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## **Controlling Campylobacter in the chicken meat chain: a cost-utility analysis**

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# CONTROLLING CAMPYLOBACTER IN THE CHICKEN MEAT CHAIN: A COST-UTILITY ANALYSIS

## Abstract

The aim of this study was the estimation of cost-utility of interventions to control Campylobacter contamination of broiler meat. The relative risk, the intervention costs, the disease burden (expressed in DALYs) and the costs-of-illness for the various interventions were necessary inputs for the cost-utility analysis. The cost-utility is expressed in net costs per reduced DALY. The most cost-effective interventions are: reduction of faeces leakage in the slaughter line and decontamination of the carcass by dipping in a chemical solution. Phage therapy might be another cost-effective intervention, depending on assumed costs/chicken. Irradiation is the most efficient intervention, but the least cost-effective.

**Keywords:** Food safety; cost-utility; disease burden; Campylobacter; chicken meat;

**JEL:** D61, D81, I18

## Introduction

Campylobacter infections and sequelae pose an important public health problem in the Netherlands. Approximately 80,000 persons per year (90% C.I. 30,000 – 160,000) are estimated to experience symptoms of acute gastro-enteritis (GE), whereof 30 fatal cases. Some 18,000 patients are visiting a doctor and 500 are hospitalised each year. Additionally, each year some 1400 cases of reactive arthritis, 60 cases of Guillain-Barré syndrome and 10 cases of inflammatory bowel disease are associated with a previous Campylobacter infection (Mangen et al., 2005a). These authors estimated the associated disease burden (including morbidity and mortality) to be 1,200 Disability Adjusted Life Years (DALYs) (90% C.I. 900 – 1,600 DALYs) per year. The associated costs for the Dutch society, using cost estimates for the year 2000, included direct health-care costs, direct non-health-care costs and productivity losses from missed work, were estimated to total € 21 million (90% C.I. € 11 million - € 36 million) per year (Mangen et al., 2005a).

The most important reservoirs of campylobacters are found among animals, including farm animals, wild animals and pets. A recent large scale case-control study in the Netherlands, the CASA study, indicates chicken meat to be one of the major route, and to be responsible for at least 20% of all cases of human campylobacter infections (Doorduyn et al., 2005). We therefore decided to focus on the chicken meat chain in the current study.

In order to define the effectiveness and efficiency of potential policy options to reduce and control Campylobacter in the chicken meat chain, the aim of this study is an economic evaluation, which is applied in the form of a cost-utility analysis (CUA), taking a societal perspective. By relating the costs of the intervention applied in the chicken meat chain to 'reduced' burden of disease and 'reduced' cost-of-illness, the cost-utility ratio is obtained. The estimated cost-utility ratio will express the relative efficiency of several policy options to reduce the number of Campylobacter infections.

## Methodological approach

### *General*

The objective of this study is to analyze different intervention strategies that might result in a reduction of the incidence of human campylobacteriosis in the Netherlands. The economic setting should therefore allow us to judge the success of the intervention in terms of its impact on health status (Belli et al., 2001). Health outcomes can be expressed in monetary measures but also in health indices

(Drummond et al., 1997; Krupnick, 2004). Expressing health outcomes in health indices does have the preference in the Netherlands. Therefore, cost-effectiveness or cost-utility is the appropriated choice. Cost-effectiveness analysis (CEA) is a form of full economic evaluation, where both costs and health consequences of alternatives strategies are examined. In cost-effectiveness analysis, costs are related to a single, common effect that may differ in magnitude between the alternative programs (Drummond et al., 1997). The results of such comparisons may be stated either in terms of cost per unit of effect, or in terms of effects per unit of cost. A special form of CEA is cost-utility analysis (CUA) (Drummond et al., 1997); some also call this form a 'weighted' cost-effectiveness analysis (Belli et al., 2001). Here, the aim is to link net cost of an intervention to the combined effects of the intervention on mortality and morbidity, expressed in integrated health indices such as QALYs (quality adjusted live years) and DALYs (disability adjusted live years). The quality adjustment (disability adjustment) is based on a set of values or weights that are called van Neuman-Morgenstern utilities (Drummond et al., 1997). There are utilities for each possible health (disability) state. These utilities should reflect the relative desirability of the health state (Drummond et al., 1997). Within this study, the economic evaluation of interventions to reduce campylobacteriosis will be performed as a cost-utility analysis (unit: reduced DALYs).

### *Estimating cost-utility ratio*

The Dutch poultry meat production is an open system with considerable import and export of both live broiler chickens and broiler meat. This implies that measures taken to reduce the contamination with *Campylobacter* of broiler flocks or meat will not only have a positive effect on the health risks of consumers in the Netherlands, but also in countries that import Dutch products. On the other hand, a part of the meat consumed by Dutch consumers is not domestically produced, and consequently will not offer additional health protection if measures are only implemented in the Netherlands. Trade statistics are aggregated over the total Dutch production system and do not show the effects of transit goods, i.e. imported meat that is exported directly or after some kind of processing. However, this meat does not have an influence on the domestic market and must be excluded from calculations on the public health impact of interventions to reduce *Campylobacter* contamination. The proportion of imported meat in transit is not known. As an approximation, we assume that all fresh imported meat is sold on the domestic market (approximately 60%), and ignore the health risks of frozen imported meat, as it is either exported again or – if sold on the Dutch consumer market is associated with a considerably lower health risk due to the inactivation of *Campylobacter* by freezing. We test the importance of this assumption by sensitivity analysis. Trade statistics for the Netherlands are available at PVE (2002). Detailed information on the import and export of chicken meat can be found in Wagenaar et al. (2005).

The relative risk (see Nauta et al., 2005), the intervention costs (see Mangen et al., 2005b), the disease burden (expressed in DALYs) and the costs-of-illness (see Mangen et al., 2005a) for the various interventions were inputs necessary for the current cost-utility analysis.

