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Preface

This report contains cost analyses of intervention methods for reducing numbers of *Campylobacter* in broiler chickens and broiler meat.

The cost evaluation is an integrated part of the Campy project - *Risk perception and cost benefit analysis of interventions to control Campylobacter* - that is carried out during the years 2005-2009. It is a multi disciplinary research project with the main objective to identify 'new' cost-effective intervention methods and strategies for the broiler production chain. The strategies are evaluated in consideration of *Campylobacter* reducing ability, technical feasibility, costs, public perception of *Campylobacter* risk versus public acceptance of suggested reduction techniques, the consumer's willingness to pay for low-risk products, and the saved socio-economic costs due to an expected lower number of human infections.

We would like to thank the large number of experts, broiler farmers and representatives from the industry, who have provided inputs to the economic analysis. We would like to thank Ulf Nonboe, Force Technology, Niels Borre, Vestergaard Frandsen Company, Allan Balle OK-Miljø, Per Klitte and Jacob Pedersen, Danpo, Broiler producers, Thomas Knudsen, Henning Fynboe Madsen, Karin Lieder and Fleming Hjørt, Skoping, Disinfection Service providers, Benny Kristensen and Finn Rasmussen for their important contributions to the cost calculations. And especially thanks to Hanne Rosenquist, the leader of the CAMPY project, who has shown great interest in the cost analyses and provided valuable comments and suggestions for improvements of the work.

The report has been written by assistant professor Lartey G. Lawson, senior researcher Jørgen Dejgaard Jensen and research director Mogens Lund.

Institute of Food and Resource Economics
University of Copenhagen, May 2009

Henrik Zobbe

Summary

The objective of the report is to analyse the costs and cost-effect ratios of intervention methods against *Campylobacter* infections along the broiler supply chain defined by the primary stage (i.e. farms) and the secondary production stage (i.e. slaughter and processing).

The cost evaluation is an integrated part of the Danish Campy project - *Risk perception and cost benefit analysis of interventions to control Campylobacter* - that is carried out during the years 2005-2009. It is a multidisciplinary research project with the main objective to identify ‘new’ cost-effective intervention methods and strategies for the broiler production chain. The strategies are evaluated in consideration of *Campylobacter* reducing ability, technical feasibility, costs, public perception of *Campylobacter* risk versus public acceptance of suggested reduction technologies, the consumer's willingness to pay for low-risk products, and the saved socio-economic costs due to an expected lower number of human infections.

The costs of an intervention technology are measured as the change in costs compared to a baseline, which has been chosen to be the production and economic results obtained in the Danish broiler sector in 2004. Thus, changes in the total costs associated with adaptation of an technology are the sum of capital costs that cover long term investments and extra variable costs, which are directly related to additional resources used in the production process. Variable costs cover labour used in the production, materials (e.g. disinfectants) and miscellaneous inputs (e.g. water and energy). In order to estimate the cost changes, the accounting, economic-engineering and the econometric approach have all been applied. Furthermore, the cost-effect ratio (CE-ratio) of an intervention measure is defined as the change in additional costs relative to the change in the occurrence of Campylobacter (ΔCosts/ΔCampylobacter). Hence, intervention measures with low CE-ratios are the most preferred.

The investigated interventions against *Campylobacter* at the farm stage are:
- Rodent control
- Growout house standard
- Fly-screen for growout houses
- Feeding strategy
- Change in rearing duration
- Phage therapy

The technical and economic data utilized are obtained from 278 Danish broiler producers in 2004, Danish and international literature, expert consultations and a recent Danish epidemiological study of *Campylobacter* risk factors in primary production. Some main results from the cost analyses of four interventions at the farm level are shown in table l. The table is a summary of information presented in table 3.13.

Table 01. Costs and cost-effect ratio of four interventions at the farm level

	Rodent control	Feeding strategy	Fly screen	Growout house Renovation
Costs, DKK per bird	0.0180	-0.0014	0.1310	0.1620
Cost-effect ratio	0.2950	-0.0108	0.7710	1.7230

In general, the intervention on Danish broiler farms with the lowest cost-effect ratio is the early feeding of whole-wheat followed by rodent control, fly-screens and as last growout house renovation. This ranking by CE-ratio is however only true when considering average farms. Decomposed according to farm sizes, it is revealed that small and medium broiler farms are obtaining greater cost-effectiveness by implementing the fly-screen intervention compared to the renovation of growout houses. It exemplifies that specific farm characteristics matter in choosing the cost minimizing intervention methods.

At the slaughterhouse stage the following interventions are analysed:

- Extensive additional washing of broilers
- Steam-Ultrasound
- Trisodium acid decontamination
- Crust freezing
- Marinating
- Scheduling

In the empirical estimations at the slaughterhouse stage data have been obtained from the Danish Broiler Association, Statistics Denmark, slaughterhouses, manufacturing companies, public authorities, Danish and international literature, experts and the Danish experimental research study on Campylobacter control using physical and chemical decontamination measures at slaughter, which is part of this research project.

The costs and CE-ratios of four intervention technologies estimated for large and small slaughterhouses are shown in table 2. The costs and CE-ratios are information obtained from table 4.9 and 4.10, respectively. The ranking of the interventions are quite similar between small and large plants. Steam ultrasound is a promising intervention if the use of TSP is not publicly acceptable or legal as marinating is only limited to a portion of broiler meat. Generally, the costs per bird of introducing new technologies to reduce *Campylobacter* are higher for small slaughter plants than for large plants. For this reason, the profitability of small slaughterhouses is more affected by the implementation of new intervention methods than is the general case for large plants.

Table 02. Costs and cost-effect ratios of selected interventions at large and small slaughter plants

	TSP 15 seconds	[3]Steam Ultrasound	Marinating	[5]Crust-freezing
Large plants				
Costs, per bird in DKK	0.042	0.119	0.053	2.043
Cost-effectiveness ratio	0.022	0.047	0.035	1.148
Small plants				
Costs, per bird in DKK	0.077	0.119	0.045	1.837
Cost-effectiveness ratio	0.041	0.047	0.030	1.032

3 and 5, see table 4.10.

In the report the intervention technologies to combat *Campylobacter* have been analysed one by one. However, in reality both broiler farms and their slaughterhouses might need to adapt a portfolio of interventions in order to provide an acceptable safety level against *Campylobacter* infections. The optimal composition of these portfolios is important for the profitability of broiler firms and for the future competitiveness of the whole broiler chain.

There are also important shortcomings in the use of cost-effect ratio analysis as a decision-making and policy tool because the focus is on the CE-ratio of food safety improvements without considering alternative uses of the resources consumed. CE-ratio analysis simply shows how changes in e.g. food hazards are related to cost changes.

1. Introduction

Human *Campylobacter* infection is known to cause diarrhoeal illness in a number of countries. In the Netherlands, *Campylobacter* infection was associated with 10 per cent of the cases of gastroenteritis (De Wit MA et al., 2001). In Denmark, the steady increase in the number of human cases of campylobacteriosis and high prevalence of *Campylobacter* in chicken broiler meat in the 1990s prompted a risk profile and a risk assessment analysis (Rosenquist et al., 2003).

The Danish *Campylobacter* Risk Assessment Project (CAMPY) as a follow up for the Danish Campylobacter Risk Assessment is designed to identify cost-effective intervention methods and strategies to combat *Campylobacter* infections along the Danish broiler supply chain. The first step in the cost-effectiveness analysis is the identification of potential intervention measures against *Campylobacter* colonization at the farm level and the spread of *Campylobacter* at the slaughter and processing stage. The selection of *Campylobacter* control intervention methods was based on a Danish epidemiological risk analysis for primary production (Sommer and Heuer, 2007), research to prevent *Campylobacter* vector carrier flies entering the broiler houses (Hald, 2007), Danish studies with focus on Campylobacter reduction using physical and chemical decontamination methods (Boysen and Rosenquist, 2009 and Riedel et al., 2009), the international literature on *Campylobacter* risk factors as well as intervention measures selected in dialogue with experts and the industry.

The objective of this report is to analyse costs and CE-ratios of intervention methods against *Campylobacter* colonization and contaminations along the broiler supply chain defined by the primary (i.e. farms) and the secondary production stage (i.e. slaughter and processing), respectively. Chapter 2 provides some methodological considerations regarding alternative approaches to estimate the costs of interventions to improve food safety. The estimation of intervention costs at the farm and slaughterhouse levels are presented in chapters 3 and 4, respectively. Finally, chapter 5 discusses some implications and extensions of the results obtained in this study.

2. Cost approaches

The broiler supply chain is defined as covering farms at the primary stage producing growouts and slaughterhouse units in the secondary stage engaged in slaughtering and processing. Farms engaged in the production of day old chick stocks are excluded from the analysed chain. Basically, chicks from the day old chick producing units are assumed to be free from *Campylobacter* infections when they are delivered to the grower farms. Additional information about the broiler chain and the sector as a whole is found in Graversen (2003).

The main approaches for costing the supply of food safety or preventing food-borne infections focus on; only the extra costs (accounting approach); combining accounting costs with the level of food safety produced (economic engineering approaches); and how the changes in food safety affects the level of output and input factors and thus the total costs of production (econometric approach). In this report, the accounting, economic-engineering and the econometric approaches (Antle, 2001) have all been applied.

Accounting approach

By the accounting approach costs are calculated without estimating a parametric representation of the cost function. Typically, data from a single company or a small group of companies are collected and used to calculate the extra capital costs in the production process or the higher labour costs incurred by implementing new interventions, e.g. crust-freezing. Therefore, the approach is straightforward to perform and can accommodate a rather high level of detail in the cost analysis. However, as noted by Antle (1999) among others, the approach is subject to methodological shortcomings. Firstly, cost information based on a single or a few companies hardly depict the average costs of producing safe food products as well as cost differences between e.g. large and small firms. Secondly, the approach lacks the characteristics of the underlying cost structure and hence the companies' opportunities for adjustments to new interventions, e.g. product innovation and technological adjustments.

