What Can Be Learned from Economic Analyses of the Danish Salmonella Control Programs?

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During the last few decades the industrialized countries have experienced significant increases in the registered number of human infections related to food risks. At the same time, there has been an increasing interest in food safety from citizens and the media. This development has induced governments to spend millions of dollars on food safety (Käferstein, Motarjema, and Bettcher 1997), and from a social-welfare point of view it is important to highlight the economic implications of food safety policy.

An unfortunate rise in the number of human Salmonella infections in Denmark during the 1980s and 1990s (Danish Zoonosis Centre 2008) led the Danish government and the industries concerned to formulate Salmonella control programs. This paper presents economic evaluations of these programs. In particular, the paper illustrates the dependence of economic analyses on whether private or social performances are included as well as on assumptions regarding time horizon, the behavior of agents, and the availability of reliable data. Because the Salmonella controls in Denmark and the other Nordic countries are considered leading-edge by international standards (Wahlström 2006), the lessons learned from the Danish Salmonella control can be used to guide future Salmonella control and other food-safety policies in Denmark and other countries.

This paper begins with a discussion of the costs and benefits involved in food-safety policy in general, followed by a description of the food-safety policy implemented in Denmark and estimation of the policy's effect on public health. Two inherently different economic analyses are presented. In the first analysis, we compare direct costs with direct benefits estimated by using a cost-of-illness approach. The second analysis incorporates derived effects of Salmonella control using a general equilibrium approach. The final section contains concluding remarks and policy perspectives.

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Economic Analysis of Food-Safety Policy

The main cost of food safety is typically carried by the food producers as they incur direct costs related to increased hygiene requirements, internal control, and documentation. Moreover, food producers have indirect costs arising from restrictions on their production possibilities (Antle 2001). The public sector entails direct costs of food safety due to monitoring and control. The public and/or private sector encounters indirect costs in terms of research and development of new technology. The main benefit arising from increased food safety is improved population health. From a societal perspective the most visible direct economic effects are reductions in public-health expenditures and increased workforce productivity arising from fewer sick days and fewer premature deaths (these effects are typically denoted costs of illness [Kenkel 1994]). Benefits from increased food safety also include utility of improved health that goes beyond avoiding hospital stay and loss of earnings. Additionally, there is a potential utility gain associated with increased trust in food products, just as regulation of a food-safety problem might increase incentives for development of improved technologies for food production in relation to food safety as well as other areas. Finally, some implications from enhanced food safety cannot *a priori* be classified as either costs or benefits. For example, increased costs due to regulation may induce food producers to raise output prices, inducing consumers to substitute domestically produced food products with imported products and other goods and services. This change in consumption is a disadvantage for domestic food producers and beneficial for other domestic producers and/or foreign producers.

In theory, consumer willingness to pay for reduced risks of illness and premature death is the best estimate of the economic benefits of enhanced food

safety (Buzby, Roberts, and Allos 1997). Because such estimates are typically not observable in the market, consumer surveys are often used to elicit stated preferences for food-

safety, the methodological issue of how to obtain reliable and generally applicable estimates remains a significant obstacle of this method. This brings into focus the main advantage of the cost-of-illness (COI) method: the availability of data. It should be noted, however, that even though such data can normally be retrieved, there are many ways to perform the actual estimations. Furthermore, the main criticism of using the COI method to evaluate food-safety policies is that the costs of illness only capture the (ex post) costs directly related to persons being ill; they do not capture the (ex ante) costs of facing the risk. Keeping the limitations of the COI method in mind, we will apply this measure of benefits.

Economic evaluations of food-safety policy depend on whether the costs and benefits are seen from an industry's or from a societal perspective. As an example, public monitoring and control costs, public research and development expenditure, and public-health costs are not included in an industry-level analysis, but they are highly relevant in a social-welfare analysis. Also, increased productivity in any sector enhances welfare to society, whereas an industry sector considers increased productivity in its own sector to be a positive change but increased productivity in competing sectors is considered a negative development.

Assessing the effect on market prices or production volumes of a food-safety policy requires specific assumptions regarding how producers, consumers, and other economic agents adjust to the new policy. In particular, assessment of the economy-wide effects on market prices and production volumes requires assumptions of the links between the markets for regulated and non-regulated products through producers' and/or consumers' behavior. The most widespread type of cost-benefit analysis of food-safety policy is to compare direct costs to the producers and the public sector with direct benefits based on COI estimates. This approach is based on an assumption that economic agents do not adjust behavior when confronted with a new food-safety policy. However, when agents optimize utility and profit, their behavior is adjusted when relative prices change. For example, if an industry sector's production costs rise, the producers try to pass on the extra costs to consumers by increasing output prices. Similarly, if consumers face a higher price for a product, they will substitute with other goods that have become relatively cheaper. Quantifying the behavioral patterns of producers and consumers and their relations with each other requires modeling of the entire economy and agents' behavior within a general equilibrium set-up.