For our cost-utility calculations, we define the following variables (see Figure 1):

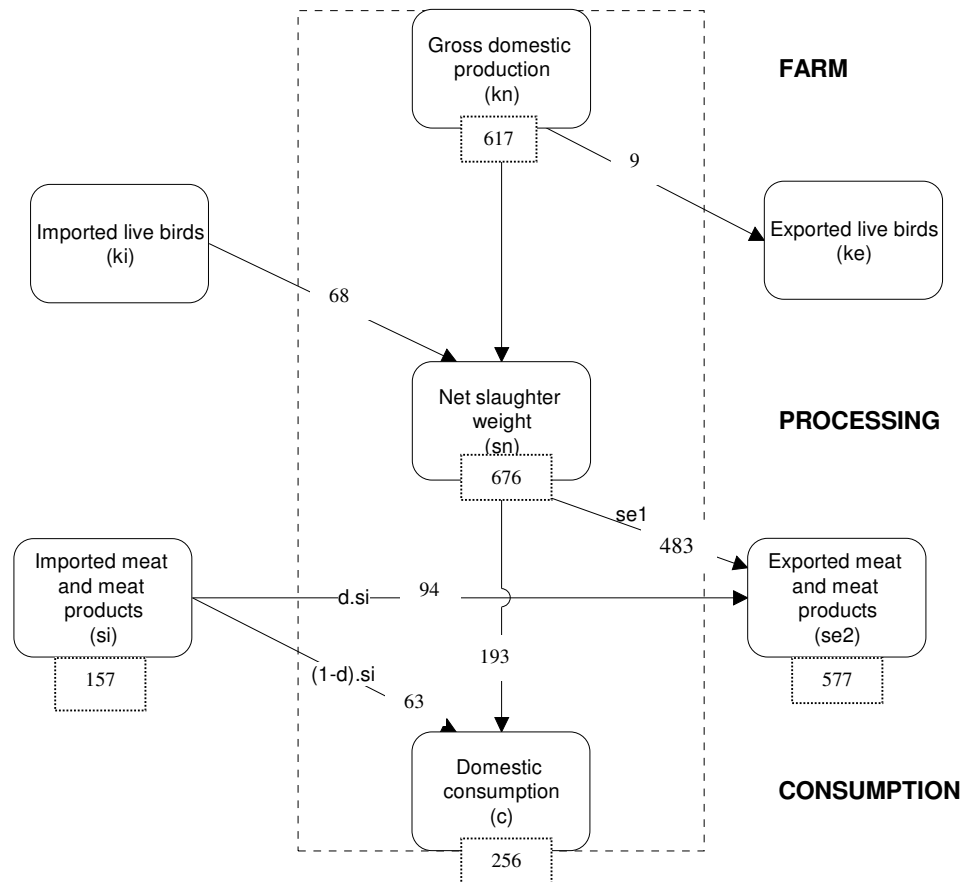


Figure 1. Diagram of the Dutch broiler meat chain in 2000 (slaughter weight in tons per year)

Whereby  $sn$  is:

$$sn = kn + ki - ke \quad (1)$$

$fn$ : fraction of net domestic slaughter weight that is produced on Dutch farms is:

$$fn = (sn - ki) / sn \quad (2)$$

$d$ : transit factor (proportion of  $si$  that is exported again);

$1-d$ : fraction of  $si$  that is sold on the domestic fresh meat market

$se1$ : export of broiler meat excluding transit

$se2$ : export of broiler meat including transit

$se1$  is the variable that is of importance for cost-effectiveness calculations, but  $se2$  is the variable that is reported in trade statistics.

$$se1 = se2 - d.si \quad (3)$$

The consumption of broiler meat ( $c$ ) in the Netherlands can be calculated as:

$$c = sn - se1 + (1-d) si = sn - se2 + si \quad (4)$$

Of  $c$  tons of consumed meat, a fraction,  $cn$  ( $cn = (sn - se1) / c$ ) is produced domestically and  $ci$  ( $ci = (1 - d) si / c$ ) is imported. For 2000, and assuming  $1-d$  is 40%,  $cn$  is 75% and  $ci$  is 25%. The

fraction  $cn$  is made up from animals raised in the Netherlands ( $cn1 = fn.cn = 68\%$  for 2000) and imported animals ( $cn2 = fn.(1-cn) = 8\%$  for 2000).

The risk model of the CARMA project (for details see Katsma et al. (2005) and Nauta et al. (2005)) calculates the relative risk associated with consumption of broiler meat in an intervention scenario as compared to the baseline scenario. Interventions can take place in different stages of the production chain: at the farm, during processing and in the consumer phase. The model considers a food chain that is confined to the Netherlands: broilers are raised on a Dutch farm, are slaughtered in a Dutch processing plant and are marketed, prepared and consumed in the Netherlands. If measures to reduce *Campylobacter* contamination of broilers or broiler meat would only be implemented in the Netherlands, the risk to Dutch consumers would only be reduced for the proportion of the meat that is produced under Dutch regulation.

Interventions in the consumer phase affect all meat that is sold in the Netherlands, irrespective of its origin. Hence, for these interventions, the effects of import and export are not relevant.

$i$  cases of campylobacteriosis are associated with a disease burden  $b$  (DALYs per year) and cost of illness  $m$  (€ per year). Table 1 shows the calculation of these variables as a function of the attributable fraction ( $af$ ) and the total estimates for campylobacteriosis by all causes (symbols in capital letters). As in the calculations of the intervention costs, where long-lasting investment costs are depreciated, using an interest rate of 4%, the estimates for disease burden and cost of illness are also discounted at this rate.

Table 1. Incidence of campylobacteriosis, associated disease burden and cost-of-illness in the Netherlands for the year 2000

I	79,000	cases per year
B	850 <sup>a</sup>	DALYs per year
M	€ 19,400,000 <sup>a</sup>	Per year
$af$	20% <sup>b</sup>	-
$i$	15,800 <sup>c</sup>	cases per year
$b$	170 <sup>a, c</sup>	DALYs per year
$m$	€ 3,880,000 <sup>a, c</sup>	per year

<sup>a</sup> Discounted at 4%.

<sup>b</sup> Uncertain assumption; sensitivity analysis is applied.

<sup>c</sup> If assuming that only Dutch broiler meat is consumed in the Netherlands.

