year 0 as a benefit in year 15.

In the calculation of the net present value for each of the alternatives, we chose the year 2002 for a common price level and used a discount rate of 6% as recommended by The Danish Ministry of Finance (*Anon.*, 1999).

In the calculations, we used the software program at Risk (Palisade Corporation, Newfield, NY) whereby Monte Carlo simulations provided the net present values as distributions instead of absolute values. Each of the scenarios was simulated using 10,000 runs, which was sufficient to produce stable distributions.

The detailed quantification of the four alternatives together with related assumptions (partly in Danish) can be obtained from the corresponding author upon request.

2.2. Materials

Data originated mainly from the DMA and the Danish Zoonosis Centre. In case no data were available, assumptions and parameter values were based on informally elicited expert opinion. Most of these experts (all mentioned under Acknowledgements) were in-house people with several years of experience within their field. Some data were associated with a non-negligible degree of uncertainty. For such parameters we used a Pert distribution where minimum and maximum values were assessed by experts. Parameter values, associated distributions (where relevant) and source of information are presented in Table 1.

The main parameters included: (1) the potential effect of the alternatives on the *Salmonella* prevalence in pigs and/or pork and the number of human salmonellosis cases, and (2) the investment costs of the different alternatives as well as changes in production and maintenance costs on either farms or slaughterhouses following the investment. The values of costs and benefits for farmers and DMA slaughterhouses were based on various annual statistics and expert opinion.
<table>
<thead>
<tr>
<th>Variables</th>
<th>Mode (minimum; maximum)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DMA(^a) market share, domestic pork (%)</td>
<td>67</td>
<td>Expert opinion, DMA</td>
</tr>
<tr>
<td>Recorded human cases of salmonellosis due to domestic pork</td>
<td>202</td>
<td>Anon. (2004a)</td>
</tr>
<tr>
<td>Registered salmonellosis cases that die of the infection (%)</td>
<td>1.9 (1.6; 2.2)</td>
<td>Helms et al. (2003), Helms (personal communication)</td>
</tr>
<tr>
<td>Days sick, registered salmonellosis case</td>
<td>13</td>
<td>Korsgaard et al. (2005)</td>
</tr>
<tr>
<td>Days sick, unregistered salmonellosis case</td>
<td>3</td>
<td>Do.</td>
</tr>
<tr>
<td>Lost working days, registered salmonellosis case</td>
<td>8</td>
<td>Do.</td>
</tr>
<tr>
<td>Lost working days, unregistered salmonellosis case</td>
<td>2</td>
<td>Do.</td>
</tr>
<tr>
<td>Registered salmonellosis cases hospitalised (%)</td>
<td>26.5</td>
<td>Do.</td>
</tr>
<tr>
<td>Hospitalised salmonellosis cases operated (%)</td>
<td>2.3</td>
<td>Do.</td>
</tr>
<tr>
<td>Salmonellosis cases registered (%)</td>
<td>12.5</td>
<td>Do.</td>
</tr>
<tr>
<td>Salmonellosis cases consulting physician (%)</td>
<td>35</td>
<td>Do.</td>
</tr>
<tr>
<td>Consultation in general practise, euro</td>
<td>11</td>
<td>Do.</td>
</tr>
<tr>
<td>Culture (faecal sample) <em>Salmonella</em>, euro</td>
<td>120</td>
<td>Do.</td>
</tr>
<tr>
<td>Hospitalisation with gastroenteritis, euro</td>
<td>2800</td>
<td>Do.</td>
</tr>
<tr>
<td>Hospitalisation and surgery, euro</td>
<td>8900</td>
<td>Do.</td>
</tr>
<tr>
<td>Value of lost work day, euro</td>
<td>160</td>
<td>Do.</td>
</tr>
<tr>
<td>Cost of sanitary slaughter, euro per pig</td>
<td>7.8 (7.0; 8.6)</td>
<td>Expert opinion, DMA</td>
</tr>
<tr>
<td><strong>Hot-water decontamination</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decrease in <em>Salmonella</em> prevalence in pork (%)</td>
<td>90 (85; 95)</td>
<td>Unpublished results, DMRI(^b)</td>
</tr>
<tr>
<td>Price of decontamination facility, €1000</td>
<td>202 (134; 269)</td>
<td>Expert opinion, DMA</td>
</tr>
<tr>
<td>Average investment in buildings, €1000 per slaughterhouse</td>
<td>269 (67; 470)</td>
<td>Do.</td>
</tr>
<tr>
<td>Maintenance of decontamination facility, €1000 per year</td>
<td>6.7 (1.3; 13)</td>
<td>Expert opinion, DMRI</td>
</tr>
<tr>
<td>Production costs of hot-water decontamination, euro per pig</td>
<td>0.15 (0.13; 0.25)</td>
<td>Do.</td>
</tr>
<tr>
<td><strong>Sanitary slaughter</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decrease in <em>Salmonella</em> prevalence in pork (%)</td>
<td>7</td>
<td>Estimated by authors</td>
</tr>
<tr>
<td><strong>Home-mixed feed</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decrease in <em>Salmonella</em> prevalence in pigs on farms shifting feeding system (%)</td>
<td>63 (43; 83)</td>
<td>Unpublished results, DMA</td>
</tr>
<tr>
<td>Slaughter pigs presently produced on home-mixed feed (%)</td>
<td>50</td>
<td>Expert opinion, DMA</td>
</tr>
<tr>
<td>Feed mixer, €1000</td>
<td>89</td>
<td>Do.</td>
</tr>
<tr>
<td>Change in production costs when shifting to home-mixed feed, slaughter pig herds (cost per pig), euro</td>
<td>0.3</td>
<td>Do.</td>
</tr>
<tr>
<td>Change in production costs when shifting to home-mixed feed, integrated herds (gain per pig), euro</td>
<td>0.5</td>
<td>Do.</td>
</tr>
<tr>
<td><strong>Acidified feed</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decrease in <em>Salmonella</em> prevalence in pigs (%)</td>
<td>50</td>
<td>Expert opinion, DMA</td>
</tr>
<tr>
<td>Reduction in number of sanitary slaughterings, 1000 pigs</td>
<td>40</td>
<td>Estimated by authors</td>
</tr>
<tr>
<td>Changed production costs, acidified feed (cost per pig), euro</td>
<td>0.4 (0; 0.8)</td>
<td>Expert opinion, DMA</td>
</tr>
</tbody>
</table>