In all types of analyses, the time horizon may be important because costs and benefits develop differently over time. In the provision of food safety there are often substantial investment costs in the policy-implementation phase (such as those associated with the initiation of slaughterhouse and livestock-production routines and large initial costs arising from large numbers of infected animals and eggs in the first years of implementation) whereas benefits tend to be incurred gradually over time because there is a reaction time between the introduction of a new food-safety policy and the improvements in food safety and human health.

A Study of the Danish Salmonella Control Programs

The Danish Salmonella control is used to illustrate how differences in assumptions might affect economic results. By comparing an analysis of direct costs and benefits (where no behavioral adjustments are considered) with a general equilibrium (CGE) analysis (where economy-wide adjustments are taken into account) we illustrate the differences between industry- versus social-level analysis and the importance of choice of time horizon.

Denmark has implemented monitoring and surveillance programs for Salmonella for all major food animals and food of animal origin (National Food Institute 2006). A long list of Salmonella control programs started in 1989 when the first voluntary surveillance scheme was implemented in the primary broiler production. The Salmonella control efforts in Denmark involve several policy instruments. Overall, the programs prescribe surveillance in all parts of the production chains through tests of pen fecal samples, meat juice, blood, and eggs; increased hygiene requirements; restrictions on fodder and trade with animals; targeted action towards infected rearing herds; and differentiated payment according to Salmonella status in the herds (Ap-

pendix I provides an overview). At the EU level, a recent zoonosis directive initiated EU baseline studies of Salmonella prevalence in animal production in order to generate comparable prevalence data with the purpose of setting common EU targets in the future.[1]

The goal of the current Salmonella control program for pork was reached in 2005: a reduction in the prevalence of Salmonella in fresh pork at the slaughterhouses to 1.2 percent. Surveillance data of the 12,000 pig herds in June 2006 indicate that 97 percent could be categorized as Level 1 herds (those with the lowest levels of Salmonella), 2.3 percent as Level 2 herds, and 0.7 percent as Level 3 herds (those with the highest levels of Salmonella). Salmonella DT104 was found in 30 herds in 2005 (National Food Institute 2006).

Salmonella is almost non-existent in poultry rearing flocks. In broiler flocks, the annual prevalence was reduced from 24 percent in 1995 to 2.2 percent in 2006 and the mandatory end-product examination of chicken cuts shortly prior to packaging shows annual prevalence of 1.9 percent. Similarly, the number of Salmonella-infected egg-laying flocks declined from 20 percent in 1997 to 1.1 percent in 2005. As the Salmonella risks in Danish broilers and eggs are considered very low, the next goal is to pursue zero-tolerance status, as do Sweden and Finland (Ministry of Family and Consumer Affairs 2006).

The Effect of Salmonella Control on Public Health

The benefits from improved population health generated by the Salmonella control programs are estimated along the lines of Korsgaard, Wegener, and Helms (2005). The registered number of human cases of Salmonella infections are published annually (National Food Institute 2006). This estimate is subject to uncertainty since many infections are not registered, as they occur without physician consultation or hospitalization. It is often assumed that between five and 20 percent of the total number of human infections are registered (Hoogenboom-Verdegall, de Jong, and During 1999). This analysis assumes that ten percent of all human cases of illness are registered, and the resulting expected number of human cases is calculated by inflating the registered number of cases by the inverse of the proportion of registered cases (Korsgaard, Wegener, and Helms 2005). The likely source of infection for each registered case since 1997 is also documented (National Food Institute 2006).

Following Korsgaard, Wegener, and Helms (2005), we assume that the annual number of human cases of illness due to domestically produced meat and eggs in the absence of Salmonella control would stay at the level observed the year before the relevant control program was implemented. This means that the annual number of human cases of salmonellosis from pork is assumed to be the same as in 1993, Salmonellosis from eggs would stay at the same level as in 1995, and the 1997 level is used for salmonellosis from broilers. This assumption is likely to provide a conservative estimate of the effect of Salmonella control since the numbers of infections were increasing in the years prior to implementation of the programs. There is a small risk of dying as a direct or indirect result of the Salmonella infection shortly after hospitalization. In the present analysis, the risk of dying prematurely is assumed to be two percent of the registered number of cases, based on the analysis by Helms et al. (2003) on excess mortality of persons with Salmonella infections.