Let  $pc$  be the relative risk after implementation of an intervention in the consumer phase, as compared to the baseline risk (see Nauta et al., 2005 for details). Then, the reduction in cases of campylobacteriosis is:

$$\Delta ic = (1-pc) i \text{ (cases per year)} \quad (5)$$

We assume that a reduction in the incidence of campylobacteriosis cases causes a proportional reduction of disease burden and cost of illness (i.e. the reduction in incidence of mortality, Guillain-Barré syndrome, reactive arthritis and inflammatory bowel disease is proportional to the reduction on cases of GE). Then, the reduction in disease burden is:

$$\Delta bc = (1-pc) b \text{ (DALY per year)} \quad (6)$$

and the reduction in the cost of illness is

$$\Delta mc = (1-pc) m \text{ (€ per year)} \quad (7)$$

When implementing an intervention measure, additional costs are made in the chicken meat chain. Apart from the direct treatment costs, e.g. costs for irradiating meat, other directly related costs, as for example in the case of irradiation the transport costs from processing plant to irradiation plant and back, are included in the estimated 'treatment' costs. Furthermore, in the case of channelling (treating positively tested flocks differently from negatively tested flocks), the testing costs for on-farm testing and for control in the processing plant, are also included in the estimated intervention costs for intervention  $y$ . For more details see Mangen et al. (2005b). If the costs of an intervention in the consumer phase are  $e$  (€ per year), then the cost-utility ratio (CUR) is:

$$uc = (e - \Delta mc) / \Delta bc \text{ (€ per DALY averted)} \quad (8)$$

Interventions in Dutch processing plants will not affect the quality of imported meats and this needs to be accounted for in cost-utility calculations. Meat consumed in the Netherlands is made up of domestically produced and imported meat, which may be associated with a different risk factor. However, we have no information on the magnitude of this difference, and assume therefore that the risk is equal for domestic and imported meat.

Let  $ps$  be the relative risk of consuming domestically produced meat after implementation of an intervention in the processing plant. This intervention only affects the domestically produced meat (a fraction  $cn$  of all meat consumed in the Netherlands). Then, the reduction in cases of campylobacteriosis, disease burden and cost of illness are, respectively:

$$\Delta is = (1-ps) cn.i \text{ (cases per year)} \quad (9)$$

$$\Delta bs = (1-ps) cn.b \text{ (DALY per year)} \quad (10)$$

$$\Delta ms = (1-ps) cn.m \text{ (€ per year)} \quad (11)$$

Cost-utility ratios are calculated as shown in equation (8).

Interventions at Dutch farms only will not affect the Campylobacter status of live imported birds, thus further reducing the health benefits for Dutch consumers. Following the above example, the reduction in cases of campylobacteriosis, disease burden and cost of illness are, respectively:

$$\Delta if = (1-pf) cn.fn.i \text{ (cases per year)} \quad (12)$$

$$\Delta bs = (1-pf) cn.fn.b \text{ (DALY per year)} \quad (13)$$

$$\Delta ms = (1-pf) cn.fn.m \text{ (€ per year)} \quad (14)$$

Cost-utility ratios are calculated as shown in equation (8).

As the majority of Dutch broiler meat is exported, the above cost-utility calculations for the Dutch population do not reflect all health benefits that are associated with interventions in the Netherlands. A precise estimate of these benefits would require assessment of the health risks, disease burden and cost of illness for consumers in importing countries. Such data are not available. As a first estimate, we can assume that these factors are proportional to the Netherlands. As most Dutch broiler meat is exported within the European Union, this assumption is defensible. The amount of exported meat that is produced domestically is  $sn$ . Part of this production is exported as frozen meat, and this is associated with a low risk because freezing kills up to 2 log-units of Campylobacter. For the purpose of this analysis, we neglect the risks of frozen meat and assume that only consumers of fresh exported meat benefit from interventions. Similarly, the health risks to the Dutch population are only related to the fraction  $fr$  that is sold as fresh meat in the Netherlands. Exact figures are unknown, but the fraction of broiler meat that is sold as fresh meat in the Netherlands is estimated to be around 90% (van Horne, LEI, personal communication; December 2004). We test the importance of this assumption by sensitivity analysis.

### *Sensitivity analysis*

In order to estimate the CUR for the various intervention measures under study, a few assumptions had to be made. Sensitivity analysis is applied on the most critical assumptions that are:

- attributable fraction (af)
- transit factor (d)
- fraction of fresh meat consumed in the Netherlands (fr)

The assumed values for the baseline scenario and for the sensitivity analysis for of these different parameters are summarized in Table 2.

Table 2. Applying sensitivity analysis to Cost-effectiveness of interventions in the farm phase, for all consumers of Dutch broiler meat

Parameters	Base	Alternative I	Alternative II
Attributable fraction (af)	20%	40%	n.a.
Transit factor (d)	60%	80%	40%
Fraction of fresh meat consumed in NL (fr)	90%	95%	85%

However, the estimated relative risk after implementation of intervention  $y$  is also an uncertain estimate. We therefore estimate the CUR by not only using the most likely value, but applied by using the lower (optimistic) and upper (pessimistic) estimated values of applied sensitivity analyses for relative risk after implementation of intervention  $y$ .

Furthermore, when estimating the potential intervention costs for the various intervention measures under study, assumptions and best guesses of some costs had to be made either due to scarce data sources or due to a lack of data. We therefore perform some additional what-if-scenario on these cost estimates in order to check for the robustness of our results.

In the Netherlands, about 90% of sold broiler meat is estimated to be fresh meat. But some of the intervention measures under study might result in side-effects that might not be conform to the current demand for 'fresh' poultry meat on the Dutch market. For example, a too high concentration of lactic acid might result in 'paler' meat (Snijders et al., 2004; Stekelenburg and Logtenberg, 2004), and might therefore not be recognised by the consumer as being fresh. Another example is irradiated poultry meat. Irradiated poultry meat has to be labelled, but according to numerous studies, irradiated food is hardly accepted. Processed and prepared meat or frozen meats are no fresh meat products. Therefore, apart from the 'treatment' costs, mainly processing plants might suffer additional losses because of being forced to sell the chicken carcasses and chicken meat at a lower price. Broiler meat imported from Brazil and Thailand are one of the major competitors of Dutch broiler meat (Bondt and Horne, 2002). But high import duties imposed on the EU borders protects the EU fresh broiler meat market, which is the main market for Dutch broiler meat, from the potential 'lower' non-EU countries broiler meat. However, for non-fresh broiler meat, e.g. by adding salt, the import duties for non-EU countries are lowered considerably. Sensitivity analysis will be applied here.

