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Costs and benefits of controlling Campylobacter in the Netherlands

Integrating risk analysis, epidemiology and economics

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Abstract

Costs and benefits of controlling Campylobacter in the Netherlands – integrating risk analysis, epidemiology and economics.

A combination of decontamination with a chemical such as lactic acid and technical measures to reduce leakage of feces during slaughtering have been shown by model calculations in a Netherlands study to be the most economic method to improve the safety of broiler meat. Campylobacter bacteria form the most common bacterial cause of foodborne infections in the Netherlands, with approximately 80,000 cases of gastroenteritis per year. Of the many different routes by which humans can be exposed to Campylobacter, the most important are the consumption of broiler meat and other raw food products, and direct contact with animals. Results above are derived from a multidisciplinary study on the costs and benefits of measures to reduce the contamination of broiler meat. Model calculations also showed additional hygienic measures to theoretically reduce the contamination on broiler farms, but it is not yet clear what exact measures should be taken. In the short term, more effect can be expected from additional measures in the processing plant to reduce the level of contamination of meat. Model calculations indicate that in the Netherlands alone, this would result in the prevention of 12,000 cases of gastrointestinal illness per year. Successful implementation of these measures will require additional studies on a practical scale. Because of unfamiliarity and additional costs, there is little support for measures among consumers and industry. Therefore active communication will be paramount.

Keywords: Campylobacter, exposure routes, prevention, broiler chicken meat, cost-utility ratio, societal support

Het rapport in het kort

Kosten en baten van Campylobacter bestrijding in Nederland – integratie van risico-analyse, epidemiologie en economie

Een combinatie van decontaminatie met een middel als melkzuur en technische maatregelen om de verspreiding van mest tijdens het slachten tegen te gaan, lijkt volgens modelberekeningen de meest economische methode om de microbiologische veiligheid van kippenvlees te verbeteren. Campylobacter-bacteriën zijn de belangrijkste bacteriële veroorzakers van voedselinfecties in Nederland, met ongeveer 80.000 gevallen van gastro-enteritis per jaar. Onder de vele verschillende routes waarlangs de mens aan Campylobacter kan worden blootgesteld nemen consumptie van kippenvlees, direct contact met dieren en rauw geconsumeerde producten een belangrijke plaats in. Genoemde resultaten zijn verkregen in een multidisciplinair onderzoek naar de kosten en baten van maatregelen om de besmetting van kippenvlees terug te dringen. Aanvullende hygiënemaatregelen op de boerderij zouden volgens modelberekeningen in theorie de besmetting bij het pluimvee sterk terug kunnen brengen, maar het is nog niet duidelijk welke maatregelen precies genomen moeten worden. Op korte termijn is meer effect te verwachten van aanvullende maatregelen op het slachthuis om de besmettingsgraad van het vlees te verminderen. Volgens modelberekeningen kunnen alleen al daardoor in Nederland ongeveer 12.000 gevallen per jaar van gastro-enteritis worden voorkomen. Om deze maatregelen succesvol te kunnen invoeren is nog wel aanvullend praktijkonderzoek nodig. Door onbekendheid met de maatregelen en de additionele kosten is het draagvlak bij de consument en ketenpartijen gering zodat actieve communicatie van groot belang is.

Trefwoorden: Campylobacter, blootstellingsroutes, preventie, kippenvlees, kosten-utiliteit, maatschappelijk draagvlak

Preface

The CARMA (**Ca**mpylobacter **R**isk **M**anagement and **A**ssessment) project, which has been performed throughout the years 2001-2004, is a collaboration between the National Institute for Public Health and the Environment (RIVM), the Animal Sciences Group-Lelystad (ASG Lelystad), the Agricultural Economics Research Institute (LEI), the Food and Consumer Product Safety Authority (VWA/KvW) and RIKILT – Institute of Food Safety. The full results of the project have been documented in a number of reports and publications. Appendix 1 contains an overview of these documents, which are also accessible through the website www.rivm.nl/carma. These reports are not further referred to in this text. There are referrals to other sources in the text. The reports and publications contain an overview of all the collaborators who have worked on the project and provide detailed background information.

This report is a summary of the most important results of the project, written for a broader audience than the underlying technical reports. It is a translation of a report originally written in Dutch (RIVM report 250911008). The report builds on the contribution of all project team members. Besides the authors of the report a contribution to the underlying technical reports was made by Elly Katsma, Egil Fisher, Mart de Jong en Fimme-Jan van der Wal (ASG Lelystad), Krijn Poppe, Peter van Horne, Hans-Peter Folbert, Sandra van der Kroon, Marjolijn Smit and Hubert Sengers (LEI, The Hague), Roger Cooke and Louis Goossens (Delft University of Technology), Rinske van Koningsveld (Erasmus Medical Centre, Rotterdam), Rob Bernsen (Jeroen Bosch Hospital, ′s Hertogenbosch), Trudy Wassenaar (Molecular Microbiology and Genomics Consultants, Zotzenheim, Germany), Hans van de Kerkhof (GGD Zuid Holland Zuid, Dordrecht), Wilfrid van Pelt, Sido Mylius, Ine van der Fels-Klerx, Peter Teunis, Ardine de Wit and Winette van den Brandhof (National Institute for Public Health and the Environment, Bilthoven). Harry Verkleij (RIVM) contributed to the editing of this summary report. The authors are grateful to Noël Peters (RIVM) who translated the original Dutch report into English.

Ton van Gaasbeek (LEI) was strongly involved with the organization of this project. Regrettably, Ton has passed away shortly afterwards.

Appendix 2 gives an overview of the members of the Project Steering Committee and the Industry Forum. Besides this many experts from the field were consulted. Their contribution is accounted for in the technical reports.

In Appendix 3 definitions are given of a number of concepts used in this report and the abbreviations are further explained.

Contents

Summary

Campylobacter-bacteria are an important cause of food borne infections. There are approximately 80,000 cases of gastro-enteritis in the Netherlands per year, but also more serious syndromes and about 30 deaths. There are many different exposure routes. One important exposure route is consumption of chicken meat (20-40% of all cases of illness or 16,000-32,000 cases of gastro-enteritis). Other important exposure routes are direct contact with animals and food products that are consumed raw. In the CARMA project an estimate has been made of the possible costs and benefits of a large number of possible interventions to decrease human exposure to Campylobacter by consumption of chicken meat. The costs of intervention have been calculated in euro, the benefits in the decrease of disability adjusted life years (DALYs) and of cost of illness in euro. The focus was on interventions at broiler farms and in the processing plant. Attention was also paid to consumer information. Epidemiological, microbiological and economic knowledge as well as mathematical risk assessment models were used for the calculations.

A few potential interventions are interesting, considering their (theoretical) effectiveness and efficiency**.** Not a single evaluated intervention can be introduced directly or without any further conditions. There is intensive import and export of both live animals and chicken meat. It is not clear what the exact origin of chicken meat consumed in the Netherlands is. Both from a public health perspective and for the competitiveness of the Dutch broiler industry, it is advisable to implement measures at the European level, while taking import from third countries into account.

Reduction of contamination at broiler farms could be efficient in theory. However it is unclear which hygienic measures need to be taken, because the exposure routes on the farm are still unclear. The costs of hygienic measures can be very high. It is recommended that the hygiene at the broiler farm is gradually improved, starting with the implementation on all farms of existing hygiene standards and promoting their consistent use. The treatment of infected broiler flocks with bacteriophages has experimentally proven to be effective and could also be cost-efficient, if the effectiveness is confirmed in practice**.**

Since a major decrease of infections at the broiler farm is not expected in the short term, additional measures in the processing plant will also prove necessary. A complete ban on selling meat (as fresh product) from contaminated flocks would lead to a shortage of fresh meat in the summer period and large economic losses for industry. At this moment, guaranteed Campylobacter-free chicken meat at the retail level is not achievable. Irradiation of all the produced meat would be too expensive. The most promising interventions in the processing plant are: limiting fecal leakage during scalding and defeathering, and the separation of contaminated and non-contaminated flocks (scheduling), followed by decontamination of the contaminated flock using a product such as lactic acid. New (faster and more sensitive) test methods to detect Campylobacter infection in broilers flocks are a prerequisite for successful scheduling scenarios. Methods are being developed, but a validated test is not directly available. In addition there are questions concerning the efficiency of decontamination methods in practice and about the effect on the appearance of the products which may make them (more) difficult to sell. Other methods to decrease the contamination of meat of infected flocks such as crust-freezing and heat treatment are more expensive and/or less effective than decontamination.

There is little support for additional measures to control Campylobacter in the Dutch society. Chain partners hold each other responsible. Poultry farmers and processing plants are not convinced of the favorable effects of additional measures and fear increased costs and sales problems. A majority of consumers does not worry about contamination of chicken meat with Campylobacter. They have not yet defined their position with respect to the proposed

measures due to a lack of information. There seems to be growing acceptance of irradiation. Good communication with all stakeholders is paramount during policy making as well as the introduction of measures.

1. Introduction

Reducing food borne infections and –intoxications is one of the spearheads of national and international public health policy. The attention is mainly focused on Salmonella and Campylobacter in food of animal origin. In the Netherlands, despite political attention and efforts from the industry, the contamination of poultry meat with Campylobacter remained at a high level at the start of the project in 2001 and also the incidence of human illness had not substantially change in the preceding five years. This in contrast to Salmonella, where there is a decreasing trend of contamination of poultry meat. Also the incidence of human salmonellosis (as a consequence of contaminated poultry meat and other sources) is continuously decreasing [17].

- In 1995 the former State Secretary of the Ministry of Public Health, Welfare and Sports (VWS) announced the intention to take measures that in 5 years would lead to a reduction of 50% of the incidence of human gastro-enteritis as a consequence of contaminated food from animal origin.
- This policy plan has led in 1997 to a "Plan of Approach Salmonella and Campylobacter in the Poultry Industry" formulated by the Commodity Board for Meat, Poultry and Eggs (PVE). Trade and industry accepted an obligation to reduce the level of contamination of Salmonella and Campylobacter in chicken meat directly after processing/cutting to less than 15% on 1 November 1999 at the latest.
- In 2000 it was established that this goal was not achieved. Also on the account of the advice "Food borne infections" of the Health Council, the Ministry of Public Health, Welfare and Sports (VWS) as well as the Ministry of Agriculture, Nature and Food Quality (LNV) have announced further measures.
- On 1 August 2001 a temporary measure was registered in the "Warenwetbesluit Bereiding en Behandeling van Levensmiddelen". This measure obligates trade and industry to accommodate fresh poultry meat which is delivered to consumers with a label that warns against pathogenic bacteria.
- In 2001 the PVE published an "Action plan Salmonella and Campylobacter 2000+" in which the sector states how the agreed goals can still be achieved. In contradiction to Salmonella no goals were published for Campylobacter. The main reason for this was an insufficient apprehension of the possibilities of reducing Campylobacter contamination in the primary sector. For this reason further investigations were recommended, also in the possibilities of controlling contamination further in the chain. These research questions were also the motivation for the CARMA (**C**ampylobacter **R**isk **M**anagement and **A**ssessment) project.
- At this moment the Dutch government is considering a prohibition of Salmonella and Campylobacter on fresh poultry meat upon delivery to the consumer. This prohibition which should be of effect in 2007 should concern both imported and domestically produced meat [1]. Because the presence of bacteria is not totally avoidable on fresh meat, a "presence on a low level (zero+)" is considered. Notification of this intention to the European Committee will be made before the end of the year 2006.

The goal of the CARMA project is to advise the Dutch government about the effectiveness and efficiency of measures aimed at reducing campylobacteriosis in the Dutch population. To this aim, two key questions are being investigated:

- Which are the most important routes by which the Dutch population is exposed to Campylobacter, and can the contribution of these routes be quantified?
- Which measures can be taken to reduce the exposure to Campylobacter, what is their expected effectiveness, efficiency, and societal support?

Campylobacter infections lead to a substantial loss of health and costs of illness among the Dutch population each year.

- It is estimated that in the Netherlands (population 16 million), there are 350,000-750,000 cases of foodborne infections by known pathogens each year. Four pathogens are responsible for approximately half of these cases: *Campylobacter* spp., *Salmonella* spp., *Clostridium perfringens* and noroviruses [17].
- Based on a large-scale population-based study in 1999 (Sensor [7]) it is estimated that each year 80,000 cases of Campylobacter infections result in 18,000 patients visiting there family doctor [6]. It is estimated that more than 600 hospitalizations occur and 30, mainly elderly, patients die.
- Besides gastro-enteritis Campylobacter infections often lead to more serious syndromes. It is estimated that there are 60 cases of the Guillain-Barré syndrome (GBS, a serious paralysis), that are caused by the immune response against Campylobacter each year. This immune response also induces about 1,400 cases of arthritis (reactive arthritis). There are indications that Campylobacter infections can lead to inflammatory bowel disease (IBD) with an estimated 10 patients per year.
- Most cases of illness are reported in the summer period and among children less than 5 years of age just like among young adults (18-29 years). There is no difference in incidence of the illness between men and women. The incidence is lower in large cities than in the country side and in medium-sized cities.
- Based on laboratory surveillance it is concluded that within the past eight years a decrease of incidence of campylobacteriosis has occurred with about 30% [18]. Also in surrounding countries such as the United Kingdom and Denmark, for a number of years a decrease of incidence of campylobacteriosis has been noticed. In some countries (Belgium, Spain, France) [5] an increase has been reported, but that can also be caused by better diagnostics. There are fluctuations per year, such as in 2003 when there were substantially less cases of illness than expected based on the average trend. This could be related to the avian influenza crisis whereby consumption of chicken meat was temporarily lower [19].
- The disease burden from Campylobacter infections is estimated at about 1,200 Disability Adjusted Life Years (DALYs) per year, and is comparable with that of tuberculosis and bacterial meningitis, see Table 1. The most important contributions to the disease burden are deaths caused by gastro-enteritis and loss of quality of life as a result of gastro-enteritis and the residual symptoms of GBS.
- Costs of illness because of campylobacteriosis are estimated at about 21 million euro per year, of which three-quarters as a result of sickness leave due to gastro-enteritis.

Table 1. Disease burden of campylobacteriosis in comparison with other (infectious) diseases.