Based on these assumptions, it is estimated that the Salmonella control programs reduced the number of human infections by 180,000 cases from 1995 to 2002. Out of these, 100,000 are associated with egg infection, 65,000 with pork infection, and the remainder with poultry infection. Also, it is estimated that the Salmonella control programs have prevented 365 premature deaths. Assuming an equal risk of dying prematurely from Salmonella infected pork meat, poultry meat, and eggs implies that controlling Salmonella in eggs has had the largest impact on the number of premature deaths, while controlling Salmonella in poultry meat has had the smallest impact. In short, the analysis suggests that controlling Salmonella in eggs has produced the greatest benefits to the society in terms of improved population health.

Analysis of Direct Costs

Social Costs

The Salmonella control programs have generated substantial costs for pork, poultry, and egg produc-

[1] European Commission 2005.

ers; slaughterhouses; egg packaging units; and the public sector. Public costs of controlling Salmonella in pork are detailed in The National Audit Office of Denmark (2000), and similar information on poultry and eggs is documented in Danish Veterinary and Food Administration (2004). The Danish Meat Association provides detailed annual data concerning industry costs (producers and slaughterhouses) of Salmonella control in the pork industry (see also Goldbach and Alban 2006). For egg production, only accumulated costs of controlling Salmonella were available from the branch organization of the eggs producers. Costs to poultry producers have been estimated (Laegaard and Hedetoft 1999).

The direct costs are estimated to total US$235 million for the period 1995–2002 (Table 1).[2] The annual direct costs during the period 1995–2002 have been allocated to public vs. private costs and to costs of controlling Salmonella in pork, poultry, and eggs. The total costs of controlling Salmonella in pork are estimated to be around US$180 million, while controlling Salmonella in poultry and eggs costs US$24 and 31 million, respectively. The estimates of the public sector's costs and the pork sector's costs are considered reliable due to the high degree of details in the data. The weakest part of the data is considered to be the estimates of eggs producers' costs, due to the lack of detailed information from the branch organization of eggs producers. Of course, the multitude of data sources might increase uncertainty of the cost figures, but our overall impression is that the quality of the costs estimates is fairly good.

[2] Prices are fixed 2000 prices, and the exchange rate used is the prevailing rate from 19 June 2006 of DKK5.9207 = US$1. For more details see Andersen and Christensen (2004).

Industry-Level Costs

The ratio of direct costs of Salmonella control financed by the private sectors to total production costs is used to compare the impact of direct costs in the different sectors. Costs from the year of the implementation of the relevant Salmonella control program until 2002 are included. To egg producers, Salmonella control imposes direct costs of 2.5 percent of the total costs, whereas the direct costs of Salmonella control constitute less than 0.5 percent of pork and poultry producers' total costs. Hence, based on a simple measure of direct cost of Salmonella control relative to total costs, there appears to be an inequitable distribution of the cost burden of the Salmonella control programs across sectors, with the egg sector hit the hardest.

Social Cost-Effectiveness

The cost-effectiveness of the Salmonella control from society's point of view is assessed by relating the total direct costs to the reduction in human infections for each food product. There are no readily available data on the distribution of the severity of Salmonella infections from pork, poultry, and eggs, respectively. Accordingly, a straightforward assumption that Salmonella infections from the three sources are equally serious has been applied to estimate case-avoidance costs from each source. This exercise indicates an inequity in the distribu-

Table 1. Direct Costs of Salmonella Control, 1995–2002 (Million US$**).**

	Public sector	Animal sectors	Total costs
Total	63	172	235
Pork	34	146	180
Poultry	14	10	24
Eggs	15	16	31

Sources:
Public costs: The National Audit Office of Denmark (2000); Danish Veterinary and Food Administration (2004).
Industry costs: Danish Meat Association (2002), as well as the branch organisation of egg producers; Goldbach and Alban (2006); Laegaard and Hedetoft (1999).

tion of the associated costs: the case-avoidance costs for pork infection are nine times as high as the costs related to egg infection (see Table 2, second column). This inequality suggests that the resources involved in Danish Salmonella control could be allocated more efficiently by securing a more equable distribution across products.[3]

A Global Perspective

Up to this point, food safety policy has only been viewed from a national point of view. But Denmark is a small, open economy which exports almost 90 percent of its pork production and more than 60 percent of the poultry production. How does this affect the analysis? When the health effects of exported Danish meat and eggs are taken into account, the case-avoidance costs change dramatically (Table 2, third column). The average costs per avoided case of illness decrease from US$1,300 to US$400 (assuming that the benefits abroad are identical to the domestic effect). Another change to the results which arises when the exported benefits are incorporated is that a more equable distribution of costs appears. Since the vast majority of pork meat is exported, the costs per avoided case of illness due to Salmonella in pork are reduced by more than two-thirds, whereas the case-avoidance costs for egg infection do not change substantially. Therefore the distribution of costs across products seems more efficient from a global than from a national point of view.