### *Special considerations with respect to the applied economic analysis*

In the cost-of-illness study the friction cost method was used to estimate productivity losses, following Dutch guidelines for public health economic evaluation studies. In the friction cost method, production losses are only considered for the period needed to replace a sick, invalid or dead worker, the 'friction period'. The friction cost method places a zero value on persons outside the labor market, such as children 15 and younger and retirees 65 and older. The friction cost method takes explicitly into account the economic processes whereby a sick, invalid or dead person can and will be replaced after a period of adaptation (Koopmanschap and van Ineveld, 1992). The length of the friction period depends on the situation of the labor market. A high unemployment rate generally allows fast replacement of a sick, invalid or dead person, whereas in the case of a low unemployment rate, on



average more time is needed. Because the Dutch unemployment rate in 2000 was comparable to the one in 1998, we assume for the year 2000 a friction period of 123 days similar to the one estimated by Oostenbrink et al. (2000) for the year 1998. Non-Dutch studies estimated indirect non-health care costs often by using the human capital approach. The human capital approach estimates the value of *potential* lost production (or the potential lost income) as a consequence of disease. In the case of permanent disability or premature death at a specific age the total productivity value (or income) from that age until the age of retirement is counted as productivity losses. But according to Koopmanschap et al. (1995), the real production losses for society are smaller. The human capital method is based on neoclassical labor theory, using assumptions that are unrealistic given the contemporary European labor market. ‘The aim of the friction cost approach is to adjust the human capital estimates of productivity costs for the compensations that are likely to occur as a result of a labor market that does not adhere to neoclassical theory’ (Sculpher, 2001).

Another point to highlight is the fact that in this study, we assumed that none of the intervention measures under study would affect a) the Dutch supply of chicken meat, b) the Dutch domestic consumer demand of chicken meat and c) the export position of the Dutch broiler industry.

### **Intervention measures under study**

By mutual agreement of the Steering Committee of the CARMA project, which includes risk managers of the Ministries of Public Health and Agriculture, and after discussion with Industry Forum (composed of representatives of the Dutch chicken farmers, the Dutch slaughterhouses and processing plants as well as the research institutes involved) and experts in the field, the following intervention measures have been selected for evaluation:

1. Farm-level:
  - 1.1. Further improvement of hygiene at the farm: Additional hygiene measures to reduce transmission between stables and between successive flocks
  - 1.2. Phage therapy
2. Processing plant level:
  - 2.1. Reduction of faecal leakage: reduction of faeces leakage during scalding and de-feathering
  - 2.2. Decontamination scald tank: decontamination of the scald water by adding lactic acid; assumed concentration is 2.5%.
  - 2.3. Decontamination carcass: decontamination of the carcass
    - 2.3.1. by dipping carcass before chilling in an additional scald tank with lactic acid; assumed concentration is 2.5% (lactic acid 1x)
    - 2.3.2. by adding lactic acid to the washing and chilling water, as well as dipping after de-feathering; applied concentration is 2.5% (lactic acid 3x)
  - 2.4. Crust freezing:
  - 2.5. Irradiation: assuming gamma irradiation of poultry meat
  - 2.6. Product freezing: assuming freezing of poultry meat and carcasses for 2 weeks at - 20°C
3. Consumer level:
  - 3.1. Improvement of kitchen hygiene: the use of separate cutting boards and utensils for the preparation of the meat and for the preparation of salads or other foods that are eaten raw and hand washing are promoted
  - 3.2. Home freezing: the home freezing and storing of chicken meat for some days to a week is promoted.

The CUR is estimated for all interventions, assuming that all broilers are treated. For the interventions 1.2; 2.3, 2.4, 2.5 and 2.6, we further estimated the CUR, assuming that only broilers from positively tested flocks would be treated. In these cases, testing is applied shortly before slaughtering in order to define *Campylobacter* infected flocks. Using a PCR test, with a sensitivity of 95 and a specificity of 100 (see Katsma et al., 2005), the fraction of positively tested flocks is 0.29.

A detailed description of the various interventions under study, and an estimation of related costs can be found in Mangen et al. (2005b). Details on risk assessment modelling of the different interventions measures are given in Katsma et al. (2005) (farm) and Nauta et al. (2005) (processing plant and consumer; comparison of interventions).

## Results

Only broiler meat associated campylobacteriosis cases are considered in this study. Although we estimated for all interventions under study the reduced number of Campylobacter associated GE cases per year, the reduced annual disease burden associated with Campylobacter infections (expressed in DALYs), the reduced costs-of-illness, the cost-effectiveness ratio (CER) and the cost-utility ratio (CUR), we do show in this paper only the main results, whereby focussing only on the cost-utility ratio. Full details of the applied economic evaluation can be found in Mangen et al. (2005c), if not others indicated.

In this study, we estimated cost-utility ratio using the Dutch perspective (see Figure 2). Given that the relative risk of intervention  $\gamma$  is an uncertain estimate (see Nauta et al. (2005) for details), we have estimated also the reduced annual disease burden and the CUR for interventions without channelling only, using the lower (optimistic) and upper (pessimistic) estimated value of applied sensitivity analyses for the various estimated relative risks, respectively (see Figure 2). Whereas for the intervention costs, we do show mainly on the estimated most likely value.

There are some potential interesting intervention measures, based on their theoretical efficiency and effectiveness.

On farm-level there are two intervention measures that might be of interest, namely farm hygiene and phage therapy.

Additional hygiene at farm might be theoretically very effective in controlling Campylobacter infection of flocks, as demonstrated in the farm model (see Katsma *et al.*, 2005). But according to Bouwknegt et al. (2004), a large proportion of Dutch broiler farms have already implemented 'optimal' hygiene. Specific knowledge, however, about what factors really does matter, and furthermore, knowledge about the practical implication in the field is missing. That was also the reason why it was difficult to make cost estimates. Opposite to the other interventions, we do use here a minimum and a maximum cost estimate, respectively, see Figure 2.

The phage therapy, another intervention measure of interest, have proven to be effective. However, the phage therapy is currently under development. No cost price was available and the assumed cost price determines the CUR estimate (for details see Mangen et al., 2005 b&c). A lower (higher) cost price (results not shown), results in a better (worse) CUR than shown in Figure 2.