Amount of lost DALYs per year	Infectious diseases	Non-infectious diseases
> 100,000		Cardiovascular disease, Cancer, Depression, Diabetes, Alcohol dependancy
30,000-100,000	Pneumonia and acute bronchi(oli)tis	Traffic accidents Breast cancer Suicide
10,000-30,000	Influenza	Epilepsy Multiple sclerosis
3,000-10,000	HIV/AIDS Upper respiratory tract infections Stomach ulcers	Ulcers of the stomach and duodenum
1,000-3,000	**CAMPYLOBACTERIOSIS** Bacterial meningitis Bacterial SOA Tuberculosis	Hip fractures
< 1,000	Shiga-toxin producing *Escherichia coli* O157	

Source: RIVM

2. Exposure routes

The reservoirs of Campylobacter can be found in the animal world,(farm and domestic animals as well as animals living in the wild) and in the environment (water). There are many different routes by which humans can be exposed to Campylobacter. Which routes are most important in the Netherlands, was investigated with the help of epidemiological studies and exposure assessment. The most important routes are food (particularly chicken meat and food products that are consumed raw) and direct contact with animals. Also foreign travel is a risk factor. The exact contribution of different exposure routes is difficult to quantify. In the Netherlands drinking water plays a minor role, in contrast to what is found in some international studies.

- Two methods were used to estimate the fraction of cases attributable to consumption of chicken meat. One method was based on epidemiology (a case-control study), the second method was based on risk modeling (comparative exposure assessment). The results of these two methods were partly in agreement but there were also differences.
- In a large-scale case-control study (CaSa [8]) the following factors were associated with a higher risk of campylobacteriosis: consumption of chicken meat, not well-done meat and meat prepared on the barbecue or grill or microwave oven, eating food in a restaurant, having young dogs and cats, consumption of raw shellfish, professional contact with raw meat and contact with persons with symptoms of gastro-enteritis. People who used antacids were more often ill than others.
- Also foreign travel was associated with an increased risk, but this finding might be biased by the way patients are selected. Doctors have a tendency to submit a fecal sample for diagnosis more quickly if a patient has recently been abroad.
- Diverse protective factors were also found, although the interpretation of these factors is questionable. Consumption of various foods (meat pastries (for example croquette, sausage roll), fish, hardboiled eggs, dairy products (other than milk and cheese), salad, fruits with peel, chocolate and nuts); contact with feces of animals and visiting other households with pets was associated with a reduced probability of campylobacteriosis. To what extent these factors are really protective is unclear. They can also be related to other habits and lifestyle factors, such as little dietary variation.
- The exposure of the Dutch population via different routes was calculated based on the occurrence of Campylobacter in diverse (food) sources and on the degree to which the population gets in contact with contaminated sources. Because of the fact that much necessary information is missing, or very limited, there is major uncertainty in these calculations. Nevertheless it can be concluded that particularly direct contact with infected animals and consumption of unheated food (such as vegetables and fruits, raw fish, and non-pasteurized milk) are important exposure routes.

The calculated incidence of cases of illness caused by Campylobacter based on exposure- and dose-response models is much higher than the incidence measured in epidemiological studies. These differences can not yet be explained. The epidemiological information is assumed to be more reliable and is in this study used as the basis of the calculations of the disease burden and costs of illness.

- Although there are uncertainties in both the risk assessment and the epidemiological assessments, the detected differences are substantial enough that they can be considered of essential importance and require further study.
- Different explanations are possible for the overestimation of the risk models: differences between Campylobacter strains**,** differences in exposed populations,

effects of the matrix in which the bacteria occur, clustering of the exposure or partial protection of the exposed population by immunity.

- The dose-response relation may overestimate the risk of infection because there is a large difference between Campylobacter-strains regarding infectiveness and pathogenicity. It has been assumed that there is one dose-response relation that is valid for all Campylobacter strains. The information used for the dose-response model may represent the effect of highly virulent Campylobacter strains. Despite the availability of a large number of typing methods it is still not possible to group Campylobacter strains based on their virulence. This is caused by the fact that it is not yet clear how Campylobacter causes illness, and also because of the instability of the genome of Campylobacter, with the result of a large genetic diversity.
- Exposure and infection can lead to an immune response**,** which can lead to a temporary protection against re-infection and/or disease. Preliminary modeling has shown that the calculated incidence becomes much lower when such protection is taken into account. It has also been shown that the results of case-control studies are strongly disturbed as a result of immunity. The effect of immunity predominantly play a part among populations who are relatively frequently exposed to Campylobacter, for example through professional contact. But also for the general population immunity would result in a certain degree of protection. On the other hand the differences between Campylobacter strains can be a reason that immunological protection is only partial.
- A better understanding of the dynamic interaction between bacteria and their hosts is necessary for better risk assessments and to better interpret the results of epidemiological studies.

Contaminated chicken meat is an important source of human exposure in the Netherlands. It is estimated that at least 20% (with a maximum of 40%) of all cases of campylobacteriosis is directly or indirectly caused by contaminated chicken meat.

- In the CaSa case-control study 16% of the cases of illness are attributed to recent foreign travel.
- Of the indigenous infections (84% of the total) 23% was attributed to consumption of chicken meat. This corresponds to 19% of all cases of campylobacteriosis. This estimation is probably too low, because the contribution of foreign travel is overestimated.
- Hence, of all cases of illness caused by Campylobacter in the Netherlands at least 20% is attributable to consumption of contaminated chicken meat. So at least 16,000 cases of gastro-enteritis per year, 12 cases of GBS, 280 cases of reactive arthritis and 2 cases of IBD. The corresponding disease burden is at least 240 DALYs per year and the costs of illness are at least 4.2 million euro per year.
- The upper limit of all cases of campylobacteriosis caused by contaminated chicken meat is derived from a Belgian study [20]. During the dioxin crisis of 1999 sales of chicken meat were prohibited during a period of four weeks. In this period the incidence of campylobacteriosis was 40% lower than expected based on previous years, to then return to the normal level. This percentage is considered as the upper limit of the fraction caused by chicken meat in the Netherlands. The incidence of illness, disease burden and costs of illness can therefore be twice as high as mentioned above.

3. Research methods

In consultation with representatives of the Ministries of VWS and LNV, of the VWA and of the industry a number of interventions in the chicken meat chain were studied that could possibly lead to a reduction of the health risk of the consumer. With the help of mathematical and economical models the possible costs and benefits were estimated. Attention was also paid to the societal support for these measures among consumers and the industry. This information aims to support the political decision – making process (see Figure 1).

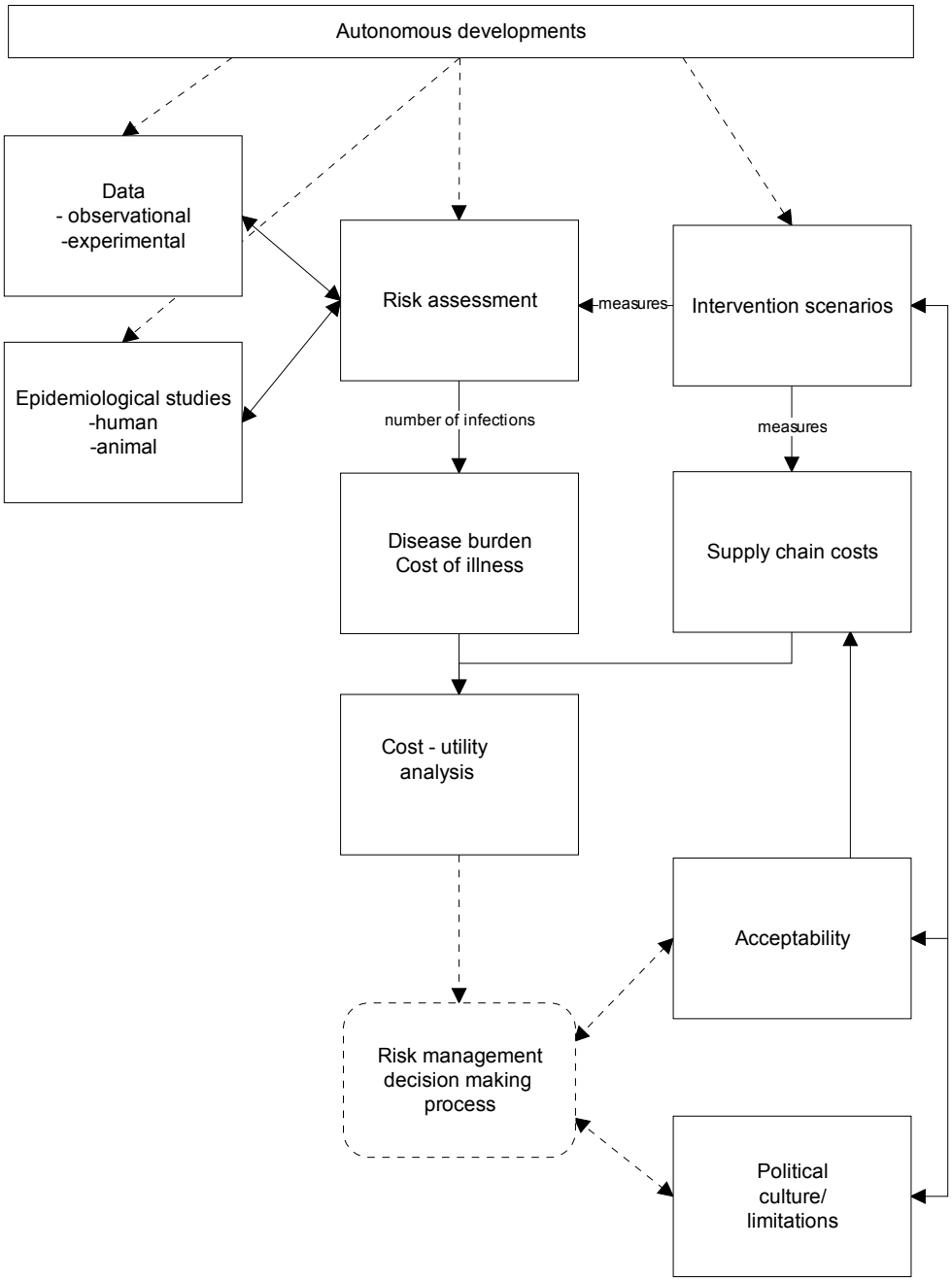

Figure 1. Design of the CARMA project.

The mathematical model for risk assessments consists of several modules: farm, processing plant, consumption and disease.

- The chosen interventions are directed against contamination with Campylobacter in different stages of the chicken meat chain, see Figure 2. These correspond with the modules in the mathematical model.
- The farm module describes the rate at which an infection spreads in a broiler house, the relationship between the probability of infection of the animals with Campylobacter and the number of houses at a farm, and in how far there is a relationship between infections of chicks in consecutive production cycles.
- The processing plant module describes the changes of the number of campylobacters on a carcass of chickens as a result of spreading of contamination through the processing environment. The model differentiates the following phases: scalding, defeathering, evisceration, washing, cooling and cutting. The calculations focus on the contamination of fillet of chicken, because this product is consumed often in the Netherlands and handled in the kitchen in such a way that cross-contamination to salads and the like can take place.
- The distribution module describes the die-off of Campylobacter during transport and storage in retail.
- The preparation module concerns exclusively the cross-contamination between a chicken breast and a salad consumed at the same meal. This route is considered representative for a large part of the chicken meat related contaminations.
- The consumption module describes the exposure of the consumer to Campylobacter by cross-contamination of salads taking consumption information into account. It is assumed that exposure from undercooked chicken meat is less important than exposure by cross-contamination.
- The disease module predicts the number of cases of illness as a result of consuming cross-contaminated salads based on a dose-response relation.
- The model accounts first for the situation in the Netherlands in the year 2000. This year was chosen at the start of the project as base year for the calculations because the information of that year is considered representative for the situation in the Netherlands. In 2000 there was no interference in the market caused by food crises or outbreaks of contagious animal diseases.
- Subsequently, the model is used to estimate the expected results of each of the chosen interventions, by changing the values of relevant parameters in the model.
- The relation between the numbers of predicted cases of illness in an intervention scenario compared to that of the baseline scenario is a measure for the effectiveness of the intervention. This refers to consumers of chicken meat produced from broilers held in the Netherlands. It is assumed that effects calculated for the contamination route chicken breast fillet → salad can be extrapolated to all cases of illness associated with consumption of chicken meat.
- Based on the predicted reduction of disease-incidence also the reduction of disease burden (averted DALYs) and costs of illness are being calculated. These values are later compared to the costs of the implementation of an intervention. To calculate the costs of an intervention investments were, as usual in economic studies, discounted using a rate of 4%. Because of comparability also the disease burden and costs of illness were discounted at the same rate, leading to respectively 170 DALYs and 3.9 million euro per year as a result of consumption of chicken meat. Discounting the disease burden reflects that people in general value their current health state higher than a similar health state in future because there is uncertainty about future possibilities to cure diseases (better).

- The cost-utility of an intervention is being calculated as the ratio between net costs of an intervention (i.e. the costs of implementation reduced with the averted costs of illness) and the averted disease burden in DALYs.
- The results of these calculations have been summarized in Table 3 (see page 38) and are explained in the following text. For many calculations information was lacking, so they had to be based on estimates of experts and of the researchers. Because of this, sensitivity analyses have been performed. For the most important uncertainties, besides the most likely value also an optimistic and pessimistic estimate is given and the effects are being analyzed. The results of the calculations in the text are generally the result of the most likely estimates. Besides that the most important results of the sensitivity analyses are being explained.