Cost-of-Illness Analysis

Direct Net Effects

To conduct a cost-benefit analysis of the Salmonella control programs, it is necessary to place a monetary value on the benefits of improved population health. This is carried out by applying the COI approach. Following Korsgaard, Wegener, and Helms (2005), Salmonella infections are categorized into seven groups according to severity, ranging from "ill without consulting a doctor" to "operation in hospital." This allocation is based on almost 25,000 Salmonella infections registered in a national database of patients during the period 1991–1998. For each group, an average measure of public-health expenditure (covering hospital costs, doctor consultations, and laboratory analyses) is estimated based on the official procedures for calculating costs of transferring patients between counties (Ministry of Health 2000), the average price for a doctor consultation (statistics database from the counties' association), and the average laboratory costs of Salmonella analyses at the Statens Serum Institut.[4] Additional medical costs are not included in this figure, and

[3] One should note that we compare average cost per prevented human infection. Hence average costs are used as rough indicators of marginal costs. It was not possible to estimate the underlying cost functions which would have allowed mapping different levels of Salmonella control costs to different levels of Salmonella prevalence.

[4] The Statens Serum Institut is a public enterprise under the Danish Ministry of the Interior and Health. The Statens Serum Institut prevents and controls infectious diseases, biological threats, and congenital disorders.

Table 2. Social Cost-Effectiveness of the Salmonella Control Programs (Average Direct Costs per Avoided Human Case of Illness), 1995–2002.

Product	National perspective	Global perspective
Average across products	1,300	400
Pork	2,800	400
Poultry	1,600	600
Eggs	300	200

Sources: See the sources mentioned in Table 1 regarding the cost data. The sources used to estimate the reduction in the number of human cases of illness are annual reports from the National Food Institute (2002 and 2006) and Hoogenboom-Verdegall, de Jong, and During (1999).

Note: The estimates are obtained as the direct costs of controlling Salmonella in the three products from 1995 to 2002 compared to the reduction in the number of human cases of illness due to Salmonella in the relevant product in the same period.

cases where a doctor has not been consulted are assumed not to elicit health costs. Also, reactions that occur long after the infection has taken place, such as reactive arthritis or chronic diseases, are not included. Bearing these limitations in mind, it is estimated that the Salmonella control programs have reduced public-health expenditure by at least US$20 million during the period 1995–2002.

A Danish survey has shown that Salmonella on average causes 14 sick days—hospitalized cases account for an average of 14–21 days, and patients diagnosed by their own doctor have ten to14 sick days (Moelbak, Baggesen, and Aarestrup 1999). Salmonella patients who do not consult a doctor are assumed to have three sick days. Furthermore, it is assumed that children under 17 years and people over 64 years do not affect labor productivity. Based on this information, the Danish Zoonosis Centre has estimated the average number of days absent from work for the seven groups. With the use of an average wage-rate per person per day (calculated as an annual equilibrium price in the CGE model), the value of increased productivity due to fewer sick days is estimated as US$96 million.

In addition, the Salmonella control programs may affect the value of production in society through their effect on the number of premature deaths. There are different approaches to estimate the productive value of an individual (Koopmanschap and Rutten 1993; Koopmanschap et al. 1995). The human-capital method estimates the value of potentially lost production from the age of premature death until retirement. The friction-cost method takes economic circumstances into account (such as the level of unemployment), which may reduce the estimated production loss compared to an estimate based on the human-capital approach. There is no production gain from fewer premature deaths in the period 1995–2002 if it is possible to replace all deaths immediately at zero costs (i.e. no friction costs) or if none of the avoided deaths generate production value (for example because they are retired during the period). On the other hand, if all 365 individuals were employed full-time in the labor market and were not replaced in the case of death, then productivity is calculated to increase by US$55 million (assuming the same average wage-rate per day as above). The societal costs of premature death are likely to be much higher than estimated since lost productivity only captures a fraction of the expected total loss.[5] The total value of direct benefits during the period 1995–2002 estimated as the sum of reduced public-health expenditure and increased productivity (due to fewer sick days and fewer premature deaths) range from US$116 million to US$171 million, with more than 80 percent of these benefits arising from increased productivity.