In processing plants, the reduction of faecal leakage seems to be the most cost-effective measure of all interventions analysed. Decontamination of carcasses from positively tested flocks by dipping in a chemical solution, with or without channeling, might be another promising cost-effective intervention. All other intervention measure are not cost effective (see Figure 2).

Reduction of faecal leakage in the first processing steps turned out to be one of the most cost-effective interventions of all analysed intervention measures in this study (see Figure 2). Although the modelling exercise, as well as first results from an experiment, does show the potential of this intervention, the estimated relative risk remains uncertain. Consequently, this intervention measure, see Figure 2, would not be cost effective at all.

Of all the different chemical decontamination intervention measures analysed in this study, is the decontamination of carcass by dipping in a chemical solution just before chilling a promising efficient and cost-effective intervention measure, see Figure 2. By treating only positively tested flocks, the averted DALYs/year is lower than if treating all carcasses, as also the related treatment costs, with as consequence a better CUR estimate (Figure 2). Lower cost price for e.g. lactic acid and/or a lower concentration does result in lower intervention costs (see Mangen et al., 2005b), and consequently in better CUR estimates (results not shown) than shown in Figure 2.

At consumer level, two interventions were analysed. Both intervention measures, i.e. mass-media campaigns to improve kitchen hygiene and home-freezing of chicken meat, are theoretically efficient control. But given that both intervention measures presume that consumers would have to change their behaviour, and mass-media campaigns in general are less effective in changing behaviour, which is difficult to establish, they turned out to be not cost-effective at all, see figure 2.

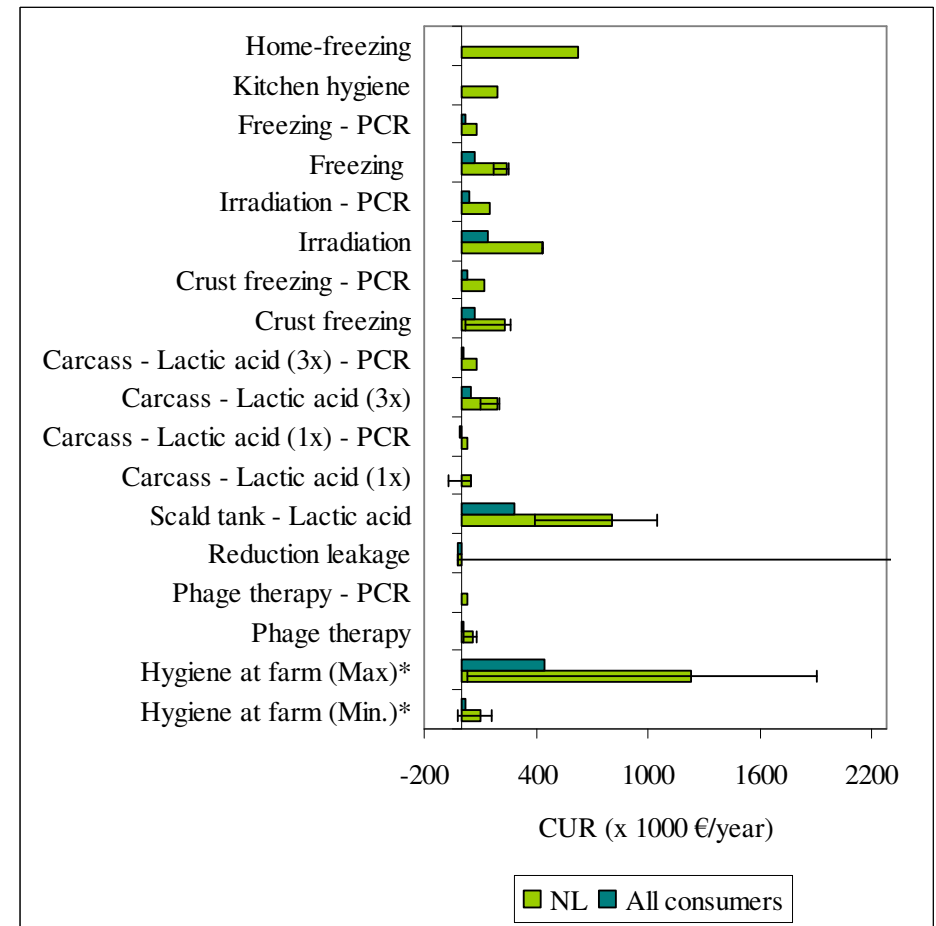
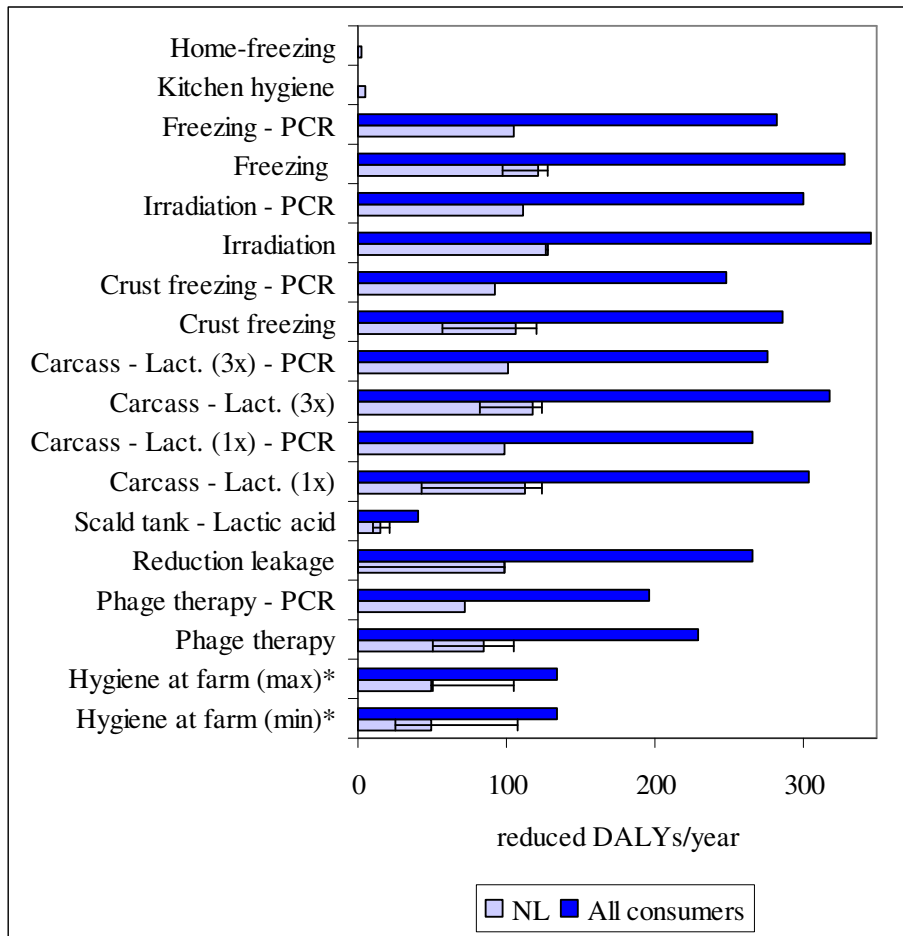