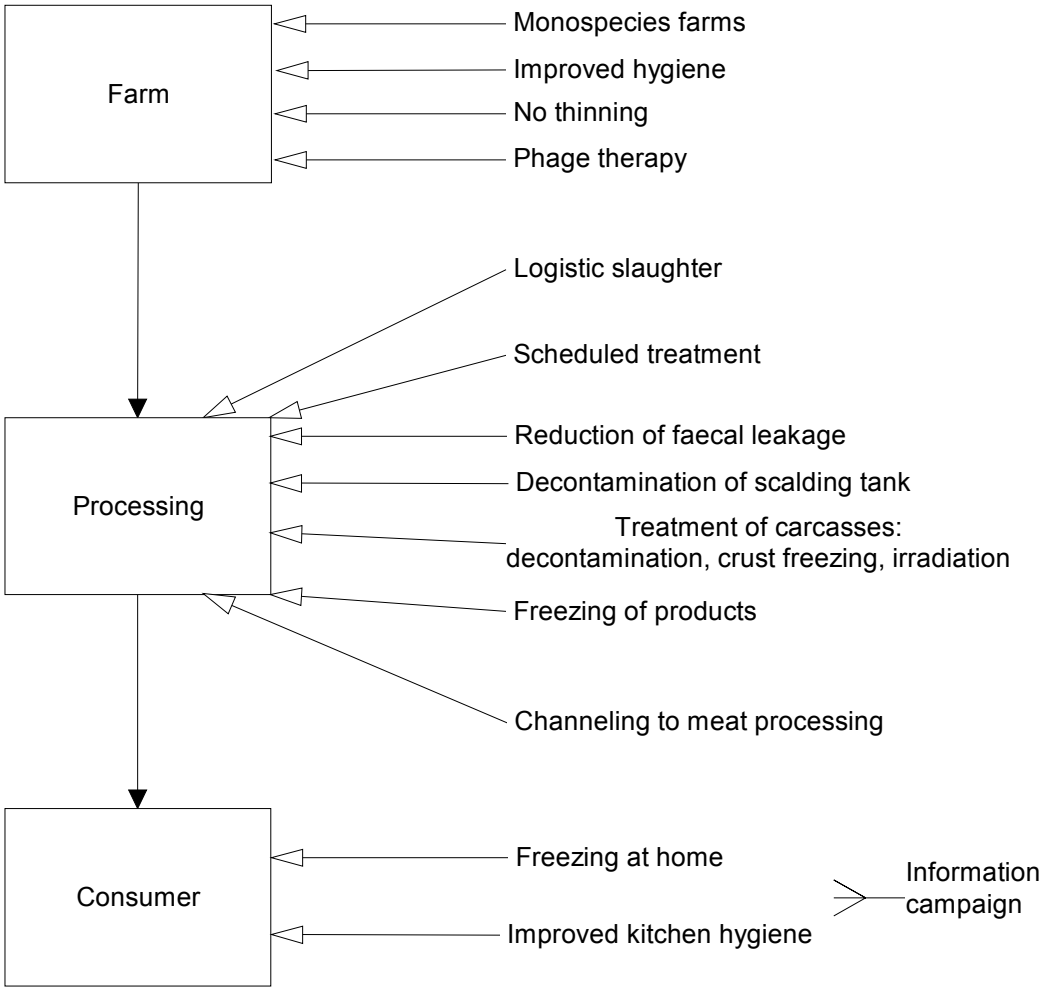

Figure 2. Evaluated interventions in the broiler chicken meat chain.

4. The significance of import and export

Only a part of the consumed chicken meat in the Netherlands originates from domestically held and processed broilers. This means that measures on the farm or in the processing plant have less effect on Dutch public health if they are not also taken in exporting countries. A large part of the chicken meat produced in the Netherlands is being exported. Measures in the Netherlands may also lead to fewer cases of illness in other countries. It turns out to be not possible to get a quantitative insight in the trade volumes concerned, especially to what extent imported meat is also exported again. This leads to uncertainty about the consequences of measures. Also the comparison of costs and benefits of measures becomes more difficult.

- According to information from the Commodity Board for Poultry and Eggs (PVE) in the base year (2000) 617,000 tons of broilers (converted to processing weight) were produced. Of that 9,000 tons was exported as living animals but also 68,000 tons of living animals were imported. So net 676,000 tons was processed, of which 90% from animals held in the Netherlands, (See Figure 3).
- In 2000 577,000 tons of chicken meat was exported, but also 157 tons was imported. So in the Netherlands 256,000 tons of chicken meat was consumed. It is unclear which part of the imported chicken meat is also exported again (the transit factor), and therefore does not end on the Dutch market. There is also crossing-border transport within one company, e.g. broilers that were held just over the Dutch border are processed and sold in the Netherlands.
- If we assume that all fresh imported meat (40%) also ends up on the Dutch market, than 68% of the in the Netherlands consumed meat originates from domestically held and processed broilers. 7% of consumed meat originates from animals held abroad but processed in the Netherlands. Measures on Dutch farms have no effect on the contamination of this meat, but measures in Dutch processing plants do have an effect. 25% of consumed meat originates from animals held and processed outside of the Netherlands. Measures in Dutch processing plants have no effect on the contamination of this meat. Measures that are focused on the consumer have an effect on all meat, regardless of origin.
- The maximum achievable effect of interventions on Dutch farms is 68% of all 16,000 cases of gastro-enteritis caused by consumption of chicken meat, i.e. about 11,000 cases.
- With measures in Dutch processing plants a maximum of 75% or 12,000 cases of gastro-enteritis can be prevented. The remaining cases can only be prevented if measures adopted in the Netherlands also apply for the producers of imported meat or by measures focused on the consumer.
- Measures on Dutch farms and in processing plants are not only favorable for the Dutch consumer but also for foreign consumers of meat produced in the Netherlands. If all consumers of chicken meat produced in the Netherlands are considered, than the cost-utility of the measures taken in the Netherlands is more favorable.

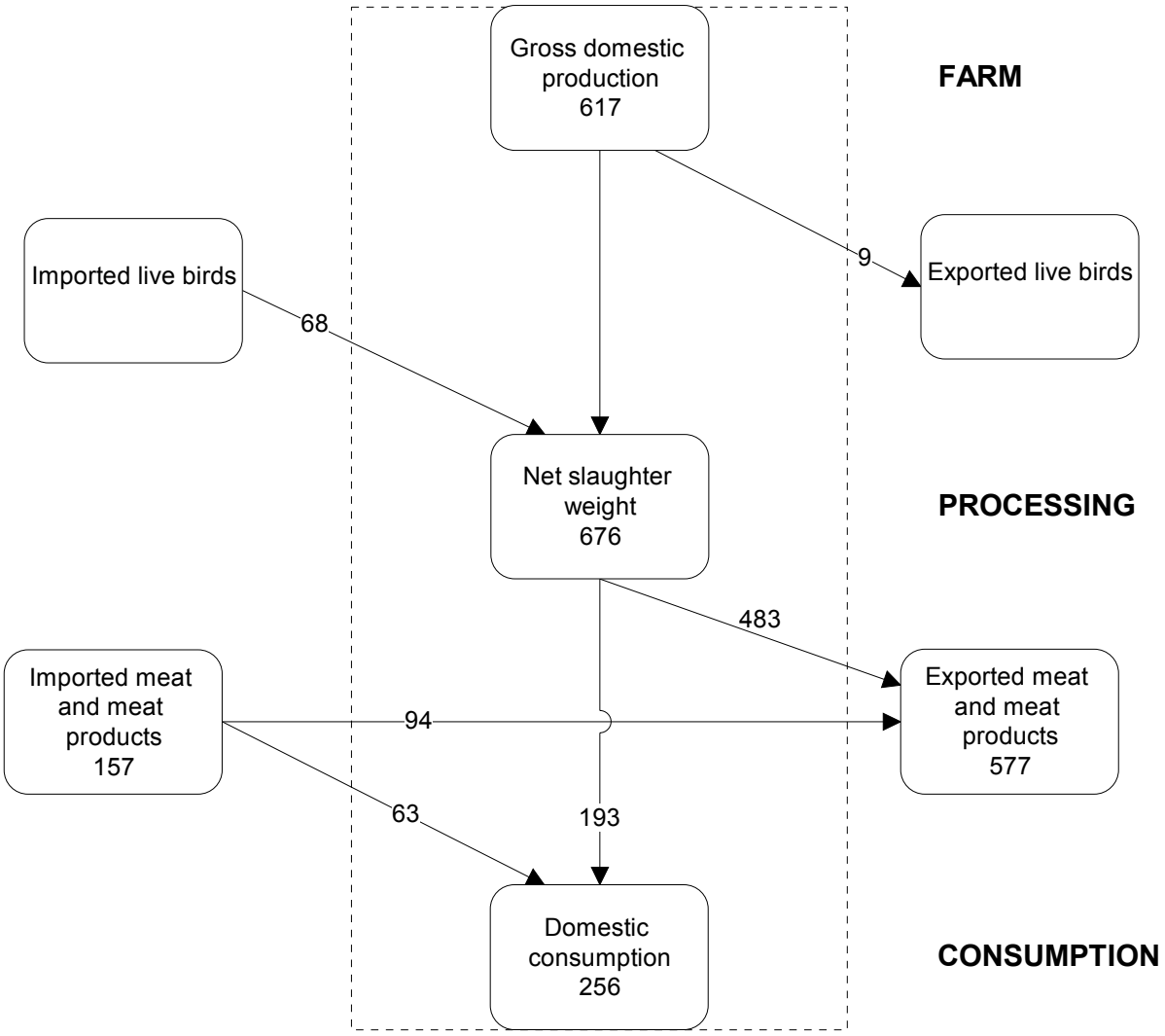

Figure 3. Import and export of broiler- and chicken meat in the Netherlands in the year 2000.

Source: PVE. All data in 1000 tons (live) processed weight. It is assumed that 40% of the imported chicken meat (the fresh part) ends up on the Dutch market.

5. Interventions on the farm and during transport

Broilers are contaminated by Campylobacter on the farm. It is still unclear which factors precisely play a role. It is clear however that it takes strict hygiene measures to keep the risk of contamination as small as possible, but that strict even application of known hygiene measures cannot guarantee the production of Campylobacter-free broiler flocks.

- According to information of the PVE in the Netherlands, in the base year 2000, upon delivery at the processing plant, an average of 36% of the processed flocks of broilers was infected with Campylobacter. Among these flocks the prevalence of contaminated animals is nearly always larger than 90%. There is a number of flocks in which contamination is introduced shortly before delivery at the processing plant and in which less than 10% of the animals are infected. These flocks usually don't show a positive result during bacteriological monitoring. According to predictions of mathematical models this concerned 8% of the flocks in 2000. Totally 44% of the flocks were contaminated with Campylobacter. During the summer months the measured percentage of infected flocks may increase to over 60%. The measured percentage of infected flocks slowly decreased over the years from 36% in 2000 to 29% in 2003 [16].
- In an epidemiological study [2] it was shown that contamination of broiler flocks increased with the age of the animals, with the number of houses on a farm, the presence of other animals on the farm or direct surroundings and the access of children to houses when no specific clothing was worn. There was strong seasonal variation with peak prevalence in summer. The causes for this seasonal variation have not yet been elucidated.
- Modeling of data from infection experiments of experimental broiler flocks showed that only after more than a week after introduction of contamination the prevalence increases to such a level that this is detectable. After about two weeks nearly all animals are infected. The animals stay infected until the processing age (approximately 42 days).
- Modeling of data from intensive monitoring of ten broiler farms showed that the more houses there are on the farm, the larger the probability of infection with Campylobacter is. The infection of a flock is also higher when the previous flock was infected as well. This statistical association does not necessarily point to survival of Campylobacters in the broiler house between two cycles. There can also be other causes such as the overall level of farm hygiene and pressure of infection.

There are possibilities to reduce infection on the farm. In the CARMA project the following possibilities have been studied: discontinue thinning, discontinue keeping several species of farm animals on one farm (so-called mono-species farms), improved hygiene and phage therapy, see Figure 4 and Table 3. The first two possibilities do not contribute – with constant production – to reducing the risk for the consumer. Improved hygiene is potentially a very effective measure, but it is as yet unclear which measures are achievable and effective in practice. Therefore is it not easy to assess the costs. Phage therapy is an experimental method which could lead to a significant reduction of risk for the consumer at relatively low costs.

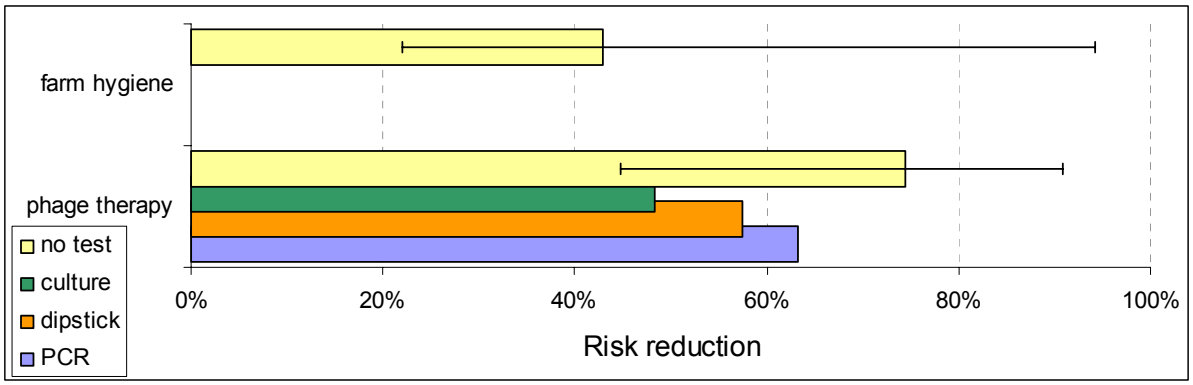

Figure 4. Risk reduction for the consumer through interventions on the farm.

The bars show the predicted reduction of the number of cases of illness as a result of intervention as percentage of the incidence in the baseline model. This reduction concerns Dutch consumers of broiler meat originating from the Dutch production chain. The error bars show the results of sensitivity analyses. These sensitivity analyses are only performed for the interventions without scheduled treatment (no test). The effects of discontinuing thinning and of mono-species farms are negligible and therefore not portrayed.

To calculate the costs of interventions on the farm a base model of the economic situation in the broiler industry in the Netherlands has been created.

- In the year 2000 there were about 1,100 broiler farms in the Netherlands with an average occupation of 58,000 animals. Totally 420 million animals (840 million kilo live weight) were produced. On average there were 2.2 houses per farm. A round lasts about six weeks, followed by a week of vacancy, so there are about seven rounds per year. Because of the avian influenza crisis and the bad economical situation (international competition, manure legislation) the poultry stock and the number of poultry farms have decreased in the last few years.
- The estimated average labor income of a broiler farm over the years 1993-2003 was 11,400 euro per farm per year. The average income of labor of all Dutch broiler farms was about 11.5 million euro per year. There are significant differences between the years, of a negative labor income of 31 million euro to a positive labor income of 47 million euro. These differences are connected to fluctuations in the farm-to-gate price that the farmer receives upon delivery to the processing plant.

The THINNING of a broiler flock is associated with a clearly larger probability of contamination of the remaining animals with Campylobacter. There is a significantly higher percentage contaminated slaughter flocks after thinning. But it is unclear if this effect can be explained adequately from the higher age of the animals or if it is a matter of additional risk as a consequence of thinning. Even if during thinning a contamination would always be introduced, the risk for the consumer is negligible according to model predictions because in the relatively short time interval between partial and full depopulation only a small proportion of animals will be infected.