Relating the total direct benefits to the direct costs of US$235 million reveals direct net costs to society in the range of US$64–119 million.[6] Thus, based on the above-mentioned assumptions, the Salmonella control programs do not seem to constitute a good monetary investment when considering the accumulated net effect during the period 1995–2002.[7] However, the above-mentioned differences in the development of costs and benefits imply that the *annual* net costs to society are systematically reduced from 1997 and onwards. This trend suggests that the accumulated net effect to society of Salmonella control may be positive in the future. Hence the time frame may be important for the result of economic evaluations of Salmonella control.

General Equilibrium Analysis

The conclusions so far have been based on the assumption that producers, consumers, and other economic agents do not react to the change in policy. In reality, it is likely that producers will try to add the extra costs of Salmonella control to the prices of their products. The sales structures and price elasticities of consumer demand contribute to determine the optimal change in output prices. Including derived effects also allows us to include the effect of relative price changes on the behavior of producers who are not directly affected by the

[5] Another source of productivity loss is when children get sick and one of the parents has to call in sick and miss work.

[6] Conducting a COI analysis at the industry level would result in larger direct net costs for the individual industries since the benefits due to improved population health in other sectors of production as well as reductions in public health expenditures would be disregarded.

[7] Other analyses of the Danish Salmonella control programs confirm these results. For example, the direct costs and benefits associated with the second poultry control program implemented in 1995 has been analysed by the Danish Veterinary and Food Administration; they estimate the direct net benefits of pork, poultry, and eggs to be in the same range as in the present analysis (Korsgaard, Wegener, and Helms 2005).

Salmonella control programs. In this section we use a dynamic applied general-equilibrium model of the Danish economy to quantify the behavior of agents as response to the Salmonella control programs (the model is described in Appendix II). The obtained results include both the direct effects of Salmonella control and the derived effects elicited by adjustments in the agents' behavior.

The analysis of the effects of Salmonella control is conducted by comparing a baseline scenario and an alternative scenario. In the baseline scenario, it is assumed that the Danish government does not conduct an active food-safety policy regarding Salmonella. In the alternative scenario, the effects of the Salmonella control programs are incorporated. Costs of Salmonella control are incorporated by shocking negatively the total factor productivity in the pork, poultry, and egg sectors. The reductions in public health-expenditures are incorporated through decreased public consumption. The increased labor productivity is assumed to affect the overall labor productivity in the economy.[8] The time horizon of both scenarios is 2012 in order to access the long-run effects of the policy. Results are reported as percentage deviations from the baseline scenario.

The Directly Affected Industries

The impact of the Salmonella control programs on the pork, poultry, and egg sectors is reported in Table 3. The table presents the long-run percentage changes in the output price, production quantity, and value of pork, poultry, and egg production.

[8] Premature deaths are not included directly in the CGE analysis based on the assumption that due to unemployment, the macroeconomic impact would be negligible.

The sectors are affected both negatively and positively when derived effects are taken into account. On the negative side, the direct costs of Salmonella control increase production costs. A natural reaction from the industries is to increase output prices, which implies a movement down the demand curves for pork, poultry, and eggs. On the positive side, the improved labor productivity from the reduced number of sick days reduces the production costs, leading to lower output prices and higher production volumes. The analysis indicates that the negative effects dominate as output prices increase (Table 3, Column 2) and production volumes decrease (Table 3, Column 3).

Even though the price of eggs increases the most, the volume of egg production decreases the least (production volume of eggs decrease by only 0.2 percent, pork production decreases by 0.4 percent, and poultry production decreases by 1.4 percent [Table 3]). Differences in the demand structure for pork, poultry, and eggs explain this finding. Eggs are primarily sold domestically, where the substitution possibilities are limited. Therefore the demand for eggs is relatively insensitive toward price changes, meaning that a large price increase has limited effect on the demand for eggs. In contrast, a large fraction of the produced meat is exported and, since there are many close substitutes to Danish-produced pork and poultry meat on the global market, meat producers face a very elastic demand where even small price increases lead to large reductions in quantity demanded.

The change in the production values provides an estimate of the total impact of the Salmonella control programs in the three sectors (Table 3, Column 4). For all sectors, the negative effect on production

Table 3. Changes in Output Price, Production Quantity, and Production Value of Pork, Poultry, and Eggs Due to the Salmonella Control Programs (Long-Run Direct and Derived Effects) (%).

Product	Output price	Production quantity	Production value
Pork	0.2	−0.4	−0.3
Poultry	0.7	−1.4	−1.2
Eggs	1.2	−0.2	1.0

Sources: Simulations with a dynamic applied general-equilibrium model of the Danish economy.