\(^a\) Danish Meat Association.

\(^b\) Danish Meat Research Institute.
With respect to the health effects, the data included the most recent number of registered human cases of salmonellosis, the relative numbers of cases of different severity categories including number of days sick and lost work days, and death risks for salmonellosis. We assumed that due to under-reporting, the registered cases of human salmonellosis represent only 12.5% of the total number of cases. This is the mid-value of the interval 5–20% found in European and American studies, Weeler et al. (1999), De Witt et al. (2001) and Mead et al. (1999). With this assumption the estimated real number of human cases in Denmark ascribed to DMA was 1208 in 2003.

The value of a lost statistical Danish life was set to €1.7 million based on recommendations from the European Commission (Anon., 2001; Anon., 2004c). The value put on “pain and suffering” was taken from the Danish Liability for Damages Act (Anon., 2002) and amounts to just over €18 per day. We then multiplied this value by the estimated number of days sick to estimate the individual utility loss of the pain and suffering associated with illness. Direct (primary and secondary health sector) and indirect costs (production loss) associated with human cases of salmonellosis were calculated on the basis of cost estimates on consultation in general practice, culture, hospitalisation, surgery and production loss and combined with estimates on the distribution of severity of the cases—as described by Korsgaard et al. (2005).

The full set of values for the different stakeholders (partly in Danish) can be obtained from the corresponding author upon request.

3. Results

The estimated annual effect of each of the four alternative strategies on human incidences is presented in Table 2.