Economic-engineering approach

With the economic-engineering approach detailed engineering data are combined with data on input costs to build a quantitative model of the production process (Jensen and Unnevehr, 2000). This process-based model of the plant's production possibilities can be used to derive a non-parametric cost function. It may provide a detailed picture of a plant's production process, but it is costly to implement for a large number of distinct plants so a small number of "representative" plants are typically modelled. By this approach it is difficult to account for the heterogeneity among firms and therefore the cost information provided may not be representative for a whole industry.

Econometric approach

By the econometric approach the cost function or derivatives thereof for an industry or large group of firms is econometrically estimated and used to measure the potential costs of new intervention technologies. This approach, unlike the accounting or economic-engineering approaches, includes less detailed cost information, but is typically more representative for a whole industry due to the utilization of large data sets. Based on the observed behaviour of plants in the industry, the method reflects the actual production choices of plant managers. Econometric methods also provide a statistical basis for testing hypotheses related to the behaviour and production structure, such as the hypothesis of joint technology in output and product quality. An example based on the variable cost function is provided in Antle (2000).

In general, the total costs of an intervention measure are the sum of capital costs that cover long term investments and variable costs, which are directly related to the current production. Variable costs cover labour used in the production, materials (e.g. disinfectants and lactic acid) and miscellaneous inputs (e.g. water and energy).

The investment costs are generally depreciated over the lifespan and thus converted into annual capital costs (annuities) following standard economic principles. The capital costs include the annual costs of purchase of equipment, installation and expenses associated with e.g. reorganisation. Whereas capital costs typically are considered as fixed costs, variable costs are related to annual volume dependent activities.

In especially the accounting and economic-engineering approaches the costs related to individual intervention methods may be obtained by a partial budget cost calculation. Partial budgeting has the general format of four distinct categories, which are additional returns, reduced costs, returns foregone and extra costs. The net costs are calculated as (returns foregone + extra costs) – (additional returns + reduced costs). A large number of studies, e.g. Jensen et al. (1998), Mangen et al. (2005a), Vosough et al. (2007), Van der Gaag et al. (2004) and Valeeva et al. (2007) have applied one or two of the approaches or the partial budgeting method to estimate the costs of food safety interventions.

Clearly, data availability and quality are important determinants in choosing the best method for evaluation of the costs of different intervention technologies and in choosing cost-effective strategies for reduction of *Campylobacter* infections. In this report the three approaches have been combined. In general, for all investments the capital costs per year are calculated using the annual interest rate of 3.61 per cent (0.0561-0.02), i.e. inflation corrected rate (DPC, 2006). The lifespan of investments is 10 years for moderate renovations and 20 years for long lasting investments, e.g. housing systems. All costs at the farm level were calculated using the production information from individual broiler units and expressed per broiler chicken. Therefore, they are farm specific. This allows accounting for differences in e.g. production size among firms, when estimating the various intervention costs.

3. The farm stage

The Danish broiler growout stage comprises approximately 278 producers. In 2004 the farms had a total of 4,383 flock rotations with input stock totalling 135.8 million chicks of a particular breed. The total production this year was 131 million birds which is equivalent to 181 million tons of broiler meat (DST, 2004). Year 2004 is used as the base year for economic evaluation of the intervention methods analysed in this study. Hence, primary data on production for the 278 Danish broiler producers was collected for 2004. The data is used to provide a description of farms and estimating the changes in costs of implementing potential *Campylobacter* control interventions at the farm level.

The farms have been grouped into three economic sizes (i.e. small, medium and large units) to account for heterogeneity among the producers. The sizes represent farms with growout house capacity of ≤ 2000, 2001-4000 and >4000 m^2, respectively. General production characteristics and some economic indicators are presented in table 3.1. The values of gross margin (an indictor of short-term profit) and the net profits may be compared with total estimated intervention costs per broiler chicken thereby providing information about which intervention measures are best suited for specific producer categories.

Table 3.1. Farm stock distribution and averages of income (farm gate), costs and profits per chicken in DKK

Farm Type	Number of farms	Flocks Number	Flock Input %	Stock Input %	Farm Gate Price	Variable Input Cost	Gross Margin	Quasi Fixed Cost	Net Profit	Net Profit std*
Small	45	430	10	9	8.86	7.58	1.28	1.14	0.14	1.35
Medium	58	939	21	24	9.01	7.65	1.36	0.64	0.72	0.29
Large	27	733	17	19	8.88	7.52	1.36	0.59	0.77	0.37
All farms#	130	2,102	48	51	8.93	7.60	1.33	0.80	0.53	0.88

Source: Own calculations; * standard deviation; # Farms with full cost information.

As shown in table 3.1, there are minor differences in farm gate prices between the three farm groups. However, medium and large farms seem to be more profitable compared to the small farm group when evaluated by the gross margins and the net profits (see columns 7 and 9 in table 3.1).

3.1. Selected intervention measures

The risk factor study by Sommer and Heuer (2007) identified a number of risk factors that are important for *Campylobacter* colonization of broiler flocks. Among these, two risk factors 1) cattle density (i.e. whether the broiler farm is located within the vicinity or not of a cattle dense area) and 2) having more than one broiler growout houses (i.e. categorisation by the number of houses) are assumed exogenous and hence beyond direct policy influence. However, the study points at four intervention methods pertaining to the broiler growout houses and its environment as well as feeding, which are of relevance. Findings from Hald (2007) demonstrate fly-screens as a preventive measure. Furthermore, various studies in the literature suggest phage therapy as a potential intervention. Hence, these two types of farm level interventions are also considered in this study. It is notable that an international expert consultation in Denmark in November 2007 (Rosenquist et al., 2008) suggested these intervention measures to be good or applicable as intermediate preventive measures. The selected interventions are shown in table 3.2.

Table 3. 2. Intervention measures at the farm stage

1.	Rodent control
2.	Growout house standard
3.	Fly screen for grow-out houses
4.	Feeding strategy
5.	Change in rearing duration
6.	Phage therapy

In what follows, the description of each intervention measure and its estimated costs are provided. The costs are presented as averages, standard deviations, minimum and maximum values for farm groups in total and per chicken. The farm groups arranged according to increasing costs of each intervention method. The groups are determined after evaluating the assumption of normality distribution with special emphasis on the estimated skewness and kurtosis of the distribution. This is done by using the “Univariate Proceduce” (SAS, 1989). Generally, the distribution of a continuous variable is normally distributed when the average and the median estimates are close to each other, while the skewness and kurtosis are close to zero. In cases where the variable is normally distributed the groups of increasing costs are constructed from the 10, 25, 50, 75 and 95 percentiles. For variables with a non-normal distribution, the groups are constructed with short and long ranges at the lower or upper end, respectively, of the distribution.

3.1.1. Rodent control

Rodent control is the provision of poison boxes at selected locations around broiler growout houses and providing service checks after every flock rotations with the goal of eliminating rodent intrusion. The Danish epidemiological study, Sommer and Heuer (2007), suggests that farms lacking this service have higher risks of *Campylobacter* infections. This is supported by the results from a Swedish investigation by Berntson et al. (1996). However, Refregier-Petton et al. (2001) and Bouwknegt et al. (2004) in French and Dutch studies did not find any correlation between the presence of rodents and *Campylobacter* infection in broiler–poultry flocks. The lack of correlation reported in these two studies might however be due to the implementation of well functioning rodent control measures a priori to the investigations. It is noted that rodent control might generally reflect good management principles.

Consistent rodent control with services covering six to eight mouse control checks is provided by professional rodent control companies at an annual costs of 6,000, 7,000 and 8,000 DKK for services associated with one, two and more than two growout houses, respectively (DLG, 2007; Absolute Pest Control, 2007). These cost figures are combined with the individual farm production data to estimate the costs of the intervention per chicken. The resulting cost variable is positively skewed with a value of 4. Hence, the distribution of farms and estimated costs for increasing costs of five groups is determined by consecutive increases of 0.020 DKK with values below 0.008 DKK as the first group. The distribution is shown in table 3.3.

Table 3.3. Distribution of farms and the costs of rodent control for increasing cost groups, per chicken

Groups of increasing costs, DKK	Chick stock %	Number of farms	Farms %	Mean DKK	Standard Deviation DKK	Minimum DKK	Maximum DKK
< 0.008	18	22	8	0.0060	0.0014	0.0037	0.0080
0.008-0.028	76	205	74	0.0154	0.0050	0.0081	0.0269
0.028-0.048	4	29	10	0.0367	0.0054	0.0283	0.0478
0.048-0.068	1	11	4	0.0556	0.0054	0.0483	0.0648
> 0.068	1	11	4	0.1211	0.0432	0.0708	0.2036

Source: Own calculations.

The last two rows of table 3.3 show that about 8 per cent of the farms with about 2 per cent of the production will incur rodent control costs greater than 0.05 DKK per chicken, while 10 per cent of the farms will incur costs between 0.03 and 0.05 DKK per chicken. The rest 82 per cent of the farms with 94 per cent of the production will incur costs below 0.03 DKK per chicken. The average costs of rodent control using the professional expertise are 0.02 ± 0.01 DKK per chicken. This amounts to 2.1 million DKK for all houses on the 278 farm units.

3.1.2. Growout house standard

Growout house standard refers to renovating broiler growout houses to improve its functionality and hygienic conditions. The Danish epidemiological study found that *Campylobacter* prevalence on farms is correlated with increasing age of broiler houses as well as the lack of hygiene (Sommer and Heuer, 2007). In the literature similar studies found that poor house conditions, e.g. poor floor surface as well as lack of hygiene, increase the risk of *Campylobacter* ***colonization*** in broiler farms (Berntson et al, 1996; van de Giessen et al., 1998; Evans and Sayers, 2000). Hence, improving the quality of houses through renovation is expected to reduce the risk of *Campylobacter* colonization among broiler flocks.