Figure 2. Estimated reduced DALYs/year and CUR, respectively, for the various interventions from the Dutch perspective (NL) and from the perspective of all consumers eating Dutch meat (ALL), respectively, whereby assuming most likely values for relative risk and intervention costs. Error bars expressing an uncertainty interval that results from using optimistic and pessimistic interpretation of the effects of the interventions, but only for the Dutch perspective. For hygiene at farm (\*) we assumed the minimum and maximum intervention cost estimates.

In general the averted number of DALYs per year is always lower for an intervention with channelling than without channelling (Figure 2). But given the reduced intervention costs, - direct costs only -, the estimated CUR are better for an intervention with channelling than without channelling. Channelling, however, might result in an increase of the current production costs due to product inefficiency during slaughtering and processing and/or logistic inefficiency. For example, additional cleaning of the processing line between the slaughtering of two successive flocks might be required, resulting in lesser chicks slaughtered per working hour. What the financial consequences of such increased product and logistic inefficiency is hard to estimate. In agreement with the processing plant managers it was therefore decided to do some what-if-scenarios (results not shown). In general increased production costs due to channelling results always in higher cost-utility ratios than if treating all broilers and broiler meat.

The Dutch broiler sector is an open economy with considerable imports and exports. Except for intervention measures at consumer level, the estimated CUR for the Dutch population, as shown in Figure 2, do not reflect all health benefits that are associated with interventions in the Netherlands. A part of the health benefits associated with interventions on Dutch farms and in Dutch processing plants, respectively, is realised in countries importing Dutch meat. For sensitivity analysis, we there used also the perspective of all consumers eating Dutch meat. Assuming that health risks, disease burden and cost-of-illness are similar for consumers in importing countries as for consumers in the Netherlands, the reduced annual disease burden for all consumers eating Dutch broiler meat is estimated, assuming the most likely value of the estimated relative risk. Based on these results, the CUR is estimated from the perspective of all consumers eating Dutch broiler meat. Results are summarized in Figure 2. Except for interventions at consumer level, the number of reduced DALYs/year doubles to triples by considering all consumers eating Dutch broiler meat, compared to Dutch consumers only. The savings in cost-of-illness are larger by considering all consumers compared to Dutch consumers only (results not shown). However, intervention costs do not change. Consequently, the estimated CUR are better when considering all consumers compared to Dutch consumers only.

Apart from the relative risk, also other factors are uncertain and assumptions had to be made. Sensitivity analysis is applied to analyse the impact of these assumptions on our results. The attributable fraction (af) is assumed to be 40% at the most (Havelaar, 2002). An increase of the attributable fraction from 20% (baseline) to 40%, results in a doubling of the estimated number of reduced annual GE cases and reduced disease burden for all interventions under study (see Figure 3). Consequently, the CUR estimates improve (results not shown).

In the baseline scenario we assume that the transit factor of imported meat would be 60%, equal to the percentage of fresh imported meat. For sensitivity analysis, we assume that the transit factor (d) would be 40% and 80%, respectively. The estimated number of reduced annual disease burden decrease and increase slightly, respectively, as shown in Figure 3. Consequently, estimated CUR increase and decrease slightly, respectively. However, the ranking of the different intervention measures is not changed. The assumed transition factor has no impact on health outcomes related to interventions at consumer-level.

The fraction of fresh meat consumed in the Netherlands (fr) was assumed to be 90% in the baseline. A change of fr does not affect the estimated number of reduced disease burden in the Netherlands, but affects only the number of GE cases generated outside the Netherlands due to Dutch exported broilers and broiler meat. Health outcome due to interventions at consumer level are not affected. Changing the fraction of fresh meat to 95% and 85%, respectively, results in a slight decrease and increase, respectively, of the total estimated reduced disease burden/year (results not shown). An increase of fr to 95% results in slightly higher cost-utility ratio. Whereas a decrease of fr to 85% does improve slightly the cost-utility ratio of the different intervention measures. The assumed fraction of fresh meat has only little impact on the estimated results and does not affect the ranking of the different interventions.