- Poultry farmers in the Netherlands use an all-in all-out system. This means that all houses are populated at the same moment by day-old chicks while all birds are also simultaneously transported to the processing plant. This transport however can be spread over several points of time, so that one house flock leads to several processing flocks. There are different reasons for this practice. First of all, the market asks for animals of different slaughter weights. Secondly, the density of broilers in a house may become too large.
- In the base year 2000 in about 40% of the cases a house flock was being transported to the processing plant as a whole. In the other cases this process took place in two or more phases. During thinning an average of 22% of the house flock was transported to the processing plant, about one week after followed by depopulation of the remaining animals.
- During thinning many people and materials access a house. Because of this there is an increased risk of contamination of the house with Campylobacter (Molecular)-microbiological research has shown [9, Viv Allen, University of Bristol, UK; pers. comm.] that after thinning, more often a contamination with new Campylobacter types can be found, that are sometimes also found on material that was brought into the house such as crates and boots.
- In epidemiological studies contradictory results are found in relation to the risk of thinning. Usually a significantly increased risk is found, but sometimes this increased risk can be totally attributed to the aging of the animals, and there is no independent contribution of thinning.
- According to the mathematical transmission model it takes about two weeks before infection of a few broilers in a flock has spread to the majority of the animals. Even if it is assumed that during thinning a contamination in the house is always introduced (the most unfavorable scenario), than after a week only a small percentage of the animals (approximately 1%) from these houses is infected with Campylobacter. The associated risk for the consumer is negligible. Furthermore, if production remains constant, the number of broiler houses will have to increase. If these are built on the same premises, then the risk of infection per flock also increases.
- Given the – even in the most unfavorable scenario– minor contribution of thinning to the health risk of the consumer, to discontinue thinning is not an efficient measure.

Having SEVERAL TYPES OF FARM ANIMALS on one farm appears in epidemiological studies to be associated with an increased risk of Campylobacter infection of broilers. However the farm model proves that discontinuing mixed farms and changing to monospecies farms does not, at a constant production, contribute to the reduction of the prevalence of contaminated flocks.

- With several types of farm animals on one farm the risk of Campylobacter contamination of the broilers is 1.8 times higher than on farms with only broilers [3]. Mixed farms usually have 1 or 2 houses with broilers.

- In a hypothetical cross-over scenario farms with other farm animals would stop keeping 1 or 2 (on average 1.6) houses with broilers and specialized broiler farms would take over this production.
- As a result of this cross-over the production of broiler chickens remains about the same. The number of farms with broilers would decrease from approximately 1,100 to approximately 800, but the average size of the farms involved increases from 1.6 to 3.6 houses per farm.
- The risk of a flock being infected with Campylobacter increases when there are more houses on a farm. Because of the increase of the average farm size the cross-over scenario leads not to a decrease of the expected prevalence of Campylobacter contaminated flocks, but to a slight increase instead.

Further improving the HYGIENE on a farm is seen as an important measure to reduce Campylobacter infection in broiler flocks. However it is still unclear in which way a broiler flock becomes infected. So it is not yet clear which measures need to be taken exactly and which effects these measures will have. Hygiene measures can be very effective if they result in a considerable reduction of the influx of Campylobacter. Which percentage is feasible in practice, is unknown. The costs are difficult to estimate but can vary between 8 and 63 million euro per year.

- The effect of hygiene measures on the influx of Campylobacter in a house is unclear. Therefore a sensitivity analyses is chosen. In theory it is calculated what the effect of an intervention could be, though in practice this is still unknown. A decrease of the probability of influx is assumed (both between rounds as between houses) with 5, 10 and 25%. It is striking that a reduction of the influx with 25% seems sufficient to almost completely resolve the infection because of non-linear feedback mechanisms. A smaller reduction of the probability of contamination with 5 or 10% reduces the calculated prevalence of highly contaminated flocks from approximately 25% to approximately 19 respectively 14%.
- As a result of the predicted lower prevalence of contaminated flocks the risk for the consumer of chicken meat produced in the Netherlands decreases with 22-94% (if the influx decreases with 5-25%). Taking the import in consideration it results in a reduction of 2,300-10,000 cases of illness in the Netherlands.
- The costs of extra hygiene measures are difficult to estimate. For the control of *Salmonella* Java (which 2-3% of all farms have to deal with) a protocol has been developed of which it was expected that some elements would also have an effect on Campylobacter. It concerns mainly the sealing of cracks and seams and extra cleaning and disinfecting between rounds. The costs of these measures can vary between 8 to upwards of 60 million euro per year, including the opportunity costs of extra labor efforts of the farmers. The costs mainly depend on the frequency in which the measures need to be repeated. The costs are also lower when the measures only need to be applied on farms with an infected flock.
- The cost-utility of hygiene measures strongly depend on the assumptions made. In the most favorable case (reduction influx 25% and costs 8 million euro per year) the cost-utility ratio is 48,000 euro per averted DALY. With less favorable assumptions the cost-utility ratio is much more unfavorable.

***PHAGE THERAPY* is an experimental method by which the animals are treated with a specific bacteriophage two days prior to processing. Bacteriophages are bacterial viruses that selectively inactivate Campylobacter but that are not dangerous to human health. If the effects of small-scale experiments would be confirmed in practice, than phage therapy would be a relatively inexpensive method to reduce risks for the consumer. The efficiency is best when phage therapy is combined with a sensitive method to detect infected flocks. Such a method is presently being developed, but not yet available for use in practice.**

- In experiments with phage therapy it was found that the concentration of Campylobacter in the feces was about 2 log-units (100 times) lower at the moment of processing than in the feces of untreated animals. It is not known if the external contamination of the animals changes because of the phage therapy.
- Assuming a reduction of the concentration in the feces with 2 log-units would, according to model predictions, reduce the risk for the consumer of Dutch meat with approximately 75%. Taking import into account this leads to approximately 7,000 prevented cases of gastro-enteritis in the Netherlands.
- Assuming that the reduction of the concentration in the feces is only 1 log-unit, than the risk reduction is limited to approximately 45%. Assuming however that there is also reduction of the contamination of the exterior of chickens with 1 log-unit, than the risk reduction for consumers could be approximately 90% (see Figure 4).
- The costs of phage therapy are not known, because there are no products on the market yet. Judging from the price of existing treatments with antimicrobials they are estimated at a value between 0.0025 and 0.035 euro per treated animal with a most likely value of 0.02 euro. If all flocks that are to be processed are treated, than the estimated costs would be between 1 and 13 million euro per year with a most likely value upwards of 7 million euro per year.
- It is also possible to only treat the flocks infected with Campylobacter. A test of the Campylobacter status of the processing flocks needs to be performed. The costs of this test are estimated at 0.6 - 1 million euro per year, but the costs of phage therapy decrease with a factor of three. The total costs than decrease to upwards of 4.0 million euro per year, which is more than half cheaper than when all flocks are being treated. However, because not all infected flocks are recognized as such, the effectiveness decreases. Depending on the chosen test method according to the model predictions the risk for the consumer decreases with about 50 - 70%, see Figure 4.
- The costs of phage therapy are estimated at approximately 60,000 euro per averted DALY, when all animals are treated. With treatment of only positively tested animals the costs are 35,000 - 50,000 euro per averted DALY, with the assumption that the costs are 0.02 euro per treated broiler. These costs are however uncertain.
- It is yet unclear if long-term use of phage therapy will lead to selection of resistant campylobacters. Also the effectiveness in practice has not been proven yet.

During TRANSPORT of the animals from the farm to the processing plant contamination can occur as a result of contaminated crates, trucks and the like. However the time between contamination and processing is very short so that only a few animals can be infected and then also with relatively low numbers. The risk for the consumer is therefore negligible. The transport phase is therefore not further included in the calculations.

6. Interventions at the processing plant

Because contamination of broilers with Campylobacter in the farm phase can not be completely prevented additional measures can be considered to reduce contamination of chicken meat. Measures regarding limiting cross-contamination during processing can be considered, as well as the separate processing of infected and non infected animals and the reduction of the level of contamination of meat. Of these possibilities reduction of fecal leakage during processing and a combination of scheduled treatment and decontamination of carcasses with chemicals appear to be the most cost-effective options, see Figure 5 and Table 3. A reliable and fast test protocol needs to be available to detect infected flocks and the decontamination needs to be technologically optimized.

- Animals from an infected flock are usually heavily contaminated with Campylobacter. Almost all animals carry the infection in the gastrointestinal tract. An exception is the animals from a flock that were contaminated shortly before processing. In such flocks, according to the farm model, the prevalence of contaminated animals can be (much) lower than 10%. Such flocks are not recognized as contaminated during the usual testing procedures.
- Tests upon delivery at the processing plant show in contaminated flocks a median Campylobacter concentration of 10^6 colony forming units (cfu) per gram feces. All animals also appear to be contaminated externally (median 8×10^6 cfu per animal).
- To quantify the spreading of Campylobacter during processing a mathematical model has been formulated. This model describes the dynamics of the Campylobacter contamination in a “typical” processing plant in the base year 2000. Interventions in the processing phase can be simulated by changing one or more parameters in the model. The parameter values of the base model are based on structured interviews with experts because suitable measurement data were hardly available.
- According to the processing model the external contamination of a carcass from a contaminated flock declines during the whole process from 8×10^6 cfu per carcass to 3×10^4 cfu per carcass (median values). The largest decline takes place during scalding.
- A model was also created for the transmission of contamination from the exterior of a carcass to the fillets of chicken breasts during cutting. This model predicts that approximately 100 cfu (median) will be present on a contaminated fillet. There is large variation of the contamination of individual fillets, between 0 and 10^4 cfu per fillet. The predicted contamination is lower than was found in practice measurements during the summer of 2004, with a median of 2000 cfu per fillet.
- The final contamination of a fillet of chicken breast depends to an approximately equal degree on the prevalence of contaminated animals within a flock, the concentration of Campylobacter in the feces and the numbers on the exterior of an animal.

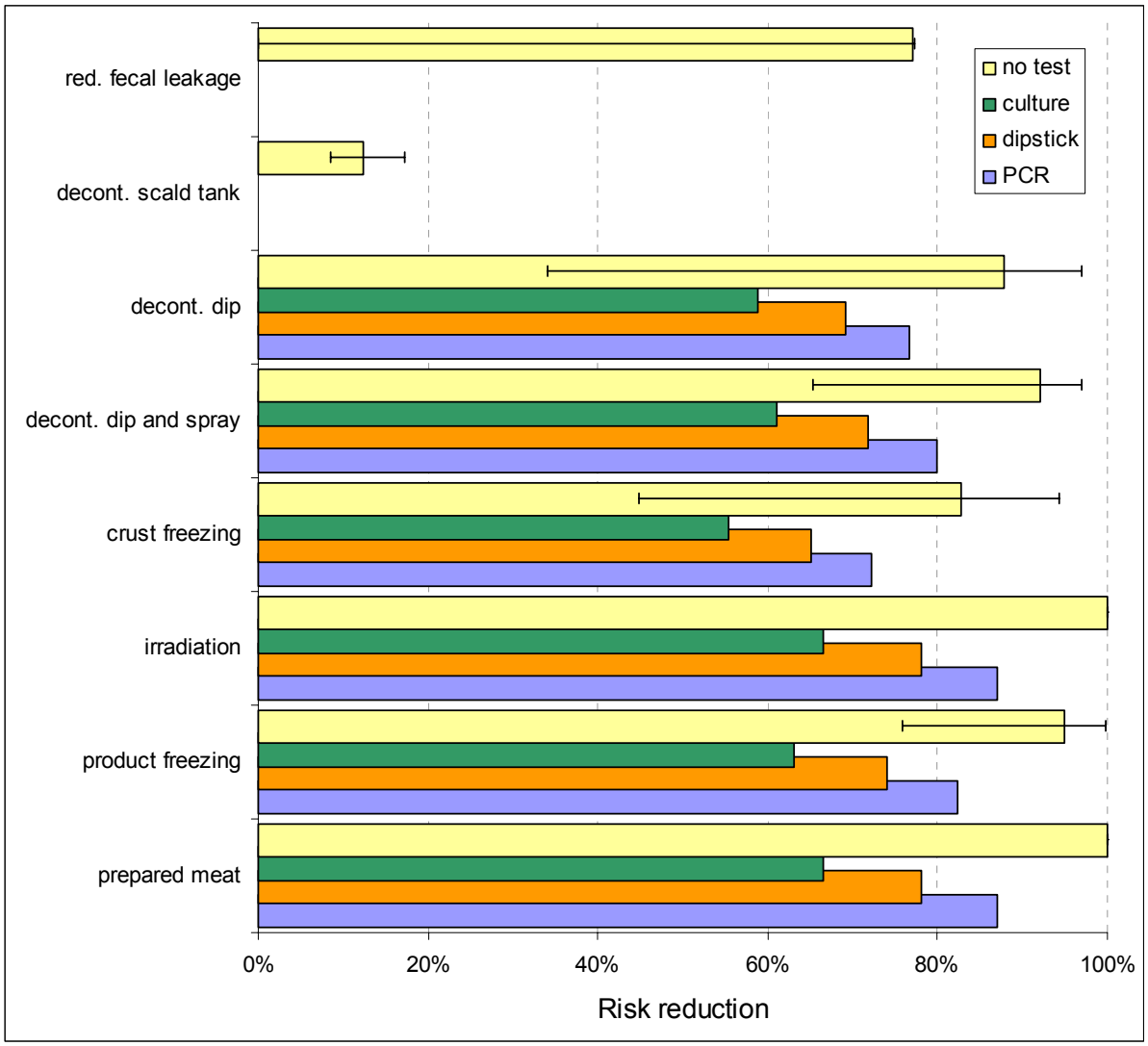

Figure 5. Risk reduction for the consumer by interventions at the processing plant.

The bars show the predicted reduction of the number of cases of illness as a result of intervention as percentage of the incidence in the baseline model. This reduction concerns Dutch consumers of broiler meat originating from the Dutch production chain. The error bars show the results of sensitivity analyses. These sensitivity analyses are only performed for the interventions without scheduled treatment (no test).

Newly developed and patented equipment aims to force a small amount of feces out of the cloaca by means of pressure on the abdomen, and to then spray the feces away with a pulse of water. The aim is to limit FECAL LEAKAGE during scalding and defeathering. Calculations show that this method can be very cost-effective.

- It is not exactly known what the effect of this method is on the fecal leakage from the carcass in the next processing steps. For the model predictions, it appears not to make a substantial difference what is being assumed. The processing model predicts that the number of campylobacters on a chicken carcass after cooling will decline with a factor 3 to 10.
- Preliminary measurements in practice (by order of a manufacturer) support the model predictions.
- Reduction of fecal leakage would, according to model predictions lead to a maximum of 80% reduction of the risk for the consumer of Dutch meat. This equals to approximately 9,000 prevented cases of gastro-enteritis per year, taking import into account.