The cost of renovating the existing growout houses can directly be estimated from investment costs associated with an ante-room, floor, port, feeding inventory and lost production (personal comm. Industry, 2007). The capital investments required are dependent on the age of the growout house. Therefore, capital investments are estimated for growout houses with an average age of 29, 9 and 4 years corresponding to investments of 420,000, 150,000 and 50,000 DKK, respectively. However, houses with very poor conditions require construction of new houses implying replacement costs of 2,350,000, 875,000 and 225,000 DKK, respectively, to cover buildings, inventories and sanitations (DPC, 2005). The variable costs for maintenance are assumed to be unchanged. Due to the extreme skewness and kurtosis with values of 9 and 87, the distribution of farms for increasing costs for the five groups are constructed as illustrated in table 3.4.

Table 3.4. Distribution of farms and the costs of growout house renovation by increasing cost groups, per chicken

Groups of increasing costs, DKK	Chick stock %	Number of farms	Farms %	Mean DKK	Standard Deviation DKK	Minimum DKK	Maximum DKK
0	19	50	18	0	0	0	0
0-0.105	62	160	57	0.051	0.028	0.007	0.104
0.105- 0.650	10	41	15	0.176	0.063	0.109	0.337
0.650-1.400	5	14	5	1.134	0.254	0.677	1.396
> 1.400	4	14	5	10.427	14.406	1.424	39.528

Own calculations. The distributions are based on 183 farms (66 per cent) with full information to estimate renovation costs. The groups of increasing costs are based on the percentile distribution of values for the 183 farms.

Table 3.4 shows that 50 farms (18 per cent) need not invest in renovation as a measure to control *Campylobacter* infections. For 72 per cent of the farms, the renovation costs range between 0.007 and 0.337 DKK per chicken (group 2 and 3). For additional 5 per cent of the farms, the costs of renovation are between 0.67 and 1.39 DKK (row 5). For the rest 5 per cent in the last row, the average costs are considerably higher. Hence, the last group with a production capacity of 320 thousand birds per year is better off by investing 1.30 DKK per bird in a new growout house. In general, the average costs of renovation are 0.48 DKK per chicken, which amounts to about 65.6 million DKK covering the respective houses on all the 278 farms.

3.1.3. Fly-screen

Fly-screen involves netting the openings, i.e. windows, doors and ports as well as chimneys of broiler growout houses (see Box 3.1), to prevent vector-carrier flies introducing *Campylobacter* to the broilers (Hald et al., 2007 & Hald et al., 2004).

Box 3.1. Fly-screen on a growout broiler house

Source: Birthe Hald

High numbers of chimneys on growout houses turn out to be positively correlated with the prevalence of *Campylobacter* in broiler flocks (Sommer and Heuer, 2007). Additionally, the case and control study by Hald et al. (2007) suggests that fly screen caused a significant reductive effect on broiler flock *Campylobacter* prevalence. Therefore, it is relevant to investigate the CE-ratio of the fly screen control measure. The costs attributed to the fly-screen netting cover capital investments as well as variable expenses including water, electricity, disinfectant solution and labour for cleaning periodically after each rotation. The cost information for small, medium and large farms is provided in table 3.5.

Table 3.5. Costs associated with the provision of fly-screen on broiler houses

Cost components	Small DKK	DKK/bird	Medium DKK	DKK/bird	Large DKK	DKK/bird
Rotations	7		7		9	
Chimneys	8		12		11	
Birds per rotation per house	15,100		26,600		46,000	
Total birds per house per year	105,700		186,200		414,000	
Fly screen investments						
Ventilation and chimney nets #	10,480		10,720		10,660	
Installation ##	7,800		7,800		7,800	
Building improvement with fly screen ###	130,000		130,000		130,000	
Sum of investment costs	148,280		148,520		148,460	
Capital costs						
Ventilators-chimney nets	1,267	0.0120	1,296	0.0070	1,289	0.0031
Installation	943	0.0089	943	0.0051	943	0.0023
Building improvement with fly screen	15,718	0.1487	15,718	0.0844	15,718	0.0380
Total capital costs	**17,928**	**0.1696**	**17,957**	**0.0964**	**17,950**	**0.0434**
Variable costs						
House Net-Washing ####	2,800	0.0265	2,800	0.0150	3,600	0.0087
Chimney Washing ####	392	0.0037	588	0.0032	693	0.0017
Chimney Net-Washing ####	4,480	0.0424	6,720	0.0361	7,920	0.0191
Water-for-Washing & electricity	500	0.0047	500	0.0027	643	0.0016
Disinfectant solution	700	0.0066	700	0.0038	900	0.0022
Total variable costs	**8,872**	**0.0839**	**11,308**	**0.0607**	**13,756**	**0.0332**
Total costs	**26,800**	**0.2535**	**29,265**	**0.1572**	**31,706**	**0.0766**

Source: Own calculations. # Polyester net bag at 60 DKK per unit (Vestergaard Frandsen, 2007); ; ## polyester net bags installation, 2 hours at 400 DKK/hour; ### OK-Miljø (2007); #### (Hjørt, 2007; Rasmussen, 2007; Lieder, 2007; Madsen, 2007; Knudsen, 2007).

In table 3.5 the differences in investment costs are due to the differences in the number of chimneys per house. The figures in the table also show that costs per bird decreases with increasing number of birds reared per year. The labour for washing, the nets on chimneys and the nets covering the windows and the doors as well as the frequency of washing account for a major proportion of the estimated variable costs.

Furthermore, the distribution of farms arranged into 10 groups by increasing costs is constructed (table 3.6). The resulting distribution is non-normal with skewness and kurtosis values of 4 and 23, respectively. It suggests that the costs of introducing fly-screen are low for many farms. The costs of the first group of farms are less than 0.10 DKK per chicken, the costs of the next five groups increase consecutively by 0.02 DKK, the next two groups by 0.05 and the last two groups by 0.10 DKK per chicken.

As shown in table 3.6, the costs of fly-screen at mean values for 70 per cent of the farms are between 0.09 and 0.15 DKK per bird (column 5, first 4 groups). For the next 12 per cent the costs range between 0.16 and 0.20 DKK per bird (columns 6 and 7 for group 5 and 6), while the costs for the rest 18 per cent ranges between 0.20 and 0.97 DKK per bird. Under the assumption that all 278 farms just have one single growout house, the total costs for fly-screens will be 8.2 million DKK for these houses. However, if it is assumed that all houses on all farms should have fly screens the total costs are between 18 and 21 million DKK (i.e. using specific costs associated with the groups of increasing costs or using the overall average costs).

Table 3.6. Distribution of farms and the costs of fly-screen by increasing cost groups, per chicken

Groups of increasing costs DKK	Stock of birds %	Number of farms	Farms %	Mean DKK	StdDev DKK	Min DKK	Max DKK
< 0.10	26	59	21	0.0911	0.0064	0.0767	0.0999
0.10– 0.12	27	68	24	0.1083	0.0058	0.1003	0.1198
0.12– 0.14	16	43	15	0.1298	0.0067	0.1202	0.1399
0.14– 0.16	12	28	10	0.1504	0.0063	0.1407	0.1597
0.16– 0.18	7	19	7	0.1695	0.0064	0.1604	0.1791
0.18– 0.20	3	14	5	0.1923	0.0045	0.1844	0.1996
0.20– 0.25	5	19	7	0.2211	0.0127	0.2028	0.2433
0.25- 0.30	2	13	5	0.2696	0.0166	0.2518	0.2939
0.30– 0.40	1	8	3	0.3526	0.0274	0.3202	0.3875
>0.40	0	7	3	0.6876	0.1976	0.4014	0.9734

Source: Own calculations.

3.1.4. Feeding strategy

Broiler feeding strategy allows for the introduction of whole-wheat grain as early as 5 days and it is meant to adapt the young chicks to the consumption of whole grain. However, biologically, early introduction of whole-wheat grain is expected to mitigate the growth of *Campylobacter* in digestive traits of birds in cases of infection. The Danish epidemiological study conducted by Sommer and Heuer (2007) evaluated the prevalence of *Campylobacter* on farms introducing whole-wheat grain during three different gestation periods, 0-5 days, 6-10 days and 11-15 days, respectively. The epidemiological study found that introducing grain early during the gestation period lowers the prevalence of *Campylobacter* among broiler flocks. The study by Berntson et al. (1996) suggests that vegetaric feedstuff compared to standard feed have lower risks of *Campylobacter* colonization. However, Bouwknegt et al. (2004) identified no association between feeding grain and broiler flock prevalence of *Campylobacter*.

The costs associated with early introduction of whole-wheat grain are estimated using the standard feed plan for broilers, which basically is composed of concentrate and whole-wheat grain feedstuffs. According to the feed plan with 22% grains during gestation period, the whole-wheat grain demand in grams per chicken is estimated to be 0, 8 and 16 grams for the three gestation periods 0-5, 6-10 and 11-15 days, respectively. The feed plan is based on expected daily feed absorption hence accounting for expected weight gain. Using partial budgeting, the costs of the required grams of whole-wheat grain are estimated as the demand multiplied by the difference between concentrate and whole-wheat grain prices.

Table 3.7 shows the plan for feeding a broiler chicken during the rearing period of 40 days. First the feed required for rearing is cumulated through the 40 days (column 2). This is then partitioned into concentrate and whole-wheat components (columns 3 and 5). The change in the cumulated whole-wheat (i.e. column 5) relative to the previous day is the daily demand for whole-wheat (column 6). For example, as shown in the last column, the 0.0115 DKK per chicken is derived from 16 grams of wheat demanded (column 6) divided by 1,000 grams and multiplied by the price difference of 0.72 DKK per kg feed. The 0.72 DKK per kg feed is the price difference between concentrate price at 1.66 DKK and grain price at 0.94 DKK. Therefore, changing the time of introducing whole-wheat grain from above 15 days to the range of 11-15 days implies a cost saving of 0.0115 DKK per chicken.