Note: The figures are percentage changes relative to the baseline scenario of no Salmonella control.

volumes is dampened by a price increase, meaning that the reduction in production values is lower than the reduction in production volumes. The value of egg production is actually estimated to increase slightly as the large direct costs and the large rise in the output price are followed by a limited demand response. In the pork and poultry sectors, production values decrease because strong competition from imports limits the sectors' possibilities for increasing output prices. Therefore the differences in the market structures imply that the meat-producing sectors are affected more negatively than is the egg-producing sector.

Societal Effects

The economy-wide effects of the Salmonella control are quantified using gross domestic product (GDP), which captures the overall level of production in society.[9] Figure 1 indicates how much real GDP changes as a consequence of the Salmonella control programs (measured in million US$). The development is very similar to the pattern found in the analysis where only direct effects were included—with large net costs in the initial years of Salmonella control turning into decreasing net costs after some years.

Figure 1 shows that the Salmonella control has a positive accumulated effect on real GDP from 2003 onward. This positive effect is driven by the increased production of commodities other than pork, poultry, and eggs as a consequence of decreasing unit-production costs in the economy and changes in the relative output prices. First, the improvement in the overall labor productivity reduces unit costs. The reduced input demand in the pork, poultry, and egg sectors also tends to reduce the unit costs in the economy. As unit costs decline so does the price level of the economy, and this implies a real depreciation which boosts export. Second, the prices of goods and services that are not directly affected by Salmonella control decrease compared to the prices of pork, poultry, and eggs. Domestic consumers react to these relative price changes and substitute with goods and services that are not subject to Salmonella control.

The CGE analysis indicates that the Salmonella

[9] GDP measures the total production volume. Hence GDP is a measure of economic activity rather than of societal welfare. This implies that reducing the number of sick people has a positive effect on GDP in terms of increased productivity in the labor markets but it also has a negative effect on GDP because the purchase of health care services is lowered. Therefore, the GDP measure should ideally be supplemented by a welfare measure.

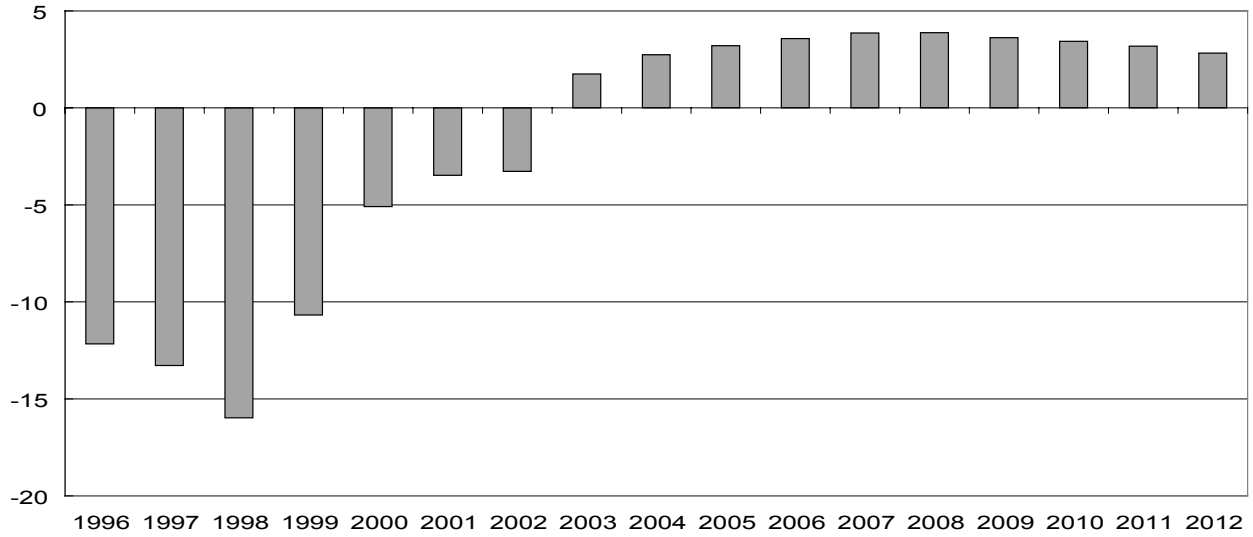

Figure 1. Cumulative Net Effect on GDP of the Salmonella Control Programs Including Direct and Derived Effects (Change in Real GDP, Million USD, 1995–2012).

control programs almost break even, as the net benefits are very small in relation to the size of the Danish economy. It is important to keep in mind that the result is subject to uncertainties. A sensitivity analysis of the CGE result shows that the positive effect on GDP increases by a factor eight when only five percent of all cases of illness are registered. On the other hand, the long-term effect on GDP is negative if it is assumed that 20 percent of cases are registered. Thus assessment of the societal effects of the policy in the long run is rather sensitive to the accurateness of the registration rate.[10] Additional uncertainties include the actual number of human cases of illness, the hypothetical development in the baseline scenario without Salmonella control, valuation of the economic consequences in terms of hospitalization costs and productivity losses, consumer utility, and valuation of safer food and the simplifying assumptions regarding behavior. Finally, it should be noted that we have not included premature deaths in the CGE analysis (cf. footnote 9).