- The annual costs of this intervention are approximately 1 million euro per year. In case the maximum risk reduction is reached the cost-utility ratio will be -15,000 euro per averted DALY. In other words, considered from the perspective of the whole Dutch society this intervention brings in net money. There is inevitably a difference between those who have to make the costs and those who profit from the benefits, see also Chapter 9.
- There is still very little practical information about the effectiveness of this technique and there are doubts whether the method will be successful under all circumstances. Further research in practice is therefore necessary to evaluate the model predictions.

DECONTAMINATION OF THE WATER IN THE SCALDING TANK is aimed at preventing cross-contamination between carcasses during the scalding process. This measure provides a small contribution to the reduction of the risk and is relatively expensive.

- A broiler from a contaminated flock is externally contaminated with (median) 8×10^6 cfu Campylobacter. As a result of the scalding process this number decreases on average with a factor 20.
- In case a decontamination agent is added to the scald water (for example lactic acid in a concentration of 2.5%), then according to the literature, the external contamination of a carcass after scalding decreases with a factor up to 100.
- However, with defeathering the external contamination of a carcass increases. In comparison to this increase, the decrease of the external contamination in the scalding tank is negligible. This intervention therefore has only little effect on the risk for the consumer. The costs (approximately 13 million euro per year) are relatively high. So there is an unfavorable cost-utility ratio (810,000 euro per averted DALY).

Tracking contaminated animals before processing and taking additional measures with regard to contaminated flocks can contribute to reducing the contamination of chicken meat with Campylobacter. With LOGISTIC PROCESSING positively tested flocks are processed at the end of the day or at a different location with an aim to prevent cross-contamination between infected and non-infected flocks. In case logistic processing is introduced as the only measure the calculated risk for the consumer will not change substantially.

- The processing model predicts that at most a few carcasses from an uninfected flock become positive because of cross-contamination. Also the numbers of campylobacters on these carcasses will be considerably lower than on carcasses of flocks already infected upon delivery at the processing plant.
- Because the possibility of human infection is directly associated with the number of campylobacters to which the consumer is exposed, the low numbers on cross-contaminated carcasses imply that the prevention of cross-contamination by logistic processing contributes little to reduction of the public health risk.
- In Iceland it is obligatory to freeze meat when it is known that the flock was contaminated with Campylobacter[1], based on testing of feces at the farm. Also for verification, coecum samples before processing and neck-skin samples after processing are tested. Sometimes a flock is found of which the coecum samples are negative but the neck-skin samples are positive. These flocks are probably cross-contaminated at the processing plant. Measurements of those flocks confirm the model predictions of low numbers of contaminated carcasses, on which only low numbers of campylobacters are found (1-2 log cfu/carcass). The Icelandic authorities have decided that additional measures for these flocks are not necessary [Jarle Reiersen, Chief Veterinary Office of Iceland, pers. comm.].

[1] Regulation no. 688/2002, amendment on regulation no. 260/1980.

With SCHEDULED TREATMENT positively tested flocks are not used for production of fresh meat. The products can be diverted to the meat-processing industry, where they can undergo a heat treatment or otherwise to reduce the contamination. The effectiveness of this measure strongly depends on the accuracy with which the contaminated flocks can be detected. The protocol based on the culture method which is currently used to detect contamination of broilers with Campylobacter is not sensitive enough to make scheduled treatment successful.

- The probability to actually detect an infected flock depends on the time between the infection of the flock (the first chicken) and the moment of sampling, the amount of samples and the sensitivity of the laboratory method.
- When a flock was contaminated two weeks or more before sampling, more than 50% of the broilers are infected. In that case the usual number of 10 samples is sufficient to detect the infection. When a flock was contaminated shorter before sampling, less than 10% of the broilers are infected. In that case the probability of detection is smaller than 5% and even with a random check of 100 samples the probability of detection is even smaller than 40%.
- The culture method can only be carried out in specialized laboratories, to where the samples need to be transported. Campylobacters are very sensitive bacteria that are easily damaged during transport. Based on experiences abroad (Norway) we estimate that only 50-75% of all contaminated samples are recognized as such, when sampling takes place a week prior to processing.
- When using the culture method, the time needed for transport of samples (with regular mail), for the analysis and for planning the processing is, at least, one week. During this week flocks can still get infected, but the significance of this seems minor. After all, during a timeframe of a few days the percentage of contaminated chickens in a flock will still be low. It is however possible that a flock is already contaminated during the moment of sampling, but not detectable because the percentage of infected chickens is still too small. A week later however all chickens among this flock are infected.
- If products from positively tested flocks using the culture method could be made totally Campylobacter free, the risk for the consumer would decrease with 67% (uncertainty margin 46-82%), see Figure 6.
- The sensitivity of a test protocol based on the culture method can probably be improved via courier transport and if necessary refrigerated. To what extent this is really the case is unknown. We estimate that the sensitivity can improve to 90%.
- Even with this sensitivity still 1% of the contaminated flocks will not be recognized as such and end up in the fresh meat channel. Scheduled treatment with this detection method reduces the risk for the consumer of meat produced in the Netherlands with a maximum of 87%.

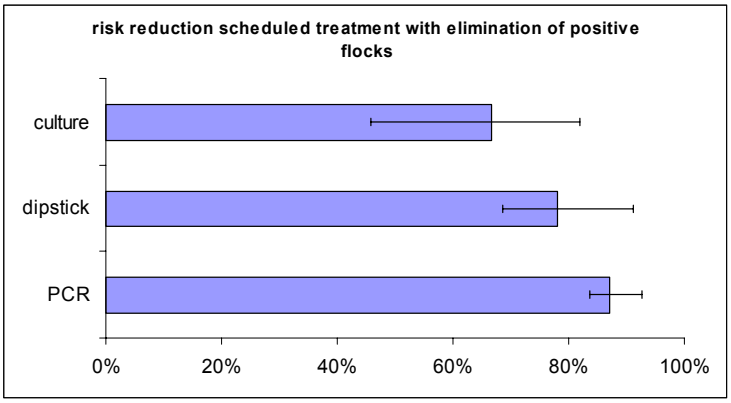

Figure 6. Theoretical risk reduction (best estimate and uncertainty range) of scheduled treatment with three different test protocols.

The figure shows the maximum achievable risk reduction for the consumer with the use of scheduled treatment based on analysis of samples on the farm using a culture method, a dipstick method and a PCR method. In each case 10 sample are obtained per house which are pooled into one test sample. The bars show the most likely estimate; the error bars the results of the sensitivity analyses.

Alternatives for the culture method are being developed, but are not yet validated nor commonly available. They could be available in one or two years and when their sensitivity lives up to the expectations they can be a good base for scheduled treatment.

- In the Netherlands a dipstick method is being developed that can be used by the farmer himself to establish the Campylobacter status of the living flocks. Because transport is not necessary, and the result is obtained immediately, the test can be performed only two days before processing. This reduces the probability that a flock gets heavily infected in the time span between sampling and processing. It has been estimated that this method will recognize 70-95% of all contaminated samples as such. There is however no practical experience yet. In case the results are confirmed in practice, scheduled treatment based on the results of this test protocol could reduce the risk for the consumer with a maximum of 70-90%, see Figure 6.
- In Denmark a molecular (PCR) method is in use by a number of companies. This test must be performed by a specialized laboratory. It is assumed that samples are taken five days before processing. Practical information is not yet available. Based on the literature [11] it is expected that 90-100% of the contaminated flocks can be detected. The risk for the consumer then decreases with a maximum of 84-93%, see Figure 6. The risk will never be totally eliminated because there will always be lightly contaminated flocks that will escape the test.

SCHEDULED TREATMENT to meat processing can result in a significant decrease of income for the chicken meat industries because fresh meat sells at higher prices. There is also a risk of permanent market loss. With the current prevalence there is not enough supply of negatively tested flocks during the summer to satisfy the demand for fresh meat.

- Scheduled treatment can make it more difficult for the industry to deliver the desired products on time. Also extra transport costs and less efficient use of processing lines can result. It is unclear to what extent these effects will show in reality, but the potential economical damage may be substantial.
- During the summer 60% of the flocks are tested positive using the culture method. The actual prevalence is much higher. Of the total production of chicken meat in the Netherlands approximately 2/3 is fresh meat. Thus there is an insufficient supply of negatively tested flocks during the summer.

To prevent major losses and to also have sufficient supply of fresh meat during the summer it can be apply a bactericidal treatment to meat from positively tested flocks. There are different possibilities to treat the meat in such a way that a substantial reduction of contamination occurs. Based on literature and modeling in the CARMA project attention is paid to DECONTAMINATION WITH CHEMICALS, to SUPERFICIAL HEATING OR CRUST-FREEZING of the carcasses, to IRRADIATION, and to FREEZING of the products. Of these possibilities irradiation has the most substantial effect. However the costs of irradiation are relatively high. Decontamination with lactic acid seems to have the best cost-utility ratio, especially when further optimization would prove that a lower concentration is sufficient. Freezing of contaminated products, which happens in some Scandinavian countries, has according to model calculations approximately the same effect as decontamination, but is more expensive. There are risks of reduced selling prices if the meat can not be considered as fresh anymore or as a result of logistical problems. These can be substantially higher than the direct costs of the interventions.

- With irradiation or heat treatment of meat from all positively tested flocks almost all Campylobacter bacteria present are killed. Because not all contaminated flocks are recognized as such contaminated meat will still enter the market. The amount depends on the used test method. In theory the PCR method can offer the best results, regarding both the number of prevented cases of disease and the cost-utility ratio. The difference with the dipstick method is small.
- Using the PCR method, according to model calculations approximately 10,000 cases of gastro-enteritis are prevented, with scheduled treatment either by irradiation or by meat processing where bacteria are inactivated by for example heating. The costs of irradiation are in the range of 20 million euro per year, especially because there is insufficient cooled storage capacity with irradiation facilities and therefore refrigerated trucks need to be used. Meat that is destined for the meat-processing industry will bring in a substantially lower income than fresh meat, the losses connected to this are estimated at approximately 80 million euro per year. The cost-utility ratio of irradiation and heating, in combination with scheduling by the PCR method are respectively 150,000 and 680,000 euro per DALY.
- According to limited available literature, treatment of carcasses with a 2.5% lactic acid solution leads to a decrease of the average contamination with Campylobacter on the carcass after cooling with a factor 6-300, with a most likely value of 60. The risk for the consumer of meat treated this way decreases with approximately 90% according to model predictions. If only PCR positive flocks are treated, than an estimated 9,000-10,000 cases of gastro-enteritis are prevented. The recommendations for using lactic acid are not univocal. Some authors [13] recommend a single immersion of the carcasses, just before cooling. In that case the costs are estimated at approximately 5 million euro per year and the cost-utility ratio is relatively favorable: approximately 30,000 euro per DALY. Other authors [12] recommend an immersion directly after defeathering, followed by spraying during washing and before cooling. In this case the costs are approximately twice as high.
- The costs of decontamination are mainly related to the use of lactic acid. In case, as suggested by some experts, a lower concentration of lactic acid is sufficient, possibly in combination with a higher temperature during treatment, the costs of the treatment will also be lower, and a better cost-utility ratio will result.
- Treatment with lactic acid can have a negative effect on the quality of the meat (mainly discoloration of the fat). The product could possibly no longer be sold as fresh meat. This can lead to a major decrease in the selling price. These losses are not

included in the above mentioned estimation of the costs. Optimization of decontamination is therefore an economic prerequisite for introduction.

- There are different alternatives for lactic acid such as chemical decontamination. Of chemicals such as trisodiumphosphate (TSP) it is stated that they have less negative effects on the appearance of the meat. Information about the costs is however lacking, so an evaluation of the cost-utility is not possible. It is expected that most chemical decontaminations will probably have the same effect so selection of the most optimal treatment can be based on different grounds: costs, side effects and toxicity.
- With crust-freezing of the carcasses with a stream of cold air, according to measurements on laboratory scale the numbers of campylobacters can be reduced with a factor between 3 and 60. Because the costs of this method (approximately 13 million euro per year) are relatively high, the cost-utility ratio is less favorable than decontamination.
- In a number of Scandinavian countries (Norway, Iceland, Denmark) carcasses or parts from positively tested flocks are being frozen during several weeks. According to laboratory experiments a reduction of the numbers of campylobacters between 10 and 100 may be reached with this measure. In combination with scheduled treatment based on the PCR-method freezing leads to nearly 10,000 prevented cases of gastro-enteritis, according to model calculations. The costs are approximately 12 million euro per year, so that the cost-utility ratio is quite unfavorable: approximately 87,000 euro per DALY. With this only costs of freezing have been taken into account. The fact that frozen meat will sell at lower prices than fresh meat has not been taken into account. Depending on the loss of selling price the annual costs can increase strongly: from approximately 40 million euro per year with a loss of 0.20 euro per kilogram to approximately 140 million euro per year with a loss of 0.70 euro per kilogram.
- The industry fears that scheduled treatment will cause logistical problems that may lead to product inefficiency and problems with regard to timely delivery for the export. Definite estimations are not possible. Possible losses could vary between 0.05 and 0.20 euro per kilogram, or 30-160 million euro per year. It is also feared that consumers may consider decontaminated meat of a lower quality, which would result in strongly reduced selling prices.
- Effective superficial heat treatment leads, as experiences from the United Kingdom and Italy show, to a product that is hard to sell. The appearance and the texture of the meat are strongly affected and because of the fact that the meat becomes moister on the surface, the shelf life is poor. Therefore this possibility has not been further evaluated.

Instead of scheduled treatment GERMICIDAL TREATMENT ON ALL FLOCKS can be used.

- This prevents the necessity to test for contamination with *Campylobacter* spp., and thus also the probability that false-negative flocks are being used for the production of fresh meat. As a consequence, the potential health benefits are higher, see Figure 7. There are also lower costs for tests and less complicated procedures. However, there are costs related to the treatment of all flocks instead of a selected part, and a possible negative influence on the product quality affects the total production. Investments are divided over a smaller amount of product.
- Irradiation of all produced meat is the only theoretical possibility to market Campylobacter free fresh broiler meat. The effects on the public health are a little better than irradiation combined with scheduled treatment (12,000 vs. 10,000 prevented cases of gastro-enteritis) but the costs are much higher, approximately 60 million euro per year. The cost-utility ratio is very unfavorable: more than 400,000 euro per DALY.