The resulting costs and benefits to stakeholders as well as the mean values of the total net present values are presented in Table 3. Only hot-water decontamination would be profitable from a socio-economic point of view because it was the only alternative with a positive net present value: €3.5 million. The least profitable alternative was use of home-mixed feed with a net present value of −€262.3 million, whereas for sanitary slaughter it was −€43.6 million, and for acidified feed it was −€79.9 million (Table 3). Furthermore, it can be seen in Table 3 that, regardless of the alternative chosen, it is the

<table>
<thead>
<tr>
<th>Annual decrease in number of human cases</th>
<th>Strategy regarding reduction of Salmonella in pork</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead</td>
<td>Hot-water decontamination (A) Sanitary slaughter (B) Home-mixed feed (C) Acidified feed (D)</td>
</tr>
<tr>
<td>Dead</td>
<td>2.6 0.2 0.9 1.1</td>
</tr>
<tr>
<td>Registered</td>
<td>136 11 49 57</td>
</tr>
<tr>
<td>Unregistered</td>
<td>951 74 344 396</td>
</tr>
</tbody>
</table>

* A yearly decrease in number of dead of, e.g. 0.2 means that one life is saved on average every 5 years.
pig industry (farmers and slaughterhouses) that would have to pay for the benefits of the rest of society.

Only the distributions of net present values for sanitary slaughter and acidified feed overlap slightly (Fig. 1). Therefore, we concluded that the relative ranking of the alternatives was robust.

Table 3
Results of a cost–benefit analysis of four different national strategies against Salmonella in Danish pork

<table>
<thead>
<tr>
<th>Mean values of discounted net benefits (million euro) for the time period 2005–2020</th>
<th>Hot-water decontamination (A)</th>
<th>Sanitary slaughter (B)</th>
<th>Home-mixed feed (C)</th>
<th>Acidified feed (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumers</td>
<td>45.7</td>
<td>3.5</td>
<td>4.3</td>
<td>6.4</td>
</tr>
<tr>
<td>National authorities</td>
<td>7.5</td>
<td>0.6</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Subtotal</td>
<td>53.2</td>
<td>4.1</td>
<td>5.0</td>
<td>7.4</td>
</tr>
<tr>
<td>Farmers(^a)</td>
<td>0</td>
<td>0</td>
<td>-265.8</td>
<td>-90.5</td>
</tr>
<tr>
<td>Slaughterhouses(^a)</td>
<td>-49.7</td>
<td>-47.7</td>
<td>-1.5</td>
<td>3.2</td>
</tr>
<tr>
<td>Subtotal pig sector</td>
<td>-49.7</td>
<td>-47.7</td>
<td>-267.3</td>
<td>-87.3</td>
</tr>
<tr>
<td>Total net present value</td>
<td>3.5</td>
<td>-43.6</td>
<td>-262.3</td>
<td>-79.9</td>
</tr>
</tbody>
</table>

\(^a\) For acidified feed the net benefits do not include penalties.

Fig. 1. Frequency distributions for the net present values of four different national strategies against Salmonella in Danish pork (10,000 runs, values in million euro).
4. Discussion

4.1. Hot-water decontamination

In 72% of the simulations, this alternative came out with a positive net present value (Fig. 1).

The positive net present value was primarily due to the large effect on the number of human cases and the dominant benefit stemmed from the value of saved statistical lives.

It is the slaughterhouses alone that would be paying for the benefits of consumers and public authorities. Hot-water decontamination would imply major investments in facilities and buildings as well as maintenance and higher production costs. If equity is an important aspect for the parties involved, redistribution between stakeholders (e.g. the public authorities co-financing the hot-water decontamination) might have to be considered. With a very effective decontamination of the carcasses, it could also be argued that the existing control could be scaled somewhat down without jeopardizing food safety. This would imply annual cost savings.

Hot-water decontamination would also have a reducing effect on other food–borne microorganisms such as *Campylobacter* and *Yersinia*. However, because of lack of data *Campylobacter* and *Yersinia* were not considered in the present CBA. Hereby, the net present value of this alternative was underestimated.

The process of flushing carcasses with hot water might lead to minor changes of the meat colour immediately after decontamination. However, if the pig is split along the natural separation lines, or the meat is protected by a membrane, these changes are reversible and will typically disappear after chilling (unpublished results, Danish Meat Research Institute). A preliminary analysis did not indicate changes in the meat quality due to the temporary increase in meat surface temperature (unpublished results, Danish Meat Research Institute). However, this aspect needs further investigation. So far, hot-water decontamination has not influenced the demand on domestic and international markets negatively.

