The Costs of Human Salmonellosis Attributable to Pork: A Stochastic Farm-to-Fork Analysis

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1. Introduction

While analysts estimate that bacterial foodborne diseases cost billions of dollars annually in the United States, significant uncertainty remains concerning the precise contribution of different stages in the food system to the overall burden of disease. In addition to the scientific uncertainty regarding the characterization of the risk and risk channels, considerable gaps exist in our knowledge about the economics of the burden of foodborne diseases. Furthermore, there is a dearth of comparative information about the efficiency of measures taken at different stages in the food system to prevent, detect, or treat foodborne diseases. As a means of illustrating how a farm-to-fork system approach can help address these questions, this paper estimates the cost of human salmonellosis attributable to pork consumption and provides a farm-to-fork stochastic simulation modeling framework for the case of pork products and human salmonellosis.

An estimate from USDA claimed that the annual cost of human illness for seven foodborne pathogens has reached $5.6 to $9.4 billion. Of these costs, meat and poultry account for 80 percent according to Buzby (1996). The large costs and other damages have made foodborne disease an issue of great public concern. The World Health Organization, USDA, FSIS, and many other institutions have initiated several research projects with an objective of greater understanding of the nature of the risk posed by bacterial pathogens in food. An example of such a study is the FAO/WHO risk assessment of Salmonella spp. in broilers and eggs. These pioneer studies shifted the public attention, greatly deepen our understanding of this problem and stimulated a large body of research from varying disciplines including food science, animal science, veterinary pathobiology and agricultural economics. However, a brief review of current literature shows that further economic research, in combination with methods from food science, veterinary pathobiology, and operations research, is required to deepen our understanding.

The pork industry provides the second most extensively consumed food animal in the U.S. meat market. And it is estimated that the Salmonella from meat consumption is of concern ranking next to poultry. Therefore, we place our attention here on developing a quantitative economic risk assessment of the swine production and consumption system, with a focus on Salmonella.

This study focuses on the pork pathway of Salmonella dissemination from farm to table using a stochastic simulation model. We estimate the risk of Salmonella contamination at each production stage, and we estimate the possible impacts on human health, and provide an estimate of the cost of illnesses attributable to salmonellosis originating from contaminated pork. Using @RISK software, we build our model pork system in a way that addresses multiple sources of uncertainty. The model reflects scientific uncertainty arising from differing estimates of the true prevalence of Salmonella through the pork pathway, as well as uncertainty concerning the precise levels of exposure, infection, and outcomes. An important aspect of farm to fork modeling is that it allows the development of comparative analyses into the relative efficiency of risk management strategies at different levels of the production and consumption system. While this paper does not present a detailed cost-effectiveness or cost-benefit analysis of risk management strategies, it does present sensitivity analyses that indicate the stage of the system having the greatest impact on the total cost estimate.

The farm to fork model includes five modules: on-farm; transport; lairage; slaughter and retail; and, consumption and health. Each module provides information, which analysts can use independently to construct a stage specific estimate of risk. Alternatively, a researcher can link each module to make a risk assessment for Salmonellosis for the entire pork system, from farm to the consumer's table. The subsequent sections provide a discussion of the model's design, as well as a presentation of the estimate of the cost of salmonellosis attributable to pork and a discussion of the results and sensitivity analyses.

2. Critical Model Inputs

Figure 1 displays a flow chart of the model layout and lists the different stages of the simulation model. The critical model inputs are the parameter values, probability distribution assumptions, and process assumptions built into the model design. Other key assumptions include the use of a cost of illness approach to the assignment of values to health states associated with salmonellosis attributable to pork. A further key assumption is the decision not discount the stream of healthy life years lost in the burden of disease values, instead an average value lost is assigned to each death.

2.1 On-Farm Stage

The farm level is the first stage of the farm to table model. Salmonella prevalence at this stage becomes important because of the high propensity for Salmonella transmission across animals at later stages, and because of the possibility of lengthy survival times and the ability of Salmonella to live not only on hides and in the gut, but also in the lymph nodes and in other parts of the animal.