Conclusions and Policy Perspectives

We have outlined two alternative methods for economic evaluations of food-safety policies. Our application to the Danish Salmonella control programs illustrates how the outcome of an economic analysis of food-safety policy may depend on market conditions, the behavior of agents, and the time horizon. The direct-costs analysis concluded that the Salmonella control programs for pork, poultry, and eggs are perceived very differently industrially versus socially and from a national as compared to a global perspective. From an industrial point of view, the egg sector is hit the hardest, but from society's point of view, it seems to be most cost-effective to focus on reducing the Salmonella incidence in eggs. The distribution of Salmonella control costs across pork, poultry, and eggs seems inequitable from a national perspective; from a global perspective, the case-avoidance costs are much more equally distributed across sectors.

Incorporating differences in the market structure and behavioral adjustments changed these conclusions. First, the production value of eggs actually increased when derived effects of Salmonella control were included. Likewise, several non-meat-producing sectors experienced growth as a result of Salmonella control, whereas a negative effect on pork and poultry production values was seen. Hence from an industry perspective the derived effects can be either positive or negative depending on the market conditions for the respective products. Second, the Salmonella control programs were associated with accumulated direct net costs to society in the short run which might turn into benefits in the longer run. However, when derived effects were included, the Salmonella control programs had a positive effect on GDP from 2003 onwards. These results indicate that it is important to consider market conditions, behavior, and time horizon when assessing the economic consequences of a food-safety policy. They also indicate that the sole reliance on a comparison of direct costs with direct benefits may elicit a suboptimal use of resources.

Quantifying the economic consequences of a food-safety policy is subject to uncertainties regarding the number of human cases of illness and premature deaths, the hypothetical development if the policy had not been implemented, valuation of the economic consequences in terms of hospitalization costs, productivity losses, consumer utility of safer food, and losses due to premature deaths. In particular, the net benefits found in the above analyses are most likely underestimated since consumers' willing to pay for safer food is not included, just as we have only incorporated the productivity loss of premature deaths (in the analysis of direct effects). This does not mean that economic valuations of food safety are worthless, however. Economic analyses reveal information which may be used to improve the welfare of societies. More importantly, the challenge remains to improve the quality of data and the underlying theory. Moreover, it is important to communicate not only results but also limitations of the analysis. Last of all, economic analyses are important inputs to policy making, but even economists agree that they cannot stand alone, as it is not possible to put all relevant issues into monetary terms.

The comparison of direct case-avoidance costs from a national and global perspective illustrates

[10] A similar, inconclusive result on the overall economic contribution of the programs is found when only direct effects are considered. Korsgaard, Wegener, and Helms (2005) estimate the net direct effects to range from net direct costs of EUR70 million to net direct benefits of EUR70 million based on a sensitivity analysis of registration rate.

that a large part of the benefits from domestic food-safety policy initiatives might be exported. At the same time, imported meats typically contain more bacteria than do the Danish products. In fact, out of the 1,775 registered human cases of illness due to Salmonella infections in 2005, it is conjectured that 20 percent are related to imported food products and 24 percent is travel-related (National Food Institute 2006). Hence a large part of the Danish food-safety problem is not solved by domestic food-safety policy measures. This poses several challenges for the future Danish food-safety policy and it calls for international coordination of food-safety policies in order to pursue future goals with an efficient use of social resources.

The present analysis focuses on the economic implications of the Salmonella control programs and on the differences between the Salmonella control programs for pork, poultry, and eggs. We find that Salmonella control of eggs has been the most cost-effective in terms of direct costs per avoided case, and this result is strengthened when the differences in market structure are incorporated. Another challenge is to identify the relative weights and effectiveness of the individual measures in the Salmonella control programs in order to improve future food-safety policies. Our findings indicate that future policy initiatives would benefit from a more holistic approach with (increasing) focus on improving food safety where it is most efficient—this applies when reducing the prevalence of a specific bacterium in different products, but also across different bacteria and across other food-safety problems. A related and very important topic is how to rank the different food-safety problems. Kemmeren et al. (2006) illustrate that different ranking methods might lead to different conclusions regarding the social costs of food-borne illnesses.