Table 3.7. Gram whole–wheat grain demand and cost estimates for the gestation period

Feeding Days	Feed required#	Concentrate#	Concentrate Demand	Whole-wheat#	Whole-wheat Demand	Cost Savings DKK per bird
0-5	94	94	94	0	0	0
6-10	294	286	192	8	8	0.0061
11-15	599	575	289	24	16	0.0115
16-34	3,005	2,441	1,866	564	540	0.3889
35	3,185	2,565	124	620	56	0.0400
36	3,374	2,691	126	683	63	0.0450
37	3,563	2,820	129	743	60	0.0435
38	3,754	2,950	130	804	61	0.0440
39	3,946	3,080	131	866	61	0.0442
40	4,139	3,212	131	927	62	0.0445
Total	4,139	78%	3,212	22%	927	0.6677

Source: Own calculations based on information from DLG (2007); # Cumulated values in gram.

Thus, the costs of using whole-wheat grain are dependent on the price and the amount of concentrate in feed rations and are specific for each individual farm because feed purchase prices differ. The costs of this intervention method turns out to be cost saving as the price of concentrate is higher than that of whole-wheat grain. This is supported by the observation that 87 per cent of all the broiler farms use a whole-wheat grain feeding strategy. In addition to the 87 per cent of farms with zero costs, the rest of the farms with the negative costs (i.e. cost savings) are grouped by being within the 50 per cent or higher of the cost saving estimates. Table 3.8 shows the costs and the distribution of farms by increasing costs divided into three groups.

Table 3.8 indicates that at least 87 per cent of the farms with a total bird stock of 87 per cent (column 2) do not need any further change in feed strategy at the early stages of the gestation period. For the remaining 13 per cent of the farms, the potential cost savings due to the change in feed strategy is on average between 0.0056 and 0.010 DKK per bird. It should be noticed that 22 per cent of the farms do not have any feed information in the available data but this is adjusted for in the estimated distribution in table 3.8.

Table 3.8. Distribution of the three farm groups and the associated costs arranged by the increase in feed costs, per bird

Groups of increasing costs, DKK	Stock of birds %	Farms number	Farms %	Mean DKK	Standard deviation /DKK	Min DKK	Max DKK
>-0.0060	6	17	6	-0,0100	0,0030	-0,0144	-0,0063
-0.0060-0	7	19	7	-0,0056	0,0005	-0,0061	-0,0044
0	87	242	87	0	0	0	0

Own calculations; the distribution are based on 216 farms (88%) with full feed information.

3.1.5. Change in the duration of rearing

Epidemiological studies in the literature found increasing broiler age to be correlated with increasing *Campylobacter* prevalence among broiler flocks (Berntson et al., 1996; Evan and Sayer, 2000; Bouwknegt et al., 2004). The costs attributed to the change in the duration of rearing (production costs at slaughter age), are associated with altering the average duration of producing broilers, e.g. from 37.5 to 36.5 days. The costs are estimated as the change in profit for a reduction or an increase in the average rearing period by one day. The mathematical representation of the estimation process is provided in text box 3.2 and the cost estimates shown in table 3.9.

Box 3.2. Derivation of costs related to growout duration

The profit function is given as: $\pi = py(t) - c(y,t)$ where π is the farm profit, *p* is the price for a broiler output *y* measured in kg, *t* is the duration of the rearing period and *c* is the variable costs of producing a broiler chicken. The change in profit due to the change in the duration of the rearing period is the derivation (∂) of the profit function, which is given by:

$$\frac{\partial \pi}{\partial t} = p\frac{\partial y}{\partial t} - \frac{\partial c}{\partial t} - \frac{\partial c}{\partial y}\frac{\partial y}{\partial t} \qquad \text{Eq. (1)}$$

The average product price *p* paid to broiler producers is estimated from the available broiler production data and is given as 8.93 DKK (Table 3.1). The change in output *y* due to the change in the rearing duration period *t* as well as the change in costs due to change in rearing duration period *t* and the change in cost *c,* due to change in output *y* are estimated from an econometric variable cost model and a model that estimates broiler weight at the day of slaughter *y,* as a function of the duration of rearing broiler chicken (growout duration) *t*. The estimated output function is given as $y = -11.994 + 0.67951767\, t + (½(-0.01620773)\, t^2)$, where *y* is the weight of a broiler chicken and *t* the duration of growout period. Hence the change in weight due to a day's change in growout duration is

$dy/dt_{36.5} = 0.67951767 – 0.01620773*36.5)=0.088$

The estimated translog cost function is given as *c* = -10.485 *int* + 0.102864*p1* + 0.011749*p2* + 0.183281*p3* + 0.234161*p1p1* + 0.083394*p2p2* + 0.041392*p3p3* + -0.04879*p1p2* + -0.02608 *p1p3* + -0.00459*p2p3* + -3.00815*y* + -1.13379*yy* + 0.194196*yp1* + 0.033938*yp2* + - 0.0358*yp3* + 6.970258*z1* + -0.12075*z2* + 1.243936*z3* + -2.04207*z1z1* + 0.003064*z2z2* + 5.52123*z3z3* + 0.022712*z1z2* + -0.05481*z1z3* + -0.05798*z2z3* + 0.082844*z1p1* + 0.006994*z1p2* + -0.02189*z1p3* + -0.00021*z2p1* + 0.000192*z2p2* + -0.00047*z2p3* + 0.461393*z3p1* + -0.3332*z3p2* + -0.12795*z3p3* + 1.197179*yz1* + 0.050329yz2 + 0.214874*yz3*

Where for average values, *c* is the total variable cost per bird, *p1* is the price of concentrate (1.66 DKK /kg), p2 is the price of whole-wheat grain (0.93 DKK/kg), *p3* is other variable costs (0.51 DKK/bird), *y* is output (1.90 kg/bird), *z1* is the duration of growing (37.5 days) , *z2* is the risk for footpad index (0.24) and *z3* is the share of concentrate in feed ration (0.77). Hence, a unit change in costs due to change in output *y* is *dc/dy* = -3,00815 + -1,13379*(ln(1.90)) + 0,194196(ln(1.66)) + 0,033938(ln(0.93)) + - 0,0358(ln(0.51)) + 1,197179(ln(37.5)) + 0,050329(ln(0.24)) + 0,214874(ln(0.77))= 0.5942

From equation 1 the cost of one day's reduction in growout duration from say, 37.5 days to 36.5 days ,for each farm is given by

$\frac{\partial \pi}{\partial t}$ = *(8.93*0.088) - ((7.54-7.46)+(((broiler cost*0.5942)/kg weight)*0.088)),* where the first component is the product of the output price of a broiler (8.93) and the change in output due to changed growout duration *dy/dt*, which is estimated as 0.088 as shown above. The second component is the change in cost of producing broiler from day 37.5 to 36.5. Note 7.54 and 7.46 are calculated from the above translog cost function for the two durations of rearing broilers. The last component is the product of the change in broiler production costs due to output changes measured in kg weight of broiler meat (broiler cost x 0.5942) and the change in broiler output due to one day's change in growout duration (0.088). Note that broiler cost is the farm specific total variable cost of producing a broiler chicken factor 0.5942 is the output coefficient from the variable cost function shown above.

Table 3.9 shows the distribution of farms categorised into five groups and the associated costs due to change in growout duration of the rearing intervention by increasing costs. The distribution for the 130 farms with full cost information is normally distributed with an average and the median cost per chicken at 0.495 DKK as well as skewness at -0.13. Thus, farm groups are constructed to represent around 5, 20, 50, 20 and 5 percentages for a normal distribution. The stock of birds on the 278 farms has been adjusted to reflect the distribution in table 3.9, which is obtained from the 130 farms with full cost information.

Table 3.9. The distribution of farms by increasing costs of growout duration, per bird

Groups of increasing costs, DKK	Stock of birds % #	Number of farms #	Farms %#	Mean DKK	Standard Dev. DKK	Min DKK	Max DKK
0-0.4855	4	13	5	0.4813	0.0021	0.4781	0.4841
0.4855-0.4895	19	58	21	0.4879	0.0012	0.4855	0.4894
0.4895-0.5005	50	139	50	0.4952	0.0030	0.4898	0.5004
0.5005-0.5040	22	53	19	0.5020	0.0013	0.5005	0.5039
0.5040-0.5110	5	15	5	0.5063	0.0023	0.5043	0.5106

Own calculations based on the 130 farms (47 per cent of the 278 farms) with full cost information.

The overall average costs of 0.495 DKK per bird for one day's reduction in the growout period indicates that the income lost per broiler is higher than the expected reduction in the variable costs of production. Fifty three per cent of the farms had no full cost information in the available data. However, for the 17 per cent of the farms with partial cost information, the average costs of one day reduction in the duration of the growout period are 0.4934 DKK per bird, which is close to the estimate of 0.4952 DKK per bird for the farms producing 50 per cent of the broilers (group 3 in column 1). Hence, the estimates are shown to be consistent.