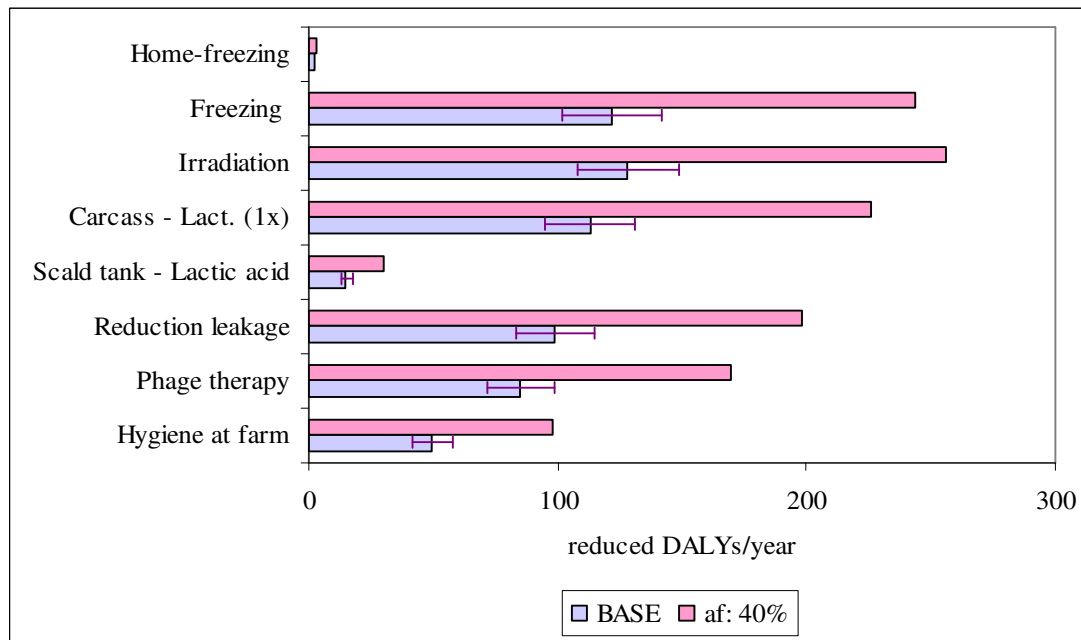


Figure 3. Estimated reduced DALYs/year in the Netherlands for some of the interventions, assuming most likely values for relative risk and intervention costs. The attributable fraction (af) is assumed to be 20% in the baseline and 40% in the alternative scenario. The transit factor is assumed to be 60% in the baseline, the error bars expressing a decrease (increase) of the transit factor by 20% points.

The estimated intervention costs, which are inputs in the current study are for a part highly uncertain (see Mangen et al., 2005b). Lower intervention costs do improve the estimated CUR, whereas higher intervention costs result in worse CUR estimates. In general when using lower and higher interventions cost estimates, the ranking of the most effective interventions measures is not affected, except for the phage therapy, making this the most cost-effective option (for results see Mangen et al. (2005c)). Lower intervention costs for the phage therapy would result in a CUR of -22,000 €/DALY, whereby considering only consumers in the Netherlands. Irradiation is the only intervention measure able at eliminating campylobacters on chicken meat. However, the CUR estimates for Dutch consumers only is 0.44 million €/DALY, assuming most likely cost estimate. And even when transport costs are not considered and only the minimum cost estimate for irradiation is taken, the estimated CUR would still be 0.2 million €/DALY.

So far, we have analysed only one intervention at a time. A combination of two or more interventions is also a way to control campylobacters. A promising combination to us was the reduction of faecal leakage and decontamination of carcasses by dipping. The relative risk of such a combination was estimated to be 0.017 (Nauta et al., 2005), resulting in a reduced disease burden of 126 DALYs/year, compared to 99 DALY and 113 DALY, respectively, for faecal leakage reduction and decontamination of carcasses by dipping only, respectively.

Organoleptic changes, product changes and non-acceptance by the consumers might result in a price reduction of the selling price at processing level. Dutch non-fresh meat might have to compete mainly with Brazil and Thai broiler meat. The difference in the estimated cost price for Dutch broiler meat and Brazilian broiler meat was, according to Bondt and Horne (2002), 0.47 € per kg in 2000. Losses due to price reduction result in worse CUR estimates than if considering treatment costs only (results not shown). For example, assuming a price reduction of 0.40 €/kg results in enormous losses for the industry, with as consequence cost-utility ratios of more than 1 million €/reduced DALY when all chicken meat would be treated. The CUR estimates lie between 1 and 0.75 million €/DALY when only broilers from positively tested flocks would be treated. These estimates are slightly overestimated, because some of the losses for the processing industry considered here might be washed out by increased welfare changes of other stakeholders further up in the chain.

## Discussion and conclusion

Depending if an intervention is applied at farm-level, processing level and consumer level, respectively, broiler meat originating from Dutch farms, broiler meat originating from broilers slaughtered in the Netherlands (Dutch and imported broilers), and broiler meat sold on the Dutch market (Dutch and foreign broiler meat), respectively, is tackled. There are some potential interesting intervention measures, based on their theoretical efficiency and effectiveness. However, there is no single intervention that could be applied without any clause.

On farm-level there are two intervention measures that might be of interest, namely farm hygiene and phage therapy. But with respect to further improvement of farm hygiene, further research about the factors that really does matter are required. Further the practical implication of potential improvement of farm hygiene measures, as well as their efficiency in controlling *Campylobacter* should be proven before forcing broiler farms to further invest in additional measures. Whereas for the phage therapy, the assumed costs per chick treated determine mainly if this intervention measure is cost effective or not (full results not shown).

In processing plants, the reduction of faecal leakage seems to be the most cost-effective measure of all interventions analysed. However, when taking the value of the upper (pessimistic) estimated value of applied sensitivity analyses for relative risk, this intervention measure would not be cost effective at all. Therefore, more research under practical circumstances to strengthen the knowledge about the efficiency of this intervention measure is recommended. Channelling and decontamination of carcasses from positively tested flocks by dipping in a chemical solution might be another promising cost-effective intervention. The cost price of the used chemical substance and the concentration of the chemical substance, are the two main factors that determine the intervention costs. Therefore further research of technical improvements and their efficacy with respect to chemical decontamination is recommended. Whereas all other interventions like crust-freezing, product freezing, prepared meat use only and irradiation are all found to be not cost-effective, despite the fact that irradiation, is the most efficient interventions of all analysed intervention measures.

At consumer level, two interventions were analysed. And although theoretically very effective, they turned out to be not cost effective at all, given that both intervention measures presume that consumers would have to change their behaviour.

If channelling is an option, product and logistic inefficiency is the first subject to concentrate on. Because increased production costs due to channelling results always in higher cost-utility ratios than if treating all broilers and broiler meat.

Product freezing and prepared meat, in particular, result in a product change. But it is explicitly the fresh broiler meat market in the EU where the Dutch broiler meat sector gets its surplus value, and consequently its ability to compete with such nations as Brazil and Thailand. And even when channelling, an average annual prevalence of over 30% positively tested broiler meat, might result in a shortage of fresh meat. Especially the summer months, with an increase in prevalence of up to 60%, the supply of fresh meat cannot cover the demand. But organoleptic changes, product changes and/or non-acceptance by the consumer might result in a price reduction of the selling price at processing level. Losses due to price reduction results in worse CUR estimates than if considering treatment costs only. But some of the losses for the processing industry considered in our study might be washed out by increased welfare changes of other stakeholders further up in the chain (e.g. retailers, consumers). However, the gainers of such positive 'benefits', if than occurring, varies from intervention to intervention. But given that most of these positive welfare changes would be exported to other countries, we had decided not to consider these stakeholders in the current study. From the Dutch society perspective, the largest part of these price 'benefits' would be exported, with as consequence that the CUR estimates would still be worse than CUR estimates of treatment costs only.