The basic components of production module include the number of market hogs and positive salmonella pork numbers. Market hog statistics are from USDA remote database on the web (http://www.nass.usda.gov:81/ipedb/slaughter.htm). The total number of hogs slaughtered in both nonfederal inspected slaughter plant and federally-inspected slaughter plants is 97,975,900 head in 2000, which includes 93,114,900 head of barrows and gilts in federally-inspected slaughter plants, and 3,005,000 head of sows and 315,700 head of stags and boars.

The shedding rate of Salmonella for barrows and gilts is 6%, which is obtained from the USDA research of NAHMS Swine 95. According to the Animal and Plant Health Inspection Service (APHIS) of the USDA (CAHM),

> "One hundred and sixty (160) of the NAHMS Swine 95 producers were selected to participate in the collection of 50 fecal samples from their farm. Samples were collected from pens of late finish hogs and sent to the USDA's National Veterinary Services Laboratories (NVSL) and National Animal Disease Center (NADC) to be tested for the presence of Salmonella and other food-borne pathogens. A total of 6,655 samples were collected from 988 pens on 152 operations…. Of the 6,655 samples collected from finisher pens, 398 samples (6.0 percent) were positive for Salmonella, indicating that Salmonella is sporadically shed at low levels."

For cull sows we use a shedding rate of 2% (McKean et al.).

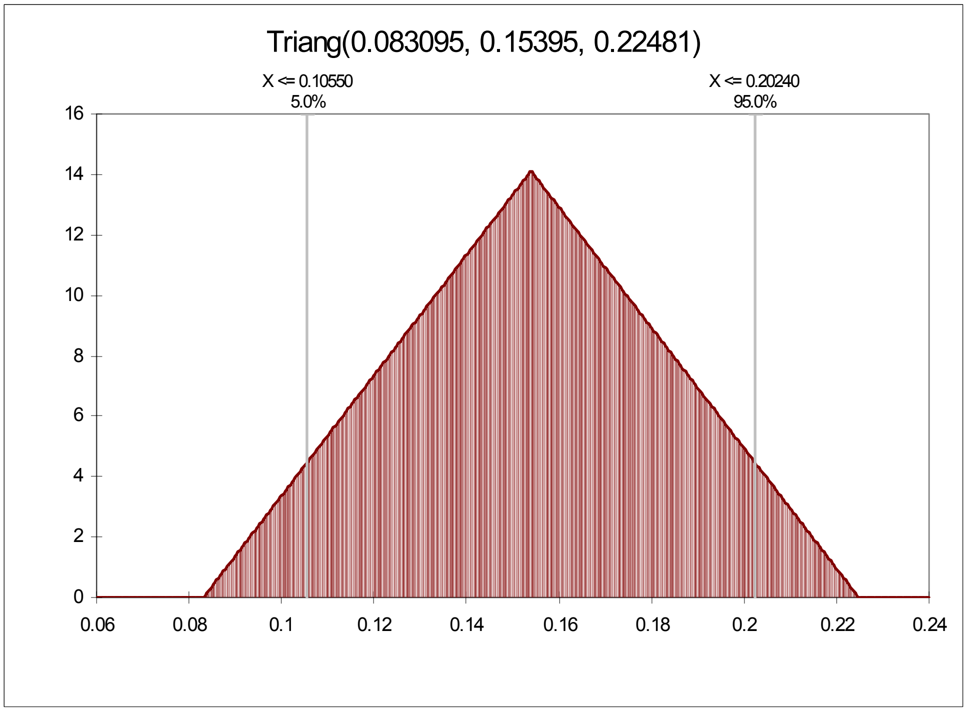
The two shedding rates above represent apparent prevalence, and these estimates are likely to overestimate or underestimate the true prevalence do to weaknesses in the testing procedures to detect the presence of Salmonella. To represent the uncertainty present in the testing regime, we estimate true prevalence based upon apparent prevalence and other information by using formula:

$$\text{True prevalence} = \frac{\text{apparent prevalence} + \text{specificity-1}}{\text{sensitivity} + (\text{specificity-1})}$$

In most cases, we cannot get sensitivity and specificity from each specific paper or test, and they are assumed to be prior information. In our analysis, we use them as prior information from other literature. The specificity is assumed to be constant with value of 0.998. Sensitivity is flexible with the varying sample size such as fecal volume used in lab test. Based on our observations of testing protocols, we define a range for the likely sensitivity values for the testing procedures as 0.26-0.7.