3.1.6. Phage therapy

Phage therapy is the use of bacteriophages (specific viruses) to combat bacteria infection due to the phage's multiplicative growth effect at expense of the bacteria cell in question (Sulakvelidze and Morris, 2001). For the pros and cons of the use of phages or corresponding phage therapy, see Sulakvelidze (2005) and Pirisi (2000). From the literature, phage therapy has been shown to reduce *Campylobacter* colony forming units (CFU) by between 1 and 3 $\log_{10}$ CFU compared to non-treated groups (Wagenaar et al., 2005). Hence, phage therapy is expected to reduce the number of

Campylobacter in farms' deliveries to the slaughterhouses. Under the assumption that each bird is treated with 250 μl (micro-litre) phage suspension as suggested by Wagenaar et al. (2005), the price of phage treatment is given as gram-stuff price multiplied by 0.250 gram. The 0.250 gram is derived from the assumption that the mass of the phage suspension is the same as for water (i.e. 250 μl = 0.250 ml = 0.250 g). Assuming that phage and antibiotic therapies are substitutes, costs of phage therapy are estimated as the costs of antibiotic treatments. Data on antibiotic consumed as well as its gram-stuff cost price for broiler farms provided from the VETSTAT database are used to estimate the costs. Table 3.10 shows the estimated costs for all the 278 farms by implementing phage therapy. In the table, the farms are divided into two groups according to cost levels which is calculated from the 19 per cent of the farms using antibiotics in 2004 (i.e. 225 farms did not use antibiotics in 2004). The cost groups representing the first 50 per cent and the rest consecutive 50 per cent are shown in table 3.10. The data is non-normal with negative skewness and positive kurtosis of -0.13 and 0.09, respectively, suggesting a higher number of farms at the lower end of the distribution compared to the upper part.

Table 3.10. Costs of phage therapy for two cost groups, per chicken

Groups of increasing costs	Stock of birds % #	Farms number #	Farms %#	Mean DKK	Standard deviation /DKK	Min DKK	Max DKK
0 -0.1798	53	147	53	0.11	0.05	0.05	0.18
>0.1798	47	131	47	0.21	0.03	0.21	0.37

Own calculations based on 53 farms (19 per cent of the 278 farms) with full cost information about use of antibiotics in 2004.

The average costs per treated bird for the two cost groups lies within the range of 0.05 and 0.37 DKK per bird. The cost estimate for a higher proportion of the farms lies within the range 0.020 and 0.27 DKK per bird reported in the Dutch CARMA study by Mangen, Havelaar and Poppe (2005a). At group averages, the total costs in the case of implementation of phage therapy by all the 278 farms amounts to 21.3 million DKK. It is noted that the cost of phage therapy, which by itself is based on antibiotic price, could represent the cost of any other additives that could reduce the load of *Campylobacter* in birds.

3.2. Summary of farm level results

The estimated average costs of intervention measures against *Campylobacter* colonization at the farm level are summarised in table 3.11. The estimates are a summary of the cost information shown in tables 3.3 to 3.10. For example, the costs of the change in duration of rearing are calculated from table 3.9 as the accumulated sum of the group specific mean costs multiplied by the stock of birds in the group. This accumulated sum has then been divided by the total stock of birds, which were 135.8 million birds in 2004.

Table 3.11 shows that the estimated costs of the intervention measures range between -0.0010 DKK for a cost saving feed strategy to 0.4953 DKK per broiler chicken in extra costs for one day's change in the duration of rearing. The costs of improving the growout house standard are quite similar to the costs of changing the duration of rearing. At average points, the costs of phage therapy are estimated to be higher than providing fly-screens on growout houses.

Table 3.11. Capital and variable costs of different intervention measures at farm level per broiler chicken in DKK

	Rodent control	Feeding Strategy	Fly screen	Growout house standard	Change in duration of rearing	Phage therapy
Capital costs	-	-	0.0820	0.4834	-	-
Variable costs	0.0155	-0.0010	0.0505	-	0.4953	0.1566
Total costs	**0.0155**	**-0.0010**	**0.1325**	**0.4834**	**0.4953**	**0.1566**
Euro equivalent [#]	**0.0021**	**-0.0001**	**0.0178**	**0.0648**	**0.0663**	**0.0210**

Source: Own calculations. [#] 1 DKK = 0.134 EURO.

The average costs of the ***control*** measures were furthermore estimated for 88 of the 130 farms, which were included in the epidemiological study carried out by Sommer and Heuer (2007). In addition to grouping by size, the cost estimates have been stratified according to whether the farm has one or more growout houses as well as whether the farm is located in a cattle dense vicinity or not. The estimated costs based on these stratification characteristics are presented in table 3.12.

Table 3.12. Changes in average intervention costs for 88 farms in DKK per chicken

Farm categories	Rodent control	Feed-ing strategy	Fly screen	Grow-out house renova-tion	Sum (4)[#]	Dura-tion of rear-ing	Phage therapy	Sum (6)[##]
Average across farms (88 farms)	0.018	-0.0014	0.131	0.162	0.310	0.495	0.160	0.960
Average across farms (130 farms)	0.016	-0.0010	0.133	0.483	0.633	0.495	0.160	1.283
One house, low cattle density	0.023	-0.0003	0.124	0.037	0.180	0.500	0.160	0.840
One house, high cattle density	0.020	-0.0012	0.107	0.021	0.150	0.500	0.140	0.790
Multiple houses, low cattle density	0.017	-0.0015	0.143	0.256	0.420	0.490	0.160	1.070
Multiple houses, high cattle density	0.016	-0.0028	0.127	0.164	0.310	0.490	0.210	1.010
Small house and cattle density								
Small farms	0.025	-0.0008	0.136	0.130	0.290	0.500	0.140	0.930
One house, low cattle density	0.026	-0.0004	0.129	0.045	0.200	0.490	0.160	0.850
One house, high cattle density	0.020	-0.0012	0.107	0.021	0.150	0.500	0.140	0.790
Multiple houses, low cattle density	0.034	-0.0009	0.220	0.580	0.830	0.490	0.110	1.440
Multiple houses, high cattle density								
Medium house and cattle density								
Medium farms	0.015	-0.0018	0.128	0.248	0.390	0.500	0.200	1.090
One house, low cattle density	0.013	-0.0000	0.100	0.000	0.110	0.500		0.610
One house, high cattle density	0.011	-0.0000	0.114	0.011	0.140	0.490		0.630
Multiple houses, low cattle density	0.016	-0.0018	0.133	0.309	0.460	0.500	0.190	1.150
Multiple houses, high cattle density	0.016	-0.0027	0.127	0.200	0.350	0.490	0.210	1.040
Large house and cattle density								
Large farms	0.012	-0.0016	0.128	0.051	0.190	0.490	0.170	0.860
One house, low cattle density								
One house, high cattle density								
Multiple houses, low cattle density	0.011	-0.0014	0.128	0.058	0.200	0.490	0.160	0.850
Multiple houses, high cattle density	0.014	-0.0032	0.129	0.000	0.150	0.500	0.210	0.850

Source: Own calculations. [#] Is the summation of the first four intervention measures; [##] Is the summation of all six intervention measures.

As shown in the first two rows in table 3.12 the cost estimates for all *Campylobacter* control measures except for growout house standard are rather similar to estimates for the 130 farms with full cost information. This reflects the robustness of the estimates for the 88 farms. Hence, the cost estimates in table 3.12 should be representative for cost changes incurred by introducing new intervention methods against *Campylobac-*

ter on Danish broiler farms. The divergence in the cost estimate for growout house standard between the two data samples suggests that there are few or no farms among the 88 farms included the epidemiological study with growout house renovation costs above 0.40 DKK per chicken. This is also supported by the fact that only 10 per cent of the 278 farms belong to the group with growout house renovation costs above 0.40 DKK per chicken. Furthermore, the average growout house renovation costs for the 88 farms are 0.162 DKK per broiler chicken which are within the range specified for the 72 per cent of the 278 farms that could implement the measure without considering growout house replacement (see table 3.4).

3.3. Cost-effect ratios of farm level interventions

As the changes in Campylobacter prevalence of implementing rodent control, feed strategy, fly screen and growout house renovation on broiler farms have been measured in the epidemiological study by Sommer and Heuer (2007) and Hald (2007), it is possible to estimate the cost-effect ratios (CE-ratio) of these intervention methods.

CE-ratio analysis refers to the evaluation of monetized costs relative to outcomes that are expressed in units other than money (Drummond et al. 1999; Levin and McEwan, 2001). This is particularly the case for non-market goods such as food safety and other physical benefits. The physical benefits related to food safety are the number of averted adverse outcomes, e.g. reduction in mortality and morbidity hazards caused by biological, chemical and/or physical agents in the food or food animal products. The cost-effect ratio (CE-ratio) is defined as the change in costs relative to the change in some non-monetised, quantitative units (ΔCosts/ΔQuantitative units). Hence, intervention measures with low CE-ratios are the most preferred.

The CE-ratios for each of the four measures are presented in table 3.13. Duration of rearing is not included in the table because the effect measure was not available from the Danish studies, while phage therapy has been excluded as the effect measure is expressed in $\log_{10}$ CFU and not in prevalence as is the case for the four intervention measures shown in table 3.13.

Table 3.13. Cost-effect ratios of four intervention measures classified by farm size

	Rodent control	Feeding strategy	Fly screen	Growout house renovation
Costs, DKK per bird				
Small	0.0250	-0.0008	0.1360	0.1300
Medium	0.0150	-0.0018	0.1290	0.2480
Large	0.0120	-0.0016	0.1280	0.0510
Average	0.0180	-0.0014	0.1310	0.1620
Prevalence				
Small	0.0640	0.1251	0.1690	0.0930
Medium	0.0580	0.1362	0.1700	0.0890
Large	0.0600	0.1292	0.1710	0.1000
Average	0.0610	0.1300	0.1700	0.0940
Cost-effect ratios				
Small	0.3870	-0.0067	0.8030	1.3870
Medium	0.2690	-0.0133	0.7580	2.7670
Large	0.1940	-0.0124	0.7500	0.5110
Average	0.2950	-0.0108	0.7710	1.7230

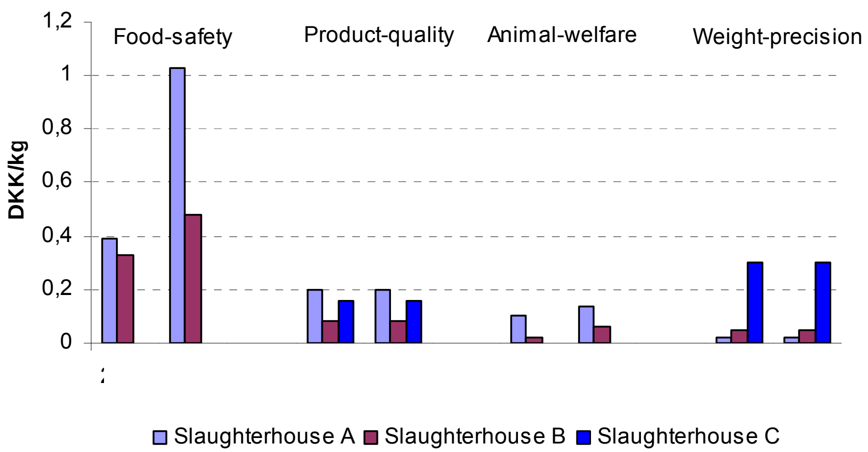
Source: Own calculations. Cost data is for the 88 farms included in the prevalence data, which is adopted from Sommer and Heuer (2007).