Given that most campylobacteriosis cases are sporadic cases, traceability to a certain product or firm might be hard to make. We therefore did not consider the potential costs and losses related to product recalls and liability claims in the current study.

The Dutch broiler sector is an open economy with considerable imports and exports. Interventions at consumer-level are the only interventions tackling the problem in Dutch and foreign broiler meat sold in the Netherlands. By applying interventions at farm and processing level, huge exports of broilers and chicken meat leads to an export of a large part of the attained health benefits.

Consequently the estimated CER and CUR for the various intervention measures under study are becoming more cost-effective when considering all consumers eating Dutch broiler meat. But the ranking of the most cost-effective interventions is not affected. Nevertheless, an economic analysis from an international perspective, e.g. the EU, rather than a national perspective would be more appropriate in order to take all benefits into consideration.

Another point to highlight is the fact that in this study, we assumed that none of the intervention measures under study would affect a) the Dutch supply of chicken meat, b) the Dutch domestic consumer demand of chicken meat and c) the export position of the Dutch broiler industry. In reality, however, the chicken meat chain is strongly vertically integrated and there is also high competitiveness between countries in this sector (Bondt and Van Horne, 2002). But the interventions under study have economic implications for the partners in the food production chain. Whereas the majority of effects – such as the reduction of gastroenteritis and associated days of paid work lost - will be effectuated in other parts of society. If additional costs and losses related to the implementation of intervention measures cannot be passed on to other stakeholders then the estimated treatment costs, the potential losses due price reduction and the additional costs due to channelling would have to be borne by the Dutch chicken meat sector (e.g. farmers and processing plants), resulting in lower margins. However, higher production costs, resulting from national intervention measures, would weaken the competitiveness of the Dutch broiler farmers and the Dutch broiler processing sector, respectively, in and outside the Netherlands, leading in the long-term to a potential important shrinking of the Dutch broiler farmer and processing sector, respectively. Increased imports of less safe meat might be one of the consequences. This is a point that requests for an application of interventions at an international scale, rather than national scale. This point should not be negligee in future studies.

Increased imports and the loss of competitiveness might result in higher CUR estimates, but would hardly change the ranking of the several policy options to reduce the number of Campylobacter infections. Expressing the relative efficiency of several policy options to reduce Campylobacter infections, however, was the aim of this study. It was therefore not necessary to quantify adequately the effects of reduced competitiveness of the Dutch broiler sector.

The Dutch broiler sector might gain the additional costs back, and eventually might benefit from the situation, only if they somehow succeed in convincing consumers both in and outside the Netherlands that it is worth paying higher prices for safer broiler meat, and that Dutch broiler meat is safer than any other. But before any pay-off from the efforts would be seen, large efforts – including monetary efforts – would need to be made, especially in product development and marketing. It is unlikely, however, that all business involved can make this change in strategy. However, according to Ollinger and Ballenger (2003), the downside for such branded products is that the brand may also be used to identify the company as the source of a food borne illness. Consequently, if a serious food safety crisis occurs, producers of branded products will see their investments and efforts evaporate due to product recalls and liability claims.

In this study, we consider only the health benefits and reduced cost-of-illness associated with a reduced risk of Campylobacter infections. Consequently, health benefits due to the reduction of other food borne pathogens tackled by the applied intervention measures are not considered in this study. Estimated cost-effectiveness and cost-utility ratio are therefore overestimated.

The societal perspective is traditionally the perspective chosen in economic evaluation. The assumption hereby is that investments are worth doing, when the society as a whole is better off than when doing nothing. However, in the current study the ‘gainers’ and the ‘losers’ are not the same. Costs are made in the food production chain, while health care, employers and society at large (reduced intangible costs) benefit from these investments. The savings made in cost-of-illness for Dutch consumers only, and for all consumers eating Dutch broiler meat, respectively, approximately two third of these savings are made by employers due to fewer days off work and one third of these savings are made by sick funds (see Mangen et al., 2005). A non-monetary ‘savings’, is the reduced disease burden (reduced intangible costs), expressed in DALYs. Citizens (consumers) are benefiting from a reduced disease burden.

The cost-utility approach was the method chosen in this study. Some of the few economic studies published in the field of food safety, which do also consider human health benefits, do use a cost-benefit approach, e.g. Kangas et al. (2003) for the Finish Salmonella Control Programme for broilers and Crutchfield et al. (1999) for the evaluation of HACCP in the United States. In both studies the intangible costs for premature death, which in our study is expressed in DALYs, is expressed using a

monetary value. Kangas et al. (2003) used a combination of two separate approaches to attach a monetary value to premature death, ranking from minimum € 0.94 million to maximum € 1.7 million. The first approach was to value the lost work contributions, and the second approach expressed the willingness of society to pay for 'extended' life. Crutchfield *et al.* (1999) applied two approaches to estimate the premature death value, namely the human capital approach and the labour market approach. Both studies calculated health care costs and productivity losses for sick persons, hospitalised or not, as was done in this study. However, none of these studies do consider the intangible costs of suffering of sick, but not fatal, cases. But by using the DALY approach, we were able to account also for the intangible costs of suffering of sick persons, similar as applied in the study of Roth et al. (2003) for the brucellosis control in Mongolia.

There are also some cost-effectiveness studies available in the international literature, such as e.g. Van der Gaag et al. (2004) and Malcolm et al. (2004). But often these studies do only analyse the effect of interventions on the reduction of pathogens on the product analysed, omitting to account for the associated health benefit within the human population.

In the Netherlands, cost-utility analysis is the applied methodology in the public health sector. By using the cost-utility approach in this study, results of the various interventions to control campylobacters in the chicken meat chain can be compared with interventions applied to tackle other public health problem.

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