Hot-water decontamination is currently performed in one Danish abattoir. The facilities are the first generation of decontamination procedures, and are similar to what is being used in the USA and Australia. Developments within decontamination are in the pipeline; e.g. hand-held decontamination by use of steam suction is currently being tested. If results are promising, this decontamination procedure could imply that food safety benefits on a level comparable with those of hot-water decontamination could be obtained without the large investment costs associated with the latter. Another promising alternative is the combination of steam and ultra-sound. However, this approach needs further development.

4.2. Sanitary slaughter

In none of the simulations did sanitary slaughter come out with a positive net present value (Fig. 1).

This was due to the small effect on human cases combined with a considerable increase in slaughterhouses’ production costs.
The slaughterhouses would increase their annual production costs because the number of pigs that would be sanitary slaughtered would increase considerably (from approximately 100,000 to 700,000 pigs). In contrast to hot-water decontamination, sanitary slaughter of level-2 and level-3 herds did not have a strong reducing effect on the number of human salmonellosis cases, because these herds only account for 10.5% of the Salmonella burden among pigs.

Sanitary slaughter can reduce the prevalence—but not totally prevent Salmonella contamination of the carcass. For example, in a study by Sørensen et al. (2004) the effect of sanitary slaughter varied from 7% positive carcasses at one slaughterhouse to 24% at another. This means that we overestimated the net present value of this alternative, because we assumed total prevention.

4.3. Home-mixed feed

In no simulations did mandatory home-mixing of feed come out with a positive net present value (assuming a correlation between Salmonella in pigs and Salmonella in pork of 0.25) (Fig. 1).

The huge negative net present value of the alternative was largely due to the investment costs of the farmers. The introduction of mandatory home-mixing of feed would necessitate major investments in feeding systems for a large number of farmers. Furthermore, there would be productivity effects (increased feed use, decreased mortality, reduced daily weight gain, decreased feed price, increased work time and increased energy use) associated with feeding home-mixed feed instead of ready-mixed feed (unpublished results, DMA). For finishers, feed consumption would increase to a level exceeding the savings on feed costs; and there would be a net cost. For sow and piglet production, there would be no increase in feed consumption. This implies that with the savings on feed costs, an integrated herd would obtain a net gain per slaughter pig.

The decrease in Salmonella pre-harvest would lead to fewer level-2 and level-3 herds, which would reduce the total yearly slaughter price penalties paid by the farmers. In accordance, slaughterhouses’ income from penalties would decrease. This would be partly compensated by a decrease in production costs because fewer pigs would be sanitary slaughtered.

When feeding home-mixed feed, the feed often segregates in the tube feeding system. This results in differences in feed ingredients fed to the pigs, and thus differences in pig productivity and farmer’s income. We did not take this into account in the CBA.

Home-mix feeding systems are usually installed in connection with enlargements of the herds. It offers the advantage that feed stuffs might be purchased and stored when prices are low and it has a documented Salmonella-reducing effect. However, it might be questionable whether it is realistic to introduce mandatory use of home-mixed feeding because of the investment costs.

When we changed the correlation between Salmonella in pigs and Salmonella in pork to 0.5 and 0.75, respectively, the mean of the net present value changed to −€257.3 and −€252.3 million, respectively, and we concluded that the net present value was hardly sensitive towards this assumption. Furthermore, we concluded that the overall ranking of the alternatives was not sensitive towards this assumption.
4.4. Acidified feed

In <1% of the simulations did mandatory use of acidified feed have a positive net present value (assuming a correlation between Salmonella in pigs and Salmonella in pork of 0.25 (Fig. 1).

The lack of profitability was mainly due to the increase in feed price combined with a limited effect on Salmonella.

The costs of the alternative would be borne solely by farmers through the increase in production costs. As for home-mixed feed, the decrease in Salmonella prevalence pre-harvest would lead to fewer level-2 and level-3 herds and hence reduce the penalties paid by farmers. The slaughterhouses would get a decrease in income from penalties, which would be partly compensated by a decrease in production costs because fewer pigs would be sanitary slaughtered. Data were not available to obtain an estimate for these reductions, and therefore the penalties were not included for this alternative.