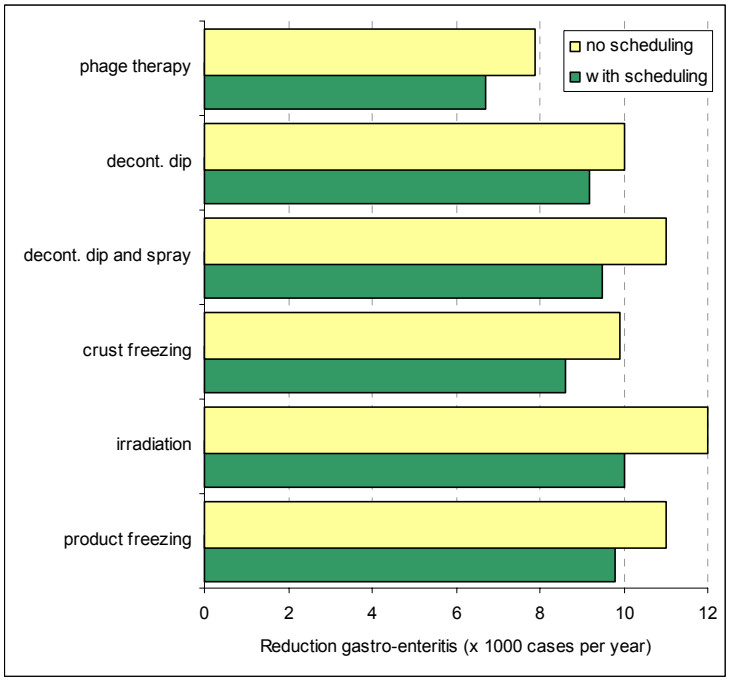

Figure 7. Health benefits of interventions on the farm and in the processing plant with and without scheduled treatment of positively tested flocks (PCR-method).

- Also for all other germicidal treatments investigated, it appears that in comparison to scenarios with scheduled treatment the health benefits of scenarios without scheduled treatment are relatively small, while the cost-utility ratio is considerably more unfavorable, see Figure 8. The only exception is crust-freezing, that has a better cost-utility ratio if all flocks are treated. The highest costs for crust-freezing are investments in equipment, whereas reduced electricity costs (no scheduling) and testing costs (with scheduling) cancel out.

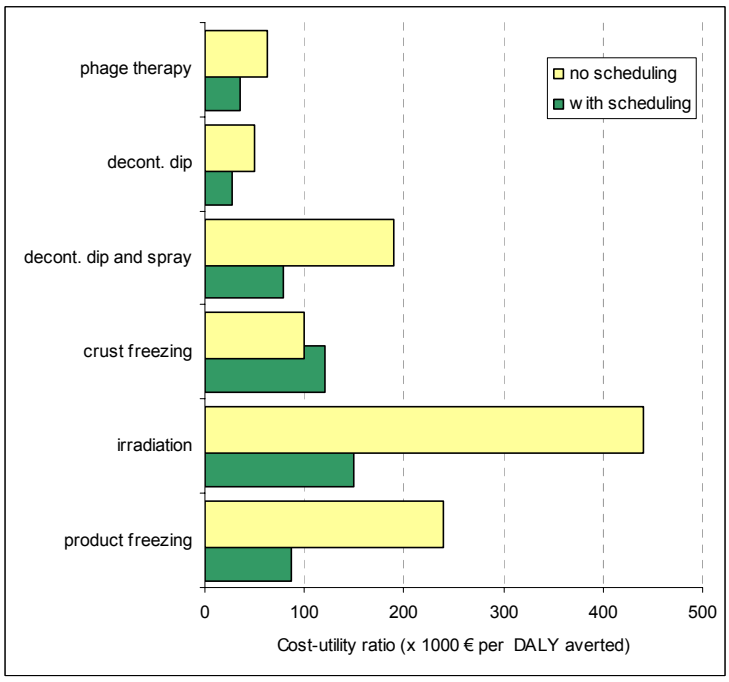

Figure 8. Cost-utility ratio of interventions on the farm and at the processing plant with and without scheduled treatment of positively tested flocks.

7. Interventions during storage and preparation of chicken meat

The preparation of meals in which chicken meat is processed is an important phase. It is assumed that chicken meat is sufficiently heated most of the times to inactivate any Campylobacters present. Exposure of the consumer mainly takes place through cross-contamination from raw meat to foods consumed raw such as salads.

- To quantify the spreading of Campylobacter during the preparation of a meal a mathematical model has been created. This model describes the cross-contamination of Campylobacter bacteria from chicken breast to a salad via hands, chopping board and kitchen faucets. The parameters in the model concern both the transmission of bacteria from one surface to the other and the frequency by which maneuvers are made (for example the chopping of a salad on a chopping board previously used for cutting chicken breast). For the estimation of a number of parameters recent, partly Dutch literature was available but in spite of that most are quite uncertain.
- According to the base model in little less than 1% of all meals a consumer is exposed to Campylobacter via salad. The ingested dose is usually very low, (1-2 cfu) but can also be larger than 100 cfu.
- The base-model predicts that more than 12,000 cases of illness per year occur as a result of consumption of Campylobacter contaminated salads. Because this route is definitely not the only one by which Campylobacter can reach humans, these predictions seem high, see also page 11.

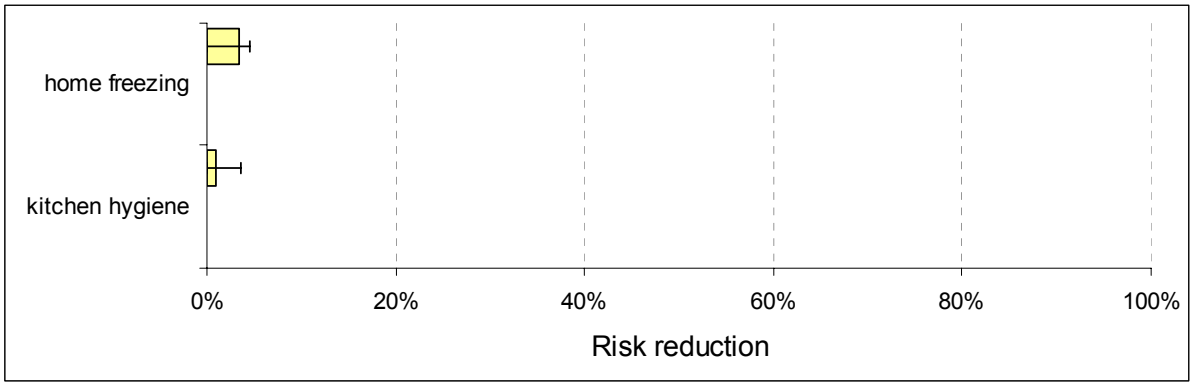

Figure 9. Risk reduction for the consumer by interventions in the consumer phase.

The bars show the predicted reduction of the number of cases of illness as a result of intervention as percentage of the incidence in the baseline model. This reduction concerns Dutch consumers of broiler meat. The error bars show the results of sensitivity analyses.

Reduction of the risk of cross-contamination is only possible by changing the behavior of those who prepare the food. A possibility to achieve this is EDUCATION. The expected effect of an information campaign is not high.

- Little is known yet about the effectiveness of information campaigns on the sustainable behavioral change of consumers. Based on the limited literature it is estimated that as a result of an information campaign 3% (with a margin between 0 and 7%) of all non-hygienic food preparers will improve their behavior.

- In that case it is calculated that the risk for the consumer will decrease with 3% (with a margin of 0-5%). This leads to approximately 500 prevented cases of gastro-enteritis.
- The costs of information campaigns are estimated at 1 million euro per year, which puts the cost-utility ratio at approximately 190,000 euro per averted DALY.

In case chicken breasts fillets are kept in the HOME FREEZER for a few days after purchase Campylobacter will die off. This measure hardly has costs. It does need an information campaign of which the expected effect is not high.

- After analogy of an information campaign about working hygienically during food preparation it is estimated that 3 (0-7)% of the consumers will change their behavior.
- The frozen fillets will be kept in the freezer for a few days up to the maximum of a week. The estimated die-off during this period is 25-70%, which results in a very small decrease of the risk for the average consumer (1% or 200 prevented cases of gastro-enteritis).
- Under the same assumption about the costs of an information campaign the cost-utility ratio is very high: more than 600,000 euro per averted DALY.
- Anyway it appears that a substantial part of the consumer already freezes freshly bought chicken meat (see page 34).

8. Societal support

At the start of the CARMA project, in 2001, research has been carried out to establish the opinion of different societal groups (government, industry, and consumers) about the contamination of chicken meat with Campylobacter and possible solutions. The government pursuits maximum food safety, but realizes that 100% safety is unachievable [17].The industry recognizes the importance of safe food, but points at the preservation of the job market and the international competitive position as preconditions. Supermarkets put the (presumed) demands of the consumer central. These demands concern the broad area of socially justified production, under which sufficient guarantees for the safety of food. There is agreement about the responsibility that the chain partners have to solve the problem, however there is a difference in opinion about the own responsibility of the consumer.

- In 2001 there was consensus about the fact that 100% Campylobacter-free chicken meat is not possible, but that the highest possible safety must be pursued.
- At the start of the project it was also noted that there was insufficient knowledge to make decisions regarding the reduction of Campylobacter contamination and to create sufficient support for this.

Studies in 2004 have indicated little support in the industry for taking additional measures to reduce the contamination of chicken meat with Campylobacter have been carried out. There is support for some measures among consumers, but not for others. Because of insufficient information about these measures and their possible effects many consumers have not (yet) taken a stance.

- On balance, broiler farmers in the Netherlands expect little effect of additional hygiene measures on the farm. This notwithstanding, they have many suggestions for improving farm hygiene and consider some measures also beneficial for animal welfare.
- With regard to the measure “discontinue thinning”, there are mixed opinions among broiler farmers. Next to doubts about the effectiveness, farmers with a negative attitude also table financial arguments. Farmers with a positive attitude see additional benefits such as animal welfare.
- In the broiler farmer sample, the age categories younger that 40 years and between 40 and 55 years, high education level and large farms (with more than 75,000 birds) were somewhat overrepresented.
- Of the 15 broiler processing plants in the Netherlands, 5 plants (locations) have responded to the enquiry. Given this low response, and because small processing plants (less than 20,000 tons of meat per year) were not represented in the sample, only a qualitative analysis of the data has been carried out. This low response and strategic differences between broiler plants lean to unequivocal information about the acceptance of possible measures.
- The respondents have the opinion that some measures are hardly or not at all effective, may increase the costs or may lead to sales differences. Processing plants do declare some concerns about the contamination of broiler meat with Campylobacter.
- It can be anticipated that the attitude of Dutch broiler processing plants towards possible measures including scheduling are strongly determined by the costs and benefits for the specific company.
- Consumers in the Netherlands hold all parties responsible for taking additional measures, but in particular farmers and processing plants.

- Consumers show a positive attitude towards measures that they could take themselves such as hygienic precautions when preparing chicken meals and home freezing of freshly bought meat. This does not necessarily mean that consumers would actually modify their behavior. A large majority of consumers state that they already freeze freshly bought broiler meat.
- On average, consumers have a positive attitude towards extra hygiene measures at the farm if it can reduce contamination of chicken meat with Campylobacter, but they are less positive about mechanical means to reduce fecal leakage during processing.
- Consumers are on balance skeptical towards phage therapy and decontamination with lactic acid. In comparison with these measures, they are less skeptical towards irradiation, but a majority of consumers indicates that they do not have a clear opinion. Up to half of the consumers have not yet defined their position towards phage therapy and decontamination, most probably because they lack information about these measures.
- The sample of consumers consisted of men and women, different age categories, educational levels and families with ort without young children. Nevertheless, the sample was not fully representative of the whole population. In particular, those aged over 65 years and with only primary school education were underrepresented.

9. Discussion

By means of an integrated approach including risk analysis, epidemiology and economics an assessment has been made of the efficiency of possible interventions to reduce campylobacteriosis in the Netherlands. It is the first time that such an integral approach has been used for a problem in the area of food safety. Despite much uncertainty it is shown to be possible to identify a number of cost-effective interventions in an important exposure chain, namely broiler chicken meat. These consist of a combination of lowering the prevalence on the farm through strict hygienic measures, reduction of fecal leakage during processing and reducing the numbers of campylobacters on the end products. Chemical decontamination seems to be the most efficient method for the latter. Also phage therapy of the living animals just before processing is an interesting possibility. In much of the information used for the calculations substantial uncertainties exist. Despite this the most important conclusions appear to be robust.

- The uncertainty in the risk model is for a major part caused by the complexity of the production system of chicken meat. There are many variations in the contamination of meat and animals with Campylobacter (within a flock, between flocks) that are hard to capture in a mathematical model. Besides this there is statistical uncertainty in the model parameters and there are very few measurements that are representative for the practical situation. Mainly this last uncertainty is of major importance. In the analysis presented the effect has been investigated with the help of sensitivity analyses. The most important conclusion is that most cost-effective interventions can not be introduced as such, but that practical research needs to establish if the theoretical effectiveness is really achievable.
- The complexity of the system means that much of the available measurement data are not easy to interpret because the history of the samples is insufficiently known. The risk models are a useful tool for the design of more focused analytical programs.
- Model validation by comparison of model predictions and measurement data is consequently only possible to a certain extent. Comparison of the model predictions and the available data suggests that the model underestimates the contamination of broiler chicken meat at retail, but overestimates the associated health risk. Possible reasons of this overestimation of the health risk have been suggested in Chapter 2. Enquiries among consumers proved that fresh meat is relatively often stored in the freezer. The die-off that is associated with this has not been taken into account. Possible reasons of the underestimation of the contamination of meat can especially be related to the fact that bacterial numbers are mainly determined by the degree to which extreme events happen (for example an animal that has a high concentration of Campylobacter in the feces, the damaging of the viscera during the evisceration etc.). Quantifying the influence of such events asks for more focused measurement strategies.
- An important uncertainty in the results of the risk model concerns the extrapolation of the risks connected to the cross-contamination of chicken breast to salad to the risk associated with the total consumption of chicken meat. To decrease this insecurity specific attention needs to be paid to other routes that have a major probability of cross-contamination such as barbequing.
- For the final conclusions mainly the ratio of the risk of an intervention scenario in comparison to the baseline model is of importance. Preliminary results show that the uncertainty in the risk ratio is smaller than the baseline risk. This is probably because many of the model uncertainties cancel out when the relative risk is calculated. A

formal quantification of the degree of insecurity of the relative risks is complex and could not be made with the available resources.

- The estimate of the incidence of illness associated with contaminated broiler meat is mainly based on epidemiological data. Despite uncertainties in their interpretation, they are considered the most reliable to assess the magnitude of the problem. All calculations were based on an annual average. Seasonal variation was not taken into account.

Controlling infection on the farm is an effective intervention in theory but it is not clear exactly which measures to take.