For all farm sizes, the intervention exhibiting the lowest cost-effect ratio is the early feeding of whole-wheat strategy followed by rodent control. Concerning interventions involving capital investments, the measure with lowest cost-effect ratio on large farms is to implement growout house renovations in comparison to the use of fly-screens. The opposite is, however, the case for small and medium broiler farms, which obtain lower CE-ratio by implementing the fly-screen intervention compared to the renovation of growout houses. In order to at least have a CE-ratio as growout house renovation, the prevalence for a one day's change in the duration of rearing should be reduced by at least 0.2864.

4. The slaughterhouse stage

In total 98 per cent of the Danish broiler production sold to consumers in 2004 were produced by three main slaughter companies with six production units. Three other small slaughter companies each with one production site and minor slaughters (butchers) account for the rest two per cent of the Danish production. Payments to the broiler farmers are to a high degree governed by contact production which includes requirements decided by the slaughterhouses (Bramsen, 2005). These requirements include e.g. the delivery weight of birds, product quality standards, the welfare of birds measured by the footpad index and food safety concerns with regards to *Salmonella* and *Campylobacter* colonization as well as the use of genetic modified grain crops (genetic modify grain are generally considered as a health hazard and hence a food safety issue in Denmark). The requirements are enforced as a form of penalties or bonuses in the basic price if the farmer doesn't comply with them. The economic magnitude of these penalties/bonuses calculated from the Danish Poultry Periodicals is shown in Figure 4.1 for 2004 and 2006.

Figure 4.1. Slaughterhouse incentive schemes



Clearly, measures to reduce the prevalence and the concentration of *Campylobacter* and other microbiological hazards and thus improve the food safety on farms play an important role in the determination of the price paid by slaughterhouses for bird input. The high penalties associated with food safety in 2006 are primarily caused by the intensified attention by slaughterhouses to focus on the control of *Campylobacter* on Danish farms. Payment penalties reduce farm income and reduce chick input cost for slaughterhouses while the opposite is the case with bonuses. An essential element in evaluating the feasibility and burden of *Campylobacter* intervention costs is the profitability generated by the slaughterhouses. As an indicator of this profitability, gross margins per bird for small, medium and large slaughterhouses are illustrated in table 4.1.

Table 4.1. Sales income, variable costs and gross margins for slaughterhouses of different size, DKK per bird

	Small	Medium	Large	All
Sales				
2004	13.27	10.26	11.41	11.65
2005	12.69	10.41	11.07	11.39
Average	12.98	10.34	11.24	11.52
Variable Costs				
2004	9.42	7.43	9.26	8.70
2005	9.20	7.67	9.21	8.69
Average	9.31	7.55	9.23	8.70
Gross margins				
2004	3.85	2.83	2.15	2.95
2005	3.49	2.74	1.86	2.70
Average	3.67	2.79	2.01	2.82

Source: Yearly annual reports – the Danish broiler industry.

Based on the figures in table 4.1, the calculated average gross margin in per cent of average sales for the two years is 28, 27 and 18 for small, medium and large slaughterhouse units, respectively. The figures for variable costs and gross margins provide an indication of the feasibility of slaughterhouses to accommodate increasing costs associated with the implementation of new control measures to combat *Campylobacter* infections.

4.1. Intervention methods at the slaughterhouse stage

In consultation with CAMPY-project partners, recommendations from an international expert consultation (Rosenquist et al., 2008) and the literature, it has been decided to investigate the costs and CE-ratios of the interventions shown in table 4.2.

Table 4.2.	Intervention measures at the slaughterhouse stage
1.	Extensive additional washing of broilers
2.	Steam-Ultrasound (physical decontamination)
3.	Trisodium phosphate decontamination (chemical decontamination)
4.	Crust freezing, cooling process (physical decontamination)
5.	Marinating
6.	Scheduling

4.1.1. Extensive washing process

Extensive washing can be defined in several ways such as: 1) repeated washing at different process stages with water; 2) washing with greater quantity of water at a single stage; 3) and hot water wash (with temperature greater or equal to 70^{o} C). Gill and Lander (2003) investigated the individual and combined effects of 1) repeated washing with water; 2) acid treatment and pasteurization; and 3) steam or hot water at four slaughter plants. Their results suggest that washing with water reduce pathogens when the prevalence is relatively high. Steam or hot water pasteurization reduces the number of bacteria effectively. However, washing birds at the temperature of 70^{o} C or more is known to deteriorate the product quality. In discussion with the industry a second washing at a new stage could be considered. When a second washing process is adopted, the additional costs per kg broiler meat are calculated to be 0.005 and 0.050 DKK for capital costs and variable costs, respectively, for large slaughterhouses. However, for small slaughterhouses the capital and variable costs are 0.041 and 0.051 DKK per kg meat. The breakdowns of the costs and the total costs per broiler chicken are shown in table 4.3.

Calculations based on the estimates in table 4.3 suggest that the total costs for extensive washing is 1.65 times higher for small plants per broiler chicken compared to large plants where total costs are about 0.12 DKK per broiler chicken. The difference in costs are primary due to the capital costs of investments, which are about 0.075 DKK per chicken higher for small plants compared to large plants. It is remarkable that capital costs for small plants account for 45 per cent of the total costs per broiler chicken compared to only 10 per cent for large slaughterhouses.

Table 4.3. Investments and costs of extensive washing for large and small slaughter plants

	Large 1000 DKK	DKK/Bird	Small 1000 DKK	DKK/Bird
Investment costs				
Equipment#	2,500.0		1,250.0	
Building	600.0		300.0	
Total Investments	**3,100.0**		**1,550.0**	
Capital costs				
Equipment	302.2	0.0101	151.1	0.0756
Building	42.6	0.0014	21.3	0.0107
Total capital costs	**344.9**	**0.0115**	**172.5**	**0.0862**
Variable costs				
Water	3,150.0	0.1050	210.0	0.1050
Electricity	2.0	6,73E-05	0.3	0.0002
Effluent /cleaning	15.6	0.0005	3.7	0.0019
Total of variable costs	**3,167.6**	**0.1056**	**214.1**	**0.1070**
Total costs	**3,512.6**	**0.1171**	**386.5**	**0.1933**

Source: Own calculations based on personal communications with the industry. #: Includes installation freight and spare parts.

4.1.2. Steam-ultrasound

The Steam ultrasound system, which is a new technology, and still under development, is a thermal treatment combining the effect of hot steam and high-frequency ultrasound to control microorganisms. Sono-steam is generated by specially designed nozzles simultaneously supplying the right dose of steam and creating the ultrasound. It is unique for very sensitive food products that don't tolerate high temperatures neither as partial nor total heat penetration.

The working mechanism of the system is such that the hot steam kills the microorganisms and the ultrasound enhances steam efficiency. The ultrasound ensures that the steam has unrestricted access to the surface and removes the protective and heat-insulating air on the surface. In this manner the heat gets into contact with the germs on the surface easier and faster and efficiently reaches the germs hidden in natural microstructures, pockets and pores. Due to the small size of the germs, they are quickly heated and destroyed. The process can therefore be completed before the heat penetrates below the surface of the product.

The steam ultrasound treatment is fast, effective and without significant heating, which results in a minimum effect on the food product being processed as well as lower consumption of energy and water (FTC, 2007). Boysen and Rosenquist (2009) in a recent Danish study reported a 2.51±0.58 log_{10} cfu reduction for treated compared to non-treated flocks. Blom (2009) in a recent poster presentation reported a 1.29 log_{10} cfu reduction for treated compared to non-treated samples of 25 broilers from a slaughter line. The total costs include capital and variable costs as shown in table 4.4. Capital costs are the leasing of the ultrasound system whereas the variable costs are use of e.g. water and energy.

Table 4.4. Costs of Steam ultrasound

	DKK/Bird	DKK/Kg
Variable costs	0.045	0.020
Capital costs	0.074	0.034
Total costs	**0.119**	**0.054**

Source: FTC (2007) where the original values were given in Euro.

The capital costs per broiler chicken account for 62 per cent of the total costs. It is notable that the new system is yet to be available for commercial purposes and until now is assumed to be financed by leasing arrangements.

4.1.3. Trisodium phosphate (TSP) rinse

Trisodium phosphate (TSP) decontamination is a rinse using a 9-10 % solution at a temperature of 25^{o}C. It involves spraying the surface of the broiler carcasses or deeping the carcasses in the solution. The Av-Guard technology uses a re-circulated solution preparation system which ensures the rinse to constantly be at 10 per cent. TSP (10 %) is reported to reduce *Campylobacter* inoculated on non-chilled chicken skin by 1.89 log_{10} cfu (Mehyar et al., 2005). Similarly, Riedel et al., (2009) in a recent Danish study suggest a 1.88±0.72 log_{10} cfu/ml reduction for 15 seconds wash. It requires capital investments and variable costs, where the variable costs beside acid solution include additional manpower, water and energy needed to heat the acid solution.