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Appendix I

In 1989 the first voluntary surveillance scheme was implemented in the Danish broiler primary production. Restrictions on chicken fodder were included in 1990. A similar voluntary surveillance scheme followed for egg layers in 1991. In 1992 the first national Salmonella program for broilers was formulated: end-product tests at the slaughterhouses were added along with increased hygiene including disinfecting houses between shifts and keeping strict hygiene barriers. The first national control program for eggs was implemented in 1996. The control on poultry was significantly intensified in 1998, with targeted focus on eliminating Salmonella in rearing flocks, introducing pasteurization of eggs from infected egg-laying flocks, and requiring Salmonella-infected broiler flocks to be slaughtered at the end of the day under strict hygiene conditions in order to reduce cross contaminating non-infected meats. Moreover, owners of infected flocks were obliged to seek advice on how to reduce the Salmonella problem.

In 1994 the first national Salmonella control program for pig and pork production introduced the principle of categorizing pig herds into three levels according to their Salmonella status (Level 1 having the lowest Salmonella level). The categorization system required Level 2 and 3 herds to formulate plans for reducing Salmonella (fines for not instituting the plans were soon introduced) and Level 3 herds were slaughtered under special hygiene standards using hot-water treatments. Surveillance and control procedures were adjusted

regularly. In 1997 the Danish Meat Association initiated penalty payments on owners that have delivered infected animals from Level 2 or Level 3 herds, thereby providing further economic incentives for the producers to reduce Salmonella risks. A zero-tolerance policy was implemented in 1998 for multi-resistant DT104 Salmonella and all meat from infected animals is treated with hot water. Detection of clinical illness among pigs due to Salmonella has to be reported to the authorities, and the herds are put under administration. Salmonella status must be available in the sales of live animals. Salmonella is not yet controlled regularly at retail level.

Sources: National Food Institute (2006), Ministry of Family and Consumer Affairs (2006) and Wegener et. al. (2003). Further documents that describe the programs in details are in Danish and available from the authors on request.

Appendix II: Description of the Dynamic General-Equilibrium Model

The model includes the behavior of five types of agents: producers, consumers, investors, a public sector, and foreigners. The database of the model identifies 74 industries which produce 82 commodities. Among these, a primary pork sector sells the majority of its products to a manufacturing pork sector, which produces pork meat for final consumption. Similarly, the poultry industry consists of a primary and a manufacturing sector. There is one egg-producing sector. There are two main categories of production inputs: intermediate inputs and primary factors. Supply of and demand for commodities and demand for primary factors are determined through optimizing behavior of agents in competitive markets. Demand is assumed to equal supply in all markets other than the labor market (where unemployment can occur). Firms in each sector are assumed to choose the mix of inputs which minimizes the costs of production for their level of output. They are constrained in their choice by nested production technologies. Investment in sector-specific capital is assumed to depend on the expected rate of return on investment in that sector, and the expectations are assumed to be static. There is a single representative household which buys bundles of goods to maximize a hierarchic system of utility functions subject to a household expenditure constraint. For example, meat consumption is determined by splitting meat into a composite good (that consists of poultry and pork meat) and beef meat, and splitting the composite good into poultry meat and pork meat. The allocation of each type of meat into a domestically produced variant and an imported variant is based on Armington's specification, where domestic and imported variants of similar goods are imperfect substitutes (Armington 1969). The government demands commodities, intervenes in markets by imposing taxes, and subsidizes production. Three categories of export goods are defined according to how their demand is incorporated in the model (following Dixon and Rimmer [2002]): traditional, non-traditional and special export commodities. Traditional export commodities face individual downward-sloping foreign-demand schedules. Commodities are treated as traditional export commodities if at least 40 percent of total production is exported. This includes, for example, pork meat, poultry meat, cereal, fish products, dairy products, textiles, and basic chemicals. Commodities where less than 40 percent of total production is exported are treated as non-traditional export commodities (e.g., eggs, beverage production, processed fruits and vegetables, and non-metallic building materials). Total demand for non-traditional exports is related to the average price of these commodities via a single downward-sloping foreign-demand schedule. The third category of exports comprises commodities for which special individual modeling is required because foreign demand is considered independent of the Danish cost structure; this includes transport and communication. Finally, three types of inter-temporal links are incorporated in the model: physical-capital accumulation, financial-asset accumulation, and a lagged adjustment process in the labor market.

Sources: Adams (2000); Adams, Andersen, and Jacobsen (2002); Dixon and Rimmer (2002).