- The farm transmission model suggests that the probability of infection in a flock is larger when the previous flock in the same house was also infected. For this reason cost estimates for farm hygiene were based on a protocol with intensive cleaning between two cycles, as developed for the control of *Salmonella* Java. Meanwhile, it has been demonstrated that even on farms where these measures are successfully applied to control *S.* Java, infections with Campylobacter are repeatedly found (Jaap Obdam, Plukon Poultry, Wezep, the Netherlands, personal communication). This is in line with the literature that suggests that transmission of Campylobacter between cycles is of little importance. It is not clear which mechanism underlies the observed statistical association. Further studies may provide important clues to control Campylobacter on the farm.
- Surveys [3] held between 1997 and 1999 indicated that most Dutch broiler farms have adequate facilities at their disposal for hygienic operational management such as anterooms, specific clothing and tools. However, boot dips were mostly not available or were poorly replenished. Meanwhile progress has been made with the implementation of hygiene standards within the framework of the IKB recognition of broiler farms. By inspections the hygiene status of the farm and the way measures are implemented is assessed once a year. However, it cannot be assessed in how far the farmer consistently applies the measures year-round (Inge Stoelhorst, PVE, personal communication).
- The experience in Scandinavian countries suggests that specific hygiene education can lead to a lower prevalence of Campylobacter (Merete Hofshagen, Norwegian Zoonosis Center, Oslo, Norway and Ingrid Hansson, Nationalk Veterinary Institute, Uppsala, Sweden, personal communications).

The cost-utility ratio of the most effective interventions ranges between -15,000 and 50,000 euro per averted DALY. This is in the same order of magnitude as interventions which are implemented in other domains of (preventive) health care, see Table 2.

- In the Netherlands there is no fixed limit for the cost-utility ratio to decide whether an intervention will be carried out or not.
- The limit of 20,000 euro per QALY[2] is used in the Netherlands to establish which target groups would and would not be considered for use of statines (cholesterol reducing agents) as prevention for cardiovascular diseases [4].
- In their research about cost-efficiency of 500 “life saving” interventions in the USA Tengs et al. [14] show that the centre of the distribution lies between 10,000 and 100,000 dollar per life year gained. Based on their own decision about acceptance or rejection of new medical technologies in the past the British “National Institute of

[2] Like DALYs, QALYs (Quality Adjusted Life Years) are a metric to integrate the effects of morbidity and mortality. QALYs are focused on the current health state and are mainly used in health care research. DALYs are focused on health losses and are mainly used in public health research. Under the same assumptions an averted DALY equals a gained QALY.

Clinical Excellence" suggests a marginal value of approximately 30,000 pounds (42,000 euro) for a healthy life year gained [15]. The World Bank suggests 3 times the Gross National Product per inhabitant as a reasonable expense for an extra healthy life year as a rule of thumb, in various Western countries the implicit marginal value lie somewhere between one and three times the GNP [10]. For the Netherlands this is in the order of 25,000 to 75,000 euro per healthy life year gained.

- Other aspects also determine up to which cost-utility ratio an intervention is implemented. This, among others concerns the size of the patient group, the absolute costs of the intervention, the severity of the illness, the perception of the problem by citizens and considerations about possible accountability and liability.

Table 2. Costs per QALY of various interventions, inside and outside the health care system.

Costs: euro/QALY	Intervention	Implementation / comensation in NL?
< 0 (cost-reducing)	Fluoridation drinking water	No
	Syringe exchange programs for drug users	Yes
	Enrichment of foods with folic acid	No
	Syphilis screening of pregnant women	Yes
	PKU/CHT screening of newborns	Yes
	Programs to reduce falling among elderly	Sometimes
	Smoke detector in houses	Voluntary
	Stop smoking interventions	No/sometimes
0-1,000	Obligatory seatbelts in cars	Yes
	Chlamydia screening	No
1,000-10,000	Pneumacoccus vaccination elderly	No
	Viagra	No
	Influenza vaccination all elderly	Yes
	Vaccination meningococcus C	Yes
10,000-100,000	Kidney replacement therapy	Yes
	Transplantation programs	Yes
	Obligatory periodical car testing	Yes
	Air-bags in cars	Voluntary
	Hip replacement by arthrosis	Yes
	Long transplantation	Yes
	Deployment helicopter traumateams	Yes
	Statines for risk groups	Yes
100,000-1,000,000	Legionella control in plumbing	No
	Neurosurgery for malign brain tumors	Yes
	EPO to control anaemia dialysis	Yes
> 1,000,000	New screening techniques to screen donorblood for HIV and Hepatitis B and C	No/sometimes

Source: RIVM

In this report the cost-utility ratio of the interventions is calculated based on the health gain achievable among Dutch consumers. Taking all consumers of chicken meat produced in the Netherlands into account the cost-utility ratio is more favorable, but is difficult to establish how much this is exactly. Also because of other reasons the cost- utility of the measures is calculated conservatively. For the ranking of the efficiency of the interventions studied this does not really matter.

- When the calculations are carried out for all consumers of chicken meat produced in the Netherlands the health gain is twice to three times higher than among Dutch consumers only. Also the reduction of costs of illness is twice to three times higher. But the costs of intervention remain the same. With that the cost-utility ratio is influenced in a positive way, see Figure 10.
- When on the other hand interventions are not only carried out in the Netherlands but also on imported (fresh) chicken meat the achievable health gain among Dutch consumers would be approximately 30% higher.
- In the calculations a best estimate of 20% of the incidence of illness as a result of consumption of chicken meat has been assumed. This fraction could also be twice as high which makes the cost-utility ratio of the interventions much more favorable.
- A number of interventions do not only have an effect on the risk of Campylobacter, but also on other bacteria such as Salmonella. Despite the fact that the control of Salmonella-contamination on chicken meat has already shown considerable effect, this multiple effect will positively influence the cost-utility ratio.
- The above mentioned factors will have approximately the same effect on all interventions, so that the ranking of the interventions will not essentially be influenced.

To reduce the disease burden even further a combination of several interventions can be considered. Mainly a combination of avoiding fecal leakage and chemical decontamination seem an efficient option.

Through this combination well over 2,000 more cases of gastro-enteritis can be prevented than with decontamination alone, so 12,000 cases totally. The cost-utility ratio remains approximately the same to the one of decontamination only.

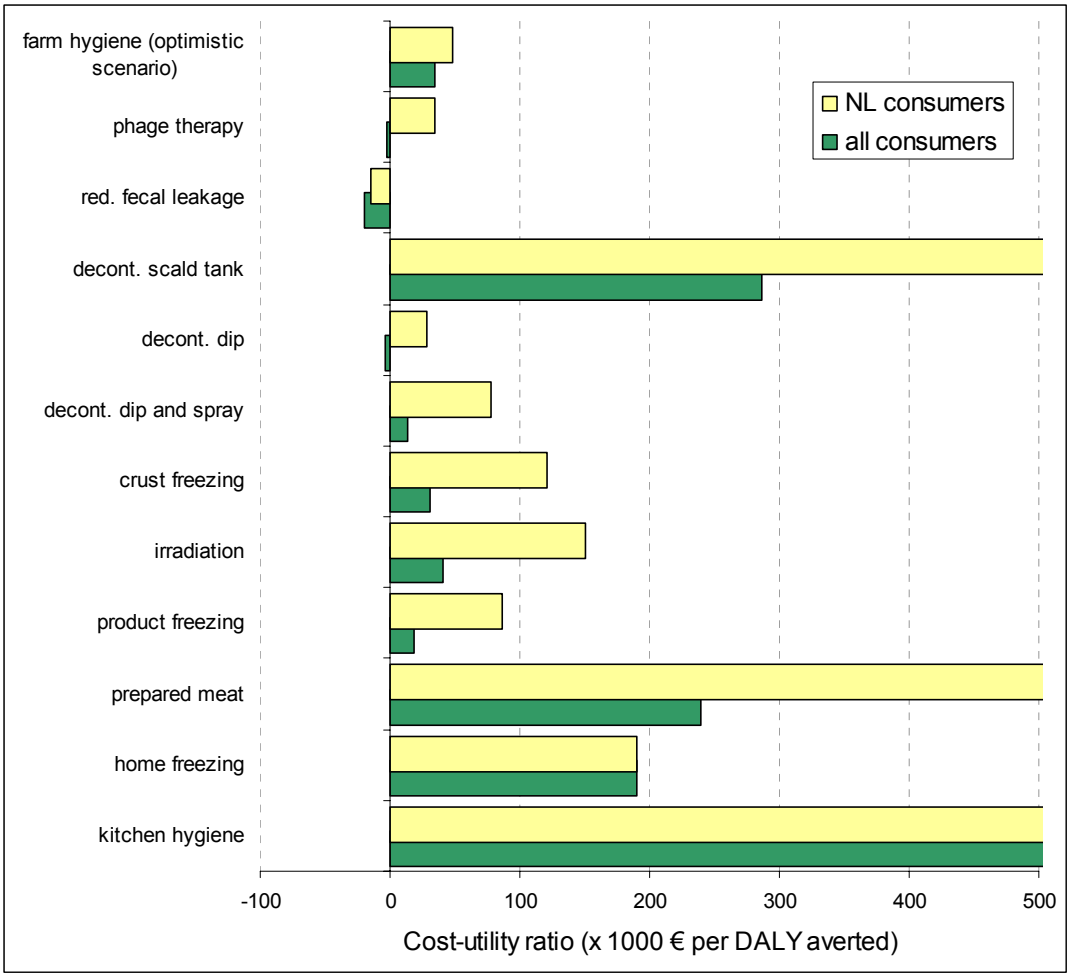

Figure 10. Cost-utility ratio of interventions in the Dutch chicken meat chain for Dutch consumers in comparison to all consumers of Dutch chicken meat.

For the calculations it has been assumed that the risk for the consumers, the disease burden and costs of illness are equal for foreign consumers to those for Dutch consumers. The calculations are based on scenarios of scheduled treatment using the PCR test.

The Dutch poultry chain is currently in a difficult stage of restructuring as a result of changing competitive positions and accentuated environmental policy. It is expected that the industry will shrink and that a focus will develop on the fresh meat market in northwestern Europe. That requires a chain inversion of supply-oriented to consumer-oriented production, in which consumer related product development becomes more and more important [12]. This development could offer possibilities for example via pre-cooked or frozen ready-made products to solve the problems with regard to product inefficiency with scheduled treatment.

- In the calculations, a welfare-economics approach was used. This approach considers costs and benefits from a societal perspective and does not account for unequal distribution of costs and benefits.
- Costs of possible measures will mainly bear on the industry, whereas benefits are mainly for individual citizens, employers and health care insurers, in the Netherlands as well as abroad.
- It was not evaluated in how far bonuses or other institutional measures could compensate potential losses by industry.

Table 3. Effectiveness and cost-utility of interventions in the chicken meat chain

The table shows the major results of the study, assuming the most likely values for the model parameters. Effects and costs of interventions with scheduled treatment are calculated based on the most cost-effective test protocol, namely sampling on 2 days prior to processing and testing using the PCR method. The first column shows the reduction of the risk with consumption of meat from broilers produced and processed in the Netherlands. The second column shows the expected decrease of the amount of gastro-enteritis cases (at the baseline 16,000 cases per year are a result of consumption of contaminated chicken meat). This reduction is calculated for the Dutch population, taking import and export of both living animals and meat into account. The third column shows the costs directly related to carrying out the intervention. Product inefficiency, market effects or a lower selling price of products have not been taken into account. The cost-utility ratio is calculated based on discounted DALYs, costs of illness and supply chain costs.

Intervention	Reduction risk (%)	Reduction gastro-enteritis (x 1000 / year)	Costs (x million euro/yr)	Cost-utility ratio (x1000 euro/DALY)
FARM				
Mono species farms	-1	n.a..	n.a.	n.a.
Improved hygiene				
- small effect	22	2.4	8-63	280-2500
- moderate effect	43	4.6	8-63	130-1300
- substantial effect	94	10	8-63	48-560
Discontinue thinning	0	n.a.	n.a.	n.a.
Phage therapy	74	7.9	7.0	63
- only positive flocks	63	6.7	4	35
PROCESSING PLANT				
Logistic processing	0	n.a.	n.a.	n.a.
Reduction fecal leakage	77	9.2	1	-15
Decontamination scalding tank	12	1.4	13	810
Decontamination carcasses				
only dipping	88	10	8	50
dipping and spraying	92	11	26	190
- with scheduled treatment				
only dipping	77	9.2	5	28
dipping and spraying	80	9.5	10	78
Crust-freezing	83	9.9	13	99
- with scheduled treatment	72	8.6	13	120
Irradiation	100	12	59	440
- with scheduled treatment	87	10	19	150
Freezing products	95	11	32	240
- with scheduled treatment	82	9.8	12	87
Scheduled treatment to meat preparation	87	10	79[b]	680
CONSUMER				
Education home freezing	1	0.2	1	620
Education improvement kitchen hygiene	3	0.5	1	190

[a] low resp. high estimation
[b] including price reduction
n.a.: not applicable

10. Conclusions

- There are different routes by which humans can be exposed to Campylobacter. In the Netherlands food (mainly chicken meat and products consumed raw such as vegetables and fruits, fish and shellfish and milk) and direct contacts with (young) animals are the most important routes. Also foreign travel is a risk factor.
- Contaminated chicken meat is responsible for at least 20% of all cases of campylobacteriosis in the Netherlands, or 16,000 cases of gastro-enteritis per year. The discounted disease burden connected to this is 170 DALYs per year and the discounted costs of illness are 3.9 million euro. At most approximately 40% of all cases are related to consumption of contaminated chicken meat, thus the numbers mentioned can also be twice as high.
- There is an intensive import and export of both broilers and chicken meat. The Dutch consumers are therefore only partly protected if measures are only taken in the Dutch production chain.
- Despite implementation of measures in the primary sector Campylobacter contamination of broilers on the farm has only decreased to a certain extent. The most important risk factors for contamination are related to influx of the bacteria during a fattening round from the direct environment.
- Although thinning might increase the risk of contamination of broiler houses, discontinuing is not effective because the time between thinning and depopulation is too short to lead to a substantial contamination of broilers. Also the number of houses needs to increase with an equal production. If these are built at the same location also the risk of contamination per house increases.
- Broilers on farms where other farm animals are kept appear to be more often contaminated with Campylobacter. Nevertheless discontinuing the production on these multi-species farms does not seem effective because with an equal production the average number of houses per specialized farm will have to increase. The added risk connected to this compensates the achieved risk reduction completely.
- Reduction of the influx of Campylobacter in the house (both between cycles as well as during a cycle) may be very effective but it is still unclear which measures precisely need to be taken. Because the costs of hygienic measures vary strongly it is also unclear what the cost-utility ratio of hygienic measures is.
- The treatment of infected flocks with specific bacteriophages is an experimentally tested possibility that, if the effectiveness is confirmed in practice, might be a cost effective measure.
- Although contamination from the environment can take place during transport of the animals to the processing plant, the associated risk for public health is negligible because an eventual contamination hardly has the chance to develop in such a short period of time.
- Testing of broiler flocks for Campylobacter infection in advance in order to logistically process the positively and negatively tested flocks to prevent cross-contamination in the processing plant is a measure which contributes little to reducing the risk for the consumer.
- When the positively tested flocks are additionally treated the risk for the consumer can be reduced substantially. Such a form of scheduled treatment always has a better cost-utility ratio than treating of all animals that need to be processed. With that it is assumed that the industry is capable to solve possible problems of product inefficiency and loss of selling price through (product) innovation. However, for an optimal effect

on public health a test protocol is necessary which with high probability can detect contaminated flocks. The currently used culture method is not suitable.