Table 4.6 shows that the total cost estimates in this study range between 0.04 and 0.08 DKK per broiler chicken for large and small plants. However, the major cost difference between the two types of plants is attributed to capital costs, which is 14.7 times greater for small plants. In the table, it is also shown that the cost estimates for large plants and those reported in a Dutch study are quite similar (Mangen, Havelaar and Poppe, 2005a). The capital and variable cost estimates per kg broiler meat produced are 0.0008 and 0.0184 DKK, respectively, for large plants. The capital and variable cost estimates for small plants are 0.0125 and 0.0230 DKK.

Table 4.5. Investments and costs for TSP decontamination for large and small slaughterhouses

	Large		Small		DUCTH#	
	1000 DKK	DKK/ Bird	1000 DKK	DKK/Bird	1000 DKK	DKK/Bird
Investment costs						
Equipment	423.9		423.9		285.0	
Installation	4.2		4.2		17.1	
Freight	4.2		4.2		2.7	
Spare parts	4.2		4.2		2.9	
Total	**436.6**		**436.6**		**307.7**	
Capital costs						
Equipment	51.2	0.001708	51.2	0.0256	34.5	0.0011
Installation	0.5	0.000017	.5	0.0003	2.1	0.0001
Freight	0.5	0.000017	.5	0.0003	.3	0.0000
Spare parts	0.5	0.000017	.5	0.0003	.3	0.0000
Total	**52.8**	**0.001760**	**52.8**	**0.0264**	**37.2**	**0.0012**
Variable costs						
Labour	90.7	0.003024	21.6	0.0108	90.7	0.0029
Water	44.5	0.001482	2.8	0.0014	44.5	0.0014
Electricity	2.1	0.000071	.3	0.0002	2.1	0.0001
Cleaning	15.8	0.000525	3.8	0.0019	15.8	0.0005
Solution	1128.6	0.037618	71.8	0.0359	1128.6	0.0359
Total	**1281.6**	**0.042720**	**100.3**	**0.0501**	**1281.6**	**0.0408**
Total costs	**1334.4**	**0.044480**	**153.1**	**0.0765**	**1318.8**	**0.0419**

Source: Own calculations based on information supplied by Danisco (2007). #Based on estimates from a Dutch study (Margan, Havelaar and Poppe, 2005a).

4.1.4. Crust freezing

Crust freezing is a system by which e.g. fillets and whole birds are quickly frozen to reduce the activity level of naturally occurring *Campylobacter* flora. Carcasses are subjected to rapid freezing to their freezing points just before chilling using nitrogen or CO_2. This allows for the formation of crusty ice on the surface. The temperature is then allowed to equilibrate as the carcasses progress through the chillers. The method was first developed to accelerate maturation processes of carcasses (Kennedy and Miller, 2004). The positive externality of the process is the reduction in thermophilic *Campylobacter* on the surface of the carcass (Kennedy and Miller, 2004). Crust freezing used 1) together with steam for 10 seconds; or 2) hot water at 80^{O}C; or 3) alone reduces *Campylobacter* by 3.17 log_{10}, 2.91 log_{10} and 1.78 log_{10} cfu, respectively (James et al., 2007). In Denmark, Boysen and Rosenquist (2009) reported an average reduction of only 0.42±0.03 log_{10} cfu for treated compared to non-treated flocks. Capital investments include purchase, installation and re-organisational costs (Industry, 2007). Representatives from the industry suggest that the investments for crust freezing are 1.5 million DKK. With a life span of 10 years and a interest rate of 3.4 per cent the total capital costs are 181,363 DKK per year. The costs of $C0_2$ energy as well as related labour activities are 0.16 and 0.84 DKK per kg meat, respectively. The cost of labour activities of 0.84 DKK per kg meat covers expenses associated with moving crates of meat to an offline CO_2 crust-freezing unit. This entails using manual labour for unloading crates for freezing in the CO_2 chamber as well as returning the crust-frozen meat to the packages unit prior to delivery. The industry representatives furthermore suggest that the price of filet is 40 DKK per kg meat and 15 DKK per kg for fresh chicken. These prices are used to calculate the variable costs for fresh meat and filet meat, respectively, which account for 75 and 25 per cent of the broiler meat output. The estimated capital and variable costs for large and small plants are shown in table 4.7.

Table 4.6. Costs for crust-freezing for large and small plants

Plant size	Large	Small
Distribution of output		
Meat fresh 75% in kg	37,800,000	2,160,000
Meat filet 25% in kg	12,600,000	720,000
Meat filet lost 1% of output in kg	126,000	7,200
Capital costs in DKK	**181,363**	**181,363**
Variable costs for crust freezing filets in DKK		
Lost sales, 1% of filets	5,040,000	288,000
Energy (CO2) for crust-freezing filets	2,016,000	115,200
Labour for various freezing activities – filets	10,584,000	604,800
Total	17,640,000	1,008,000
Variable cost for crust freezing fresh meat in DKK		
Lost sales, 1 % of fresh meat	5,670,000	324,000
Energy (CO2) for crust-freezing fresh meat	6,048,000	345,600
Labour for various freezing activities – fresh meat	31,752,000	1,814,400
Total	43,470,000	2,484,000
Costs per bird in DKK		
Capital costs	0.006	0.091
Variable costs filet	0.588	0.504
Variable costs fresh meat	1.449	1.242
Total costs	**2.043**	**1.837**

Source: Own calculations based on information from the industry, Industry (2007).

The figures in table 4.7 suggest that capital costs per broiler chicken for small plants (5 per cent of total costs) are higher compared to large plants (0.3 per cent of total costs). However, the variable costs are higher for large plants compared to small plants. It should be noted that the capital costs estimated in the Dutch study by Mangen, Havelaar and Poppe (2005a) are relatively high compared to the estimate shown in table 4.7. However, the total costs per broiler chicken are estimated to be high compared to the Dutch study, which may be equipped with an online crust-freezing unit and thus did not include the extra costs associated with an offline unit.

4.1.5. Marinating

Marinating is the process by which a brine solution composed of water, food ingredients, spices, salt and acids are used as marinade for broiler filets. Marinating is expected to inhibit bacteria, e.g. Campylobacter, in the final product for consumption. Rosenquist (2009) suggested a 1.50 $\log_{10}$ cfu/ml reduction after 3 days. Generally, the marinating involves the meat product in a mixture of marinade product for 20 minutes (India-dan, 2008). It is assumed that the facility to marinate exists. Therefore, no extra investment costs are required. However, under the assumption that the marinade is a specialised product, it is expected that the variable costs should increase. These are set to 0.125 DKK per kg. Assuming that 25 per cent of the output is used for filet production, the costs of marinating for large and small plants are shown in table 4.8.

Table 4.7. The costs of marinating filet production for large and small plants

Plant size	Large	Small
Marinated filets 25% of output in tonnes*	12,600	720
Differentiated product price per kg in DKK	0.125	0.125
Cost for 25% in 1000 DKK	1,575	90
Total costs per broiler chicken in DKK	**0.053**	**0.045**

*Marinated filet meat is estimated as 25 per cent of 72 per cent of the production capacity (72 per cent is broilers without residues).
Source: Own calculations based on information from India-dan (2008).

As shown in table 4.8, the costs of marinating are slightly higher for large plants compared to small plants.

4.1.6. Scheduling

Scheduling here refers to testing and identifying *Campylobacter* positive farms with the aim of re-scheduling slaughtering of chickens from these farms at the end of the day or to alternative production. This implies that the testing and the classification of broilers prior to slaughter needs to be conducted as close as possible to the slaughter day, which should not be later than 1-4 days before slaughter. Therefore, sorting requires changes in the existing rules for testing. Today, *Campylobacter* tests are performed 7 – 10 days prior to delivery and hence test results arrive 1 to 4 days before slaughter. It implies that infections occurring 7 – 10 days after the test are not taken into considerations today. Current practice may thus result in misplacement of birds into *Campylobacter* free and *non-Campylobacter* free groups. Besides testing costs, which is accounted for by the current practice, additional logistic costs are most important from a processing perspective if a more timely testing should be performed. For the slaughter company logistic costs include rescheduling of catching, transportation and manpower requirements as well as changes in product deliveries to customers and product portfolios produced for specific markets. The Danish broiler industry estimates these extra logistic costs to be 0.056 DKK per kg broiler meat produced.

The additional catching, transportation and manpower costs are assumed to be 0.0308 DKK per kg broiler meat which are derived as: 21 thousand tonnes *Campylobacter* infected meat divided by 13 required trucks multiplied by 40 extra km (for return) at a price of 10 DKK per km (Industry, 2007). When these costs are subtracted from the overall costs of 0.056 DKK, the costs covering internal changes in product portfolios and extra freezing capacity may be calculated residually to 0.0252 DKK per kg boiler meat (Industry, 2007). The *Campylobacter* prevalence and the costs for specific slaughter plants are provided in table 4.9.

In the table plant size is defined as the per cent of the total production that is infected with *Campylobacter*. Hence, a slaughter unit with e.g. 50,000 tons production capacity could be classified as large when 42 per cent of the production is contaminated or as small when 4 per cent of its production is contaminated with *Campylobacter*. However, a slaughter unit with a production of 4,000 tons is small.

The estimated costs for sorting seem to be heavily influenced by transport costs which accounts for about 50 per cent of the total costs. Product-portfolio changes, extra freezing and changes in delivery time all together accounts for the rest. The costs per bird are slightly higher for large slaughter units compared to the small ones.

Table 4.8. Estimated costs for scheduling at large and small plants for different levels of Campylobacter prevalence

Plant size	Large	Small
Farm output infected with Campylobacter (broiler tons)	21,000	2,000
Prevalence per cent production capacity of 230,000 tons	9	1
Prevalence per cent production capacity of 70,000 tons	30	3
Prevalence per cent production capacity of 50,000 tons	42	4
Prevalence per cent production capacity of 4,000 tons		50
Costs	DKK/Bird	DKK/Bird
Extra transportation costs #	0.068	0.065
Changes in product portfolios and extra freezing costs	0.056	0.053
Total costs	**0.124**	**0.118**

Source: Own calculations using production data and cost estimates provided by the industry (2007). #For birds weighing 2.2 kg and 2.1 kg for large and small plants, which are estimates obtained from production data.