The use of organic acid in the feed has the disadvantage of increased corrosion of the feeding system. However, we judged this effect to be insignificant and omitted it from the CBA.

In contrast to implementing home-mixed feed on all farms, including organic acids in pig feed is relatively simple to achieve.

When we changed the correlation between Salmonella in pigs and Salmonella in pork to 0.5 and 0.75, respectively, the mean of the net present value changed to −€72.5 and −€65.1 million, respectively, and we concluded that the net present value of the alternative was sensitive towards this assumption. However, at the same time we concluded that the overall ranking of the alternatives was not sensitive towards this assumption.

4.5. The value of a statistical life

The major part of the benefits of each of the four alternatives stemmed from the valuation of saved lives.

The value of a lost life refers to the value consumers put on a statistical life – that is, before the fatality actually happens. It is difficult and certainly controversial to assign monetary values to life itself. We used a value of €1.7 million. This value was based on an interim “best estimate” – recommended by the European Commission (Anon., 2001) – that was adjusted for differences in purchasing power parity to apply for Danish conditions (Anon., 2004c). We chose to interpret this value as politically defined and therefore we did not include it in the sensitivity analysis. The controversial issue of assigning a money value to life itself might partly be omitted by calculating a break-even value of life, i.e. the value that would make the alternative “break-even” in the sense that the sum of benefits balances the sum of costs (or equivalently, the net present value is zero). For hot-water decontamination this value was approximately €1.6 million, for sanitary slaughter it was €23 million, for home-mixed feed it was €108 million, and for acidified feed it was €24 million. Such a break-even analysis does not exempt the decision maker completely from trading off money for saved lives, but it will serve to emphasise the relative profitability of the alternatives.
4.6. Limitations of the model

In a CBA, costs and benefits are valued and compared. However, often – and in our analysis as well – some aspects cannot be valued because of lack of data. For example, the quantitative impact of the considered alternatives on the number of human cases of yersiniosis could not be evaluated. Moreover, because of limited data we had to use expert opinion for several of the parameters and to describe the uncertainty related to these parameters. As more information becomes available, the CBA should be re-run to optimize the precision.

However, in the choice of a future control strategy for *Salmonella*, our CBA can serve as a valuable part of the basis for decision because it despite of its limitations and imprecision shows the socioeconomic consequences of the different alternatives. It is the *relative* socioeconomic profitabilities of the different alternative interventions that are the most important in this type of analysis – more than the absolute values – and these indicate that our post-harvest measures are more cost-efficient than our pre-harvest measures.

In a similar cost–benefit analysis Miller et al. (2005) analyse pre-harvest and post-harvest interventions relevant for American conditions. Much in line with our analysis, they conclude that despite of great variability in the results, the trend is that post-harvest interventions are generally much more cost-efficient than pre-harvest interventions.

5. Conclusion

Our CBA showed that of the four alternatives only hot-water decontamination was socio-economically profitable. Neither mandatory use of home-mixed – or acidified – feed nor increased use of sanitary slaughter was profitable. The output distributions from our Monte Carlo simulations indicated that this conclusion was rather robust – as did the sensitivity analysis of the correlation between the *Salmonella* prevalence in pigs and in pork.

5.1. Epilogue

After our analysis was concluded, the Danish pig sector decided to increase focus on slaughterhouse hygiene and at the same time to introduce hand-held steam-sucking on some slaughterhouses. The effect of this will be shown in the years to come.

Acknowledgements

The following persons are acknowledged for provision of data to the analyses as well as discussions of the method and the results: Hardy Christensen, Danish Meat Research Institute, Flemming Lønbæk Jensen, Danish Crown, Morten Helms, Statens Serum Institut, Gudrun Sandø, Danish Veterinary and Food Administration, as well as Finn Udesen, Jan Dahl, Henrik Wachmann, Jaap Boes, Bent Nielsen, Vibeke Møgelmose, Lene Lund Sørensen, Dan Bysted, and Lisbeth Jørgensen, all from the Danish Meat Association.
References


Anonymous, 2004c. Værdien af statistisk liv til brug i miljøøkonomiske analyser – in Danish (The value of a statistical life in environmental economics). Environmental Assessment Institute, Copenhagen, Denmark, 18 pp.