- New (faster) test methods are being developed to detect a Campylobacter infection in broiler flocks. Of these methods a higher sensitivity is expected. Also with these methods the time between sampling and the moment of processing can be reduced. The new test methods are not yet validated. In case the sensitivity and specificity live up to the expectations, they will form a solid base for scheduled treatment.
- Of all studied interventions only irradiation of all produced meat leads to the marketing of guaranteed Campylobacter free fresh chicken meat. The costs of this measure are however high. Consumers seem to be more positive towards this measure in comparison to phage therapy and decontamination with lactic acid but more than a quarter of the consumers has not yet determined their opinion with regard to irradiation. All other interventions will result in a certain degree of contamination of the end product.
- Various interventions have been identified which can lead to a substantial decrease of the risk for the consumer. This mainly concerns measures that can reduce the number of campylobacters on meat, but that will not completely eliminate the contamination. Reduction of the number of campylobacters generally seems easier to achieve, cheaper than and at least as effective as reduction of the prevalence.
- Of all possible treatments after scheduled treatment, decontamination with chemicals such as lactic acid seems to be the most cost-effective option. The current recommendations for the use of decontaminating agents are however not univocal and little is known about their effectiveness in practice. It is also still unclear to which extent an effective bacterial reduction can be reached while at the same time negative effects for the sensory aspects of the products are prevented.
- Physical methods for reduction of the number of campylobacters such as crust-freezing of the carcasses and freezing of the products seem less effective and/or (much) more expensive than chemical decontamination.
- Reduction of the fecal leakage from carcasses during scalding and defeathering seems a relatively inexpensive method which can lead to a further reduction of the risk for the consumer by lowering the number of campylobacters on the end product. In combination with chemical decontamination this method forms a very (cost-) effective intervention.
- Although in theory optimal hygiene during preparation of meals with contaminated chicken meat could prevent illness completely, little effect is expected from consumer information campaigns. It seems thus far very difficult to influence the behavior of the consumer permanently.
- The calculated cost-utility ratios are much more favorable when the health gain achieved in countries that import Dutch meat is taken into account, and with the probably also favorable effects on the risk of other pathogens such as Salmonella.
- The cost of Campylobacter reduction is mainly borne by the industry, while individual citizens, employers and health insurance companies domestic and abroad benefit from the effects. It is not clear in how far industry will be able to recover extra costs by either increasing the selling price of broiler meat or being compensated by bonuses or other institutional measures.

- There is little support among the Dutch industry for additional measures to control Campylobacter in the broiler meat chain. Parties hold each other responsible. Broiler farmers and processing plants are not convinced of positive effects of additional measures and fear extra costs or sales problems. A majority of consumers is not worried about the contamination of broiler meat with Campylobacter. They have not yet defined their position towards recommended measures because they lack information. There seems to be growing acceptance among consumers of irradiation. Good communication with all stakeholders is paramount during policy formulation as well as implementation to create further societal support.

11. Recommendations for policy makers

- Prevention of campylobacteriosis asks for a policy which is focused on reducing the exposure via a number of different routes, mainly chicken meat, food that is consumed raw and direct contact with animals. This report is mainly concerned with the reduction of exposure by broiler chicken meat. These measures are expected to have a favorable effect on the public health.
- Improvement of the hygiene on primary farms is an effective method in theory. Effective hygienic measures can lead to a lower prevalence of contaminated broilers and thus to exposure of the consumer. Also with lower prevalence scheduled treatment measures are better achievable and cheaper. Because it is unclear which measures need to be taken exactly, and because the costs and extra labor of the farmer that is needed can be high, a stepwise approach is recommended. This could begin with implementing existing standards for hygienic facilities on all farms and the assurance of a consistent and effective use of all hygienic barriers. It is also of importance that there is enough spatial spreading of poultry farms, contrary to current concentration plans on ecological grounds.
- Considering the better cost-benefit ratio of scheduled treatment in comparison to treating all animals the starting of consultation with the sector about implementation of scheduled treatment is a priority. With that also attention needs to be paid to innovation in order to prevent product inefficiency and selling price loss. A condition is that on short notice test protocols will become available to detect contaminated flocks with a high probability.
- In the current situation the prevalence of contaminated flocks, especially during the summer is so high that scheduling positively tested flocks to the meat-processing industry would lead to a shortage of chicken meat and to major losses for the industry. This underlines the necessity to reduce the prevalence of contaminated flocks via hygienic measures.
- To reduce the health risk of meat from contaminated flocks, reducing the concentration of Campylobacter on the carcasses seems to be an effective method. Implementing chemical decontamination seems with the current technology to be the most (cost) effective possibility. A further effect can be accomplished by implementing relatively cheap equipment to limit fecal leakage during scalding and defeathering or by phage therapy of contaminated flocks. Before introducing these measure on a large scale, their effectiveness in practice must be confirmed.
- Considering the results of the project an absolute zero-tolerance of Campylobacter on chicken meat is not achievable on the short term. Interventions were identified that reduce the number of campylobacters on chicken meat substantially and have a positive effect on the public health. The model results for these scenarios can form the basis for formulating quantitative standards for Campylobacter on chicken meat (Food Safety Objectives and Performance Objectives). The risk assessment indicates that both prevalence and level of contamination are important for the consumer risk. Targets in the food chain should take both aspects into account.
- Even though the effect of a single information campaign is considered small, hygienic preparation of meals is essential and hygiene education is considered an essential pillar in food safety policy. With that more insight in the expected effect of education is of importance.
- The costs and benefits of controlling Campylobacter in the chicken meat chain are calculated from a social perspective. With the implementation of the proposed interventions suggested in this report the unequal distribution of these among different

stakeholders needs to be taken into account and compensation measures and bonus arrangements can be considered.

- A part of the chicken-meat associated cases of campylobacteriosis in the Netherlands are not preventable by measures in the Dutch production chain. For this reason implementation of measures should to be aimed for at the European level and should also encompass import from third countries. This would also achieve that the competitive position of the Dutch industry is not unnecessarily affected.
- With the implementation of measures it needs to be considered that the sector has a low labor income and small margins and a difficult international competitive position. If the production costs become too high, the chance exists that the production in the Netherlands will disappear. However, with that the problem is not solved and probably becomes even more difficult to control. Also this consideration pleads for a European approach.
- An effective implementation and evaluation of interventions in the chicken meat chain asks for a high degree if transparency of the chain, both with regard to the business flow (including import and export) and with regard to the results of microbiological surveillance.
- Considering the long time span and the relatively high costs of the CARMA project an evaluation of the project and the added value for policy and research programming is in place. In this evaluation attention can also be paid to the need for further studies to reduce the most important uncertainties and to which way a cyclic process of measuring, modeling and policy decisions can be implemented.
- Considering the current degree of acceptance, the costs and the absence of a complete insight in the evaluated measures it is recommended to define and implement measures in consultation with industry and the consumers and in connection to other political fields such as animal well-being and the environment. Good communication and probing for possible adversaries is paramount.

12. Recommendations for further research

- There is still considerable uncertainty about the relative importance of different routes to the human exposure with Campylobacter. Better estimates of the attributable risk are necessary. For this purpose it is necessary to better understand the dynamics of the interaction between pathogen and host.
- To reduce the uncertainties in estimates of exposure by other routes than chicken meat, quantitative analyses are necessary of the occurrence of Campylobacter in the most important sources (products that are consumed raw such as vegetables and fruit, fish and shellfish and milk), of the amount of food that is consumed raw or partially heated and to the extent to which pathogens are transmitted by direct contact with animals.
- Further studies into the improvement of hygiene on the farm have a high priority. Besides further research into the most (cost-) effective physical barriers against contamination also social-scientific research into the hygienic behavior of poultry farmers and the possibility to strictly maintain hygienic precautions is necessary.
- Phage therapy could be a cost-effective method to reduce the risk of contaminated flocks. Further research is however necessary to optimize this method and to confirm the effectiveness in practice, just like research into the possible incidence of resistance. Further research is recommended to an effective way of education to consumers to prevent the change of doubts into opposition.
- Considering the potentially favorable cost-effectiveness of the reduction of fecal leakage during scalding and defeathering, further practical research has a high priority.
- Development of test protocols which can detect Campylobacter contamination on the farm with a high reliability are a precondition for effective scheduled treatment.
- Optimization of chemical decontamination is necessary, mainly focused on reducing the necessary concentration of the decontaminating agents and limiting of negative effects on the organo-leptic quality.
- To explain the substantial differences between the results of epidemiological research (low incidence) and quantitative risk assessments (high incidence) further research into the role of immunity and other factors showing dose-response relations that influence the risk on population level is necessary.
- Information about numbers of campylobacters are at least as important as information about prevalence, and the success of most of the interventions discussed in this report will particularly be expressed in a reduction of the numbers. Surveillance programs should be able to demonstrate these effects.
- In order to validate model results studies in practice are needed that explicitly takes complex variation among and between contaminated flocks of broilers into account. To reduce the uncertainties in the results of the processing model quantitative research is needed, mainly to the effect of cross-contamination during defeathering and cutting. Of further importance is to what extent in the model calculation different microbial populations, which are attached to carcasses in a different way need to be taken into account. Also research is needed into the die-off of Campylobacter during refrigerated storage in retail and in private households under different atmospheres, as well as the extent to which fresh meat is frozen by consumers.
- Further model development is needed to process the complex dimensions of variability and uncertainty in the model structure and to observe the influence of extreme occasions more explicitly. Also a more structured analysis of the uncertainty of the calculated effects of interventions is necessary.
- Next to the CARMA project other international research groups are active in developing risk assessment models for Campylobacter in the broiler meat chain. It is

recommended to compare and where possible integrate these different models. Attention should also be given to simplifying the model structures and to optimally use available data.

- Considering the strong international character of the chicken meat industry continuing research on a European scale is recommended, including import from third countries. This relates to the costs and the effects of interventions as well as the effects on the business trade if they are connected to the implementation of the intervention.
- To obtain a better insight in the actual hygienic behavior during food preparation and the possibilities to influence this effectively and permanently interdisciplinary research is necessary that combines the efforts of natural and social scientists.
- Consumer focused product development deserves more attention from industry and research in order to prevent possible losses that are connected to controlling Campylobacter.

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Appendix 2. Members of the Project Steering Committee and Industry Forum CARMA (2004)

Steering committee

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Cees Vermeeren (Nepluvi)
Tjep de Vries (GD)
Phil te Winkel (Nutreco)

Appendix 3. Definitions and abbreviations

Cfu: colony-forming unit.
Cost-utility ratio: A form of economic evaluation by which the costs of an intervention are compared to the effects expressed in a measure which states the utility of the achieved health gain, such as DALYs.
Culture method: A method to detect bacteria by transferring the sample to a suitable culture medium and by incubate under suitable circumstances.
DALY: Disability Adjusted Life Years are a measure for the disease burden in the population. They are the sum of years lost by premature death and years lived with illness, weighed for the severity of the disease so that they become comparable with the lost life years because of death.
Decontamination: The deployment of chemicals to kill micro-organisms.
Defeathering: The removal of feathers of a chicken carcass.
Dipstick-method: A method to detect bacteria with help of an immunological reaction.
Dose-response model: A mathematical model which shows the relationship between the degree of exposure and the incidence of health effects.
Efficiency: The result of an action in relation to the necessary means (money, expertise, time).
Effectiveness: The results of an action under ideal conditions.
Evisceration: The removal of the viscera.
GBS: Guillain-Barré syndrome is a quickly spreading paralysis of the peripheral nervous system with the result of muscle weakness and disturbances with moving and breathing.
House flock: all animals of the same age that are present in one house.
IBD: Inflammatory Bowel Disease is a generic term for chronic inflammations of the intestinal canal.
IKB: Integrated Chain Control.
Incidence: The number of persons in a certain population who become ill during a certain period.
Irradiation: The exposure of a product to beta- or gamma radiation to kill micro-organisms.
Labor income: The income that the poultry farmer earns to pay his labor. It is calculated as the return of a farm by the sale of broilers, reduced with the directly associated variable costs (a.o. one-day chicks, feed), the general costs associated with broiler production (a.o. manure disposal and –taxes, bookkeeping, energy, water) and fixed costs (a.o. debit, interest, maintenance, insurance).
LNV: Ministry of Agriculture, Nature and Food Quality
Logistic processing: The testing of broiler flocks for infection, followed by separate or one after the other processing of positively and negatively tested flocks.
Median: The middle value of a series of observations.
PCR-method: A method to detect bacteria by isolating DNA and multiplying specific parts of it.
Phage therapy: The treatment of infected animals with bacteria killing viruses (that are not harmful to humans) to reduce the degree of contamination.
Prevalence: The occurrence of illness or infection among a certain population at a certain moment.
PVE: Commodity Board for Meat, Poultry and Eggs
Scalding: The immersion of (processed) broilers in hot water so that the feathers will become lose and easy to remove.
Scheduled treatment: The testing of broiler flocks for infection, followed by separate treatment of positive and negative detected flocks.
Slaughter flock: all animals of one house flock that are simultaneously transported to the processing plant.
Thinning: A house flock of broilers is transported to the processing plant on two (or more) days with an interval of 5 or more days to provide remaining animals more space or to satisfy the demand of a specific weight from the market. Followed by depopulation when the remaining part of the house flock is being transported to the processing plant.
Transit: Imported chicken meat that, processed or not, again exported, so that the product does not end up on the Dutch consumer market.
VWA: Food and Consumer Product Safety Authority
VWS: Ministry of Public Health, Welfare and Sports