Applying the formula leads estimates of a higher and lower level of true prevalence for market hogs of 0.22 and 0.83, respectively. We represent this scientific uncertainty in the simulation model through a triangle probability distribution, and assume that the midpoint of the range is the prevalence with the highest possibility. We construct a similar distribution for the sows and boars. The on-farm prevalence distribution for market hogs is illustrated in Figure 2.

Figure 2 On-farm prevalence of Salmonella for market hogs



In fact, many factors contribute to prevalence of salmonella at farm level. Those factors can be traced in both space and time dimension, which includes operation size, varieties of feed, antibiotics, biosecurity and distance to other farms. The association between these factors and the prevalence of Salmonella in swine farms is very important to formulate relevant policies at farm level. While this model does not explicitly represent this level of detail, it does not imply these issues are not important. Further research will be required to add these details to the farm stage of this analysis.

2.2 Transport Stage

Compared with the on-farm production stage, the transport period is of much shorter duration. Nonetheless, evidence suggests that transport, with it concomitant animal stress and exposure to vehicles environments used with many different herds, can lead to significant increases in the prevalence of Salmonella in pigs.

According to USDA research based on the 1995 NAHMS Swine Survey, Salmonella prevalence is unevenly distributed across different geographic locations:

> "Evidence of Salmonella in fecal samples was found on 58 (38.2 percent) of the operations. A greater proportion of operations with positive samples in the Southeastern states (65.5 percent) as compared to the Midwest (29.9 percent) and the Northcentral states (36.1 percent)".

The research cited above illustrates two causal factors that lead to increases in the prevalence of detected Salmonella after the process of transport. One is the large difference of Salmonella prevalence among pen and operation (6% to 38.2%) "The percentage of pens on a farm that contained at least one positive sample ranges from 10 to 100 percent. Thirty-five of the 58 positive farms (60.3 percent) had a positive sample in less than half of the finisher pens tested. One-fourth (15) of the operations had evidence of active shedding of Salmonella in more than two-thirds of their finisher pens." The transportation stage facilitates the mixing of pigs and, hence, the cross-contamination of pigs from different regions, different farms or even from different pens of the same operation.

We derive our increase parameters for Salmonella prevalence during the transportation period from Williams and Newell (1970), Hurd et al. (2001) and Marg (2001). Their studies show 18% to 34.7% of negative gilts and barrows at farm become positive in the process of transport. We assume that the rate of increase in Salomonella prevalence from transport is the same for sows as for market hogs.

2.3 Lairage Stage

Lairage is the shortest period of pork production chain. However, it has been proved to be a key linkage of Salmonella contamination. Evidences have shown that a large magnitude of Salmonella contamination takes place in this period when pigs go without feed for extended periods before slaughter.

Jackowiak (1999) studied on the impacts of lairage on swine Salmonella contamination in the Australian pork industry. He found that Salmonella was present in the gut contents of about 2% of slaughter pigs where pigs had been off-feed for less than 18 hours before slaughter, but this jumped to 27% when pigs had been without feed more than 18 hours. Although it has been established long that pigs should be off-feed before slaughter for six hours to reduce the risk of contamination, it appears that having pigs off-feed for an extended period leads to increased levels of contamination. Jackowiak claimed

> "All animals have some Salmonella, but without feed, the internal chemistry within the pig's gut changes to encourage the growth of the bacteria. Salmonella growth is encouraged by the stress pigs experience when they are fasted, transported, moved into unfamiliar environments and mixed with other pigs. The Salmonella may move from the gut further afield to the lymph nodes and elsewhere, increasing the risk of carcass contamination."

Berends, et al (1996) claimed, "Between 5-30% of the animals may still excrete Salmonella spp. at the end of the finishing period, and this percentage can double during transport and lairage.” The quantitative range expressed here does not appear to be precise and the difference between the transportation and lairage is not distinguished, but the potential risk of salmonellae is clarified. Hurd et al. (2001) had found that the change in apparent prevalence was from 3.4% at the farm to 71.8% after lairage, a difference of 68.4 percentage points. They follow 280 pigs with a negative Salmonella test result at the farm level. Among those pigs, 93 were still negative in post-lairage testing. The other 187 (66.8%) become Salmonella positive after lairage. Hurd’s study also shows that 18% to 34.7% of pigs that are negative at the farm become positive due to transport. Using their results, the impacts of lairage are estimated by subtracting the prevalence after transportation from the prevalence after lariage. We use the higher and lower estimates of the increase of prevalence resulting from lairage (48.8% and 32.1%, respectively), to form the corners of a triangle probability distribution, with the peak of the triangle assumed to be the midpoint of the range.

2.4 Slaughter and Retail

The slaughter and retail stage actually involves many disparate steps, including stunning, sticking, bleeding, scalding, de-hairing, shaving, head drop, final inspection, trimming, final wash, chilling, and fabrication. These different steps all involve the potential to decrease or increase the likelihood for Salmonella to be present on pork products at the end of the processing and retail stage. In our analysis, we focus our attention on the strong effect that scalding the carcasses has on decreases the prevalence of Salmonella on pork carcasses (Dickson, Hurd and Rostagno, 2002).

According to Dickson et al., the scalding operation in a typical US slaughter plant is usually conducted with temperature 57.7 to 61 C for three to eight minutes and a typical operation would be 58.8 C for six minutes. Dickson et al. state that this "combination of temperature and time would result in greater than a 9 $\log_{10}$ cycle reduction of salmonellae" based on Humphrey et al. (1981). While the experimental work this is based upon was done with chickens, we assume that scalding would have the same effect in a pork slaughter context. Therefore, we assume that the Salmonella reduction due to scalding ranges from 0.9 to 1.0, with a midpoint of 0.95 for the assumed triangle distribution.

To our knowledge, there is no study that connects prevalence of carcass salmonella contamination with the prevalence of pork salmonella contamination. In our model, we have carcass contamination from previous linkage and prevalence of pork meat contamination from Duffy, et al (2000). The Duffy samples are used to calculate the possible contamination increase from slaughter house to retail shops. Such increase is added to the prevalence at slaughter stage. In Duffy's paper, the range of Salmonella positive pork of plant samples is 0 to 10% with a mean of 5.8%. The range of Salmonella positive pork of retail stores is 7.3% to 12.5% with a mean of 9.6. These data provide a range of Salmonella increase at retail process as 2.5% (12.5%-10%) to 7.3% (7.3%-0%) with a mean of 4.9%. We represent this uncertainty with a triangle distribution.

2.5 Consumption and Health

The consumption and health stage follows pork from the retail channels to human consumption and some incidence of salmonellosis and the associated economic burden. The following section reviews each of the components of this stage of the analysis.

2.5.1 Population exposure to Salmonella contaminated pork

Since not all people are exposed to pork and not all exposures will lead to infections with the same likelihood, we divide the population into two groups. The first group is the sensitive group. It consists of infants, the elderly, immuno-compromised persons, and all of these people are at heightened susceptibility to illness from exposure to Salmonella. The second group is non-sensitive group. They consist of all other people and show a normal response to microbial contaminated foods. The sensitive group is assumed to be 20% of the total population, remain 80% be the normal population according to Gerba, Rose and Hagen (1996).

Within each group, not all people experience an exposure to salmonella contaminated pork. The consumption behaviors of different racial and ethnic groups differ, and Salmonella are not uniformly distributed among pork products. We assume that 20% of normal population is likely to be exposed to contaminated pork and 15% of sensitive population is likely to be exposed to contaminated pork. We model each rate as a random variable with a normal distribution.

2.5.2 The intensity of exposure

The impact of salmonella on human infection does not accumulate and the intensity of exposure in our model is only associated with quantity of each serving. We assume an average serving of 3 ounces of pork for the non-sensitive group and 2 ounces of pork per serving for the sensitive group. The serving data here are referenced to a USDA analysis (1998). In addition, the quantity of meat serving is assumed to be random variable with a normal distribution.

2.5.3 The effect of cooking on Salmonella exposure

Cooking represents a powerful process of pathogen reduction, especially when meal preparers follow proper food safety practices in the kitchen. The cooking process represents the last chance in the entire farm to table system to reduce the likelihood of ingesting contaminated pork.

Evidence exists that most people understand well the need to cook foods carefully to reduce the risk of foodborne illnesses. Woodburn (1997) summarizes a survey of food preparers and states that "Salmonella contamination was recognized as a problem in food by 99%" of the respondents. Moreover, the author reports that people "said they would thoroughly cook food contaminated with bacteria to make it safe to eat (56% for salmonella and 59% for E. coli) but 40% responded that the foods either couldn't be made safe to eat or that they didn't know of a way." Veeramuthu and Sams (1998) indicated that The USDA Food Safety and Inspection Service (FSIS) has proposed to amend cooking regulations to require that any thermal process used for poultry products be sufficient to cause a 70% reduction in salmonella. In addition to the high awareness of many consumers about the need to cook food thoroughly in order to reduce or eliminate pathogens such as Salmonella, other consumers, not aware of Salmonella risk, may reduce Salmonella substantially via adhering to traditional methods of cooking pork products.

Based upon this research, we assume that 30% of the servings consumed by the non-sensitive population is contaminated pork, and 20% of the servings consumed by the sensitive population is contaminated pork. Also, we assume that Salmonella will be reduced by at least 90% after cooking process.

2.5.4 Dose-Response Model

The dose-response model simulates the relationship between contaminated food intakes and the likelihood of foodborne illness. In the case of Salmonella contaminated food, the most extensively used does-response models are as follows:

The Exponential model: $P=1-\exp(-r*dose)$

The Beta-Poisson model $P=1-(1+ (dose/Beta)^{-Alpha}$

In this study, we use Beta-Poisson distribution to characterize the possibility of salmonellosis given ingestion of a contaminated serving of pork. The parameters used here follow those used in the FAO/WHO risk assessment report. At this time, to our knowledge, no dose-response model exists based upon pork consumption and illness data.

2.5.5 Economic Burden of Disease Assumptions

Medical cost and productivity losses from bacterial infection have been addressed many studies. In this model, we rely heavily upon the framework presented by Buzby et al. (1996) for the assumptions and parameters used in our cost of illness estimates for human salmonellosis attributable to pork. We update their 1993 medical costs and values of human life to the year 2000, using the Medical Price Index of the US BLS. For the low-risk group, we assume that the treatment paths for the salmonellosis cases are: salmonellosis no physician visit, 93%; salmonellosis with physician visit, 5%; salmonellosis hospitalized, 0.019%; and, salmonellosis death, 0.001%. The cost per case varies by treatment option: no physician visit, $482; physician visit, $1,032; hospitalization, $11,812; and, death, $500,923.

3 Simulation Results

With 100,000 iterations using Monte Carlo simulation, and with the current model design, parameter assumptions, and distributional assumptions, the model provides an estimate of the total cost of illness for salmonellosis attributable to pork in the year 2000 of $45.7 million. Figure 3 presents the simulation results for the cost of illness estimate graphically. The 90% confidence interval for this estimate is from $7.7 million to $116.6 million, thus illustrating a substantial amount of uncertainty over the actual point estimate for the cost of salmonellosis attributable to pork. The bulk of the costs resulted from the treatment of the high risk group and the mean estimate for their cost of illness was $29.5 million. For the low-risk group, the mean estimate was $16.2 million.

The total number of salmonellosis cases estimated by the model was 43,505. Of these, 22,873 were from the low-risk group and 20,632 resulted from the high risk group. Compared to the cases estimated by the USDA Economic Research Service's foodborne illness calculator for Salmonella, the 43,505 cases represent about 3% of the total salmonellosis cases in a year. The foodborne illness calculator estimates an average cost per salmonellosis case of $2,126 and our model estimates an average cost per case at $1,050.

4. Conclusions

This paper presents the first estimates (to our knowledge) of the cost of illness from salmonellosis attributable to pork consumption. While the cost of illness information by itself may be useful to policy makers in terms of targeting risk reduction efforts, this model also represents a framework for developing model-based estimates of the burden of illness for foodborne diseases. Such a framework can be applied to cost-effectiveness analyses or cost-benefit analyses of alternative risk management strategies, particularly if the cost of an intervention (such as on-farm risk reduction strategies or pathogen reduction strategies in the processing plants) is known. Further research should seek to validate and test the assumptions behind the model's design, as well as further interpret the model results and test the sensitivity of the results to the key assumptions.

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Figure 1. The Farm-to-Fork Pork System