4.2. Summary of results for the slaughter stage

The summary of the obtained cost estimates for various decontamination treatments in the slaughtering process are provided in table 4.10. The table contains estimates for large and small plants, respectively.

Table 4.9. Summary of investments and costs for large and small slaughter plants per broiler chicken in DKK

Intervention	Water extensive washing	TSP	Steam Ultrasound	Marinate	Crust -freezing	Scheduling
Large plants						
Investments (1000)	3100.0	436.6	2225.1	-	1500.0	-
Capital costs	0.0115	0.0018	0.074	-	0.006	-
Variable costs	0.1056	0.0404	0.045	0.053	2.037	0.124
Total costs	**0.1171**	**0.0421**	**0.119**	**0.053**	**2.043**	**0.124**
EURO- equivalent#	**0.0157**	**0.0054**	**0.016**	**0.007**	**0.274**	**0.017**
Small plants						
Investments (1000)	1550.0	436.6	148.3	-	1500.0	-
Capital costs	0.0862	0.0264	0.074	-	0.091	-
Variable costs	0.1070	0.0501	0.045	0.045	1.742	0.118
Total costs	**0.1933**	**0.0765**	**0.119**	**0.045**	**1.837**	**0.118**
EURO- equivalent#	**0.0260**	**0.0103**	**0.016**	**0.006**	**0.246**	**0.016**

Source: Own calculations. # 1 DKK = 0.134 EURO.

The total costs of *Campylobacter* decontamination at the slaughterhouse stage for large slaughter plants range between 0.042 DKK per broiler chicken for TSP and 2.043 DKK per broiler for crust-freezing treatments. The costs of extensive water washing, steam ultrasound and marinating treatments as well as scheduling are relatively similar to each other, i.e. between 0.10 and 0.12 DKK per broiler chicken. Apart from steam ultrasound, where 62 per cent of the total costs are capital costs, the capital costs of the intervention measures are in the range of 0.3 to 10 per cent of the total costs for large slaughter houses. In large plants variable costs of crust-freezing have been estimated to 99.7 per cent of the total costs.

For small slaughter plants, the costs range are between 0.045 DKK per broiler chicken for marinating and 1.837 DKK per broiler chicken for crust-freezing, respectively. Among the small plants the relationship between capital and variable costs is less divergent for extensive washing with water. For small plants the cost components are 45 and 55 per cent for variable and capital costs, respectively, compared to 10 and 90 per cent for large plants. These results for large and small plants suggest that the profitability of a new decontamination measure depends very much on the resulting reduction in the prevalence and in the concentration of *Campylobacter* in chicken meat sold from the slaughterhouse.

4.3. Cost-effect ratios of interventions at the slaughter plant stage

In order to provide a simple economic efficiency assessment of alternative decontamination treatments, the reductions in Campylobacter concentrations obtained from Danish research (Rosenquist, 2009; Boysen and Rosenquist, 2009; Riedel et al., 2009) and the international literature are related to the estimated total costs of the investigated intervention measures. This allows for calculating the cost-effect ratios (CE-ratio) for a first hand assessment of the intervention measures. The CE-ratio is defined as in section 3.3, i.e. as the change in costs relative to the change in some non-monetised, quantitative units (ΔCosts/ΔQuantitative units). Hence, intervention measures with low CE-ratios are the most preferred. The results for large and small plants are provided in table 4.10.

For large slaughter plants, the CE-ratio of reducing the concentration of Campylobacter is lowest for chemical treatment with TSP and highest for crust freezing. It implies that from the cost-effect ratio perspective it is preferred to use TSP rather than crust freezing for reducing the number of Campylobacter in large slaughterhouses. However, at present chemical decontamination is not allowed in the European Union. The second best choice is marinating (pH<3). The cost-effect ratios are quite low for marinating and TSP rinse compared to steam ultrasound, which however has far lower cost-effect ratio compared to crust freezing. This is even the case at the Dutch study estimated total average price of 0.318 DKK per chicken (0.0283€*7.5DKK*1.5 kg per broiler). In case there is a public reservation or legalization against using the chemical decontamination treatments, steam ultrasound should provide a promising decontamination treatment. This basically is because marinating can only be used on a proportion of the meat from broilers whereas steam ultrasound is more likely to be used on all broilers. Similar interpretations apply for small plants. However, small plants are more cost-effective with respect to marinating and the use of crust-freezing compared to large slaughter plants.

Table 4.10. Cost-effect ratios of decontamination measures for large and small slaughter plants

Intervention[1]	TSP 1minute	TSP 15 seconds	Steam[3] Ultra-sound	Steam[4] Ultra-sound	Marinate	Crust[5] -freezing	Crust[6] -freezing
Large plants							
Change in costs	0.042	0.042	0.119	0.119	0.053	2.043	2.043
Change in $\log_{10}$ CFU [2]	1.74	1.88	2.51	1.29	1.50	1.78	0.42
Cost-effect ratio	**0.024**	**0.022**	**0.047**	**0.092**	**0.035**	**1.148**	**4.86**
Small plants							
Change in costs	0.0765	0.0765	0.119	0.119	0.045	1.837	1.837
Change in $\log_{10}$ CFU [2]	1.74	1.88	2.51	1.29	1.50	1.78	0.42
Cost-effect ratio	**0.044**	**0.041**	**0.047**	**0.092**	**0.030**	**1.032**	**4.37**

[1] Reduction in campylobacter for Extensive washing and Scheduling are not available. However, the changes in costs for Extensive washing are 0.117 and 0.1933 for large and small plants respectively. Similar changes in costs for Scheduling are 0.112 and 0.118 DKK for large and small plants.
[2] Source of reduction data:
TSP (Trisodium phosphate - 10 %): Riedel et al. (2009 see also under discussion).
[3]Steam Ultrasound: Riedel et al. (2009): Earlier test data.
[4]Steam Ultrasound: Blom (2009).
Marinating: Rosenquist (2009).
[5]Crust-freezing: James et al. (2007).
[6]Crust-freezing: Riedel et al. (2009).

5. Discussion

In this report, six interventions methods at the primary stage (i.e farms) and seven interventions at the secondary production stage (i.e. slaughterhouses) for the reduction in *Campylobacter* are described and the costs and cost-effect ratios of each intervention has been estimated.

At the farm level different *Campylobacter* control measures are suitable for farms with different characteristics. Similar observations are applicable at the slaughter stage. However, the choice of *Campylobacter* control options will depend on the overall economic viability of the farms and slaughter houses.

The costs of the intervention measures at the farm stage were directly linked to individual farm data. Hence, farm specific costs could be calculated and the average costs with corresponding variability estimated. The classifications of farms according to the costs of the intervention measures show clearly the significant variability in the costs between different farm types.

In estimating the costs of the individual farm intervention measures the main adopted approaches include accounting and economic-engineering (e.g. for feed strategy, growout house renovation and fly-screen on growout houses) as well as econometric methods (e.g. for the duration of rearing). The approaches provide the possibility of generating cost estimates for calculating cost-effect ratios, which are then used for economic evaluation and the ranking of alternative intervention actions. The accounting and economic-engineering approaches are concerned only with the extra direct costs associated with ***control*** measures, while the econometric approach in addition accounts for the impacts of interaction between production costs and control measures against *Campylobacter* colonization.

Comparing the total estimated intervention costs to the costs and profits of broiler production shown previously in table 3.1, small farms may face economic problems in implementing phage therapy, growout house renovation and changing the duration of rearing. On the other hand, table 3.1 and 3.12 together indicate that it is possible for all farm groups to implement the feeding strategy, rodent control and fly-screen intervention measures while still maintaining their economic viability.

At the slaughterhouse stage the main adopted cost estimation approaches were the accounting and economic-engineering methods. The cost estimates are mainly based on information collected from the producers of the considered technologies or the potential users of the intervention measures (i.e. the small and large slaughterhouses). The obtained estimates are associated with some uncertainty. However, it is perceived that the estimated costs are within realistic intervals. This is confirmed in table 4.6 were the cost estimates of trisodium phosphate per broiler chicken is rather similar to those estimates reported in the Dutch CARMA-project (Mangen Havelaar and Poppe, 2005a).

Comparing the costs of the intervention measures at the slaughterhouse stage to the profit represented by the gross margins in table 4.1, indicates that large slaughterhouses may have problems implementing crust-freezing, whereas small and medium size slaughter plants may better accommodate the use of marinating and crust-freezing. Similarly, small and medium sized plants could simultaneously better accommodate the use of water extensive washing and steam ultrasound than do the large plants judging from the gross margins presented in table 4.1. Calculations suggest that the combined costs of water extensive washing and steam ultrasound accounts for about 6 per cent of the gross margin for small plants and about 9 per cent in the case of large plants.

The performed CE-ratio analyses focus on the relative costs of preventing colonization and contaminations, and hence food safety improvements without considering the value of such food safety improvements. Thus, a CE-ratio does not tell if the improvements are worth achieving compared to alternative uses of the resources involved. CE-ratio analysis simply shows how changes in quantitative units are related to cost changes. Cost-benefit analysis (CBA) is a more holistic decision tool for evaluating alternatives as it measures economic values on both the input side, i.e. costs, and the output side, i.e. economic benefits. Thus, by CBA it is possible to evaluate and make choices between very different alternatives for food safety improvements. This is not the case for CE-ratio analysis which is limited to comparison of intervention measures with similar units of outcome, e.g. the CE-ratio of phage therapy has not been evaluated in this report because the Campylobacter reduction related to phage therapy is measured in a different unit compared to the other analysed interventions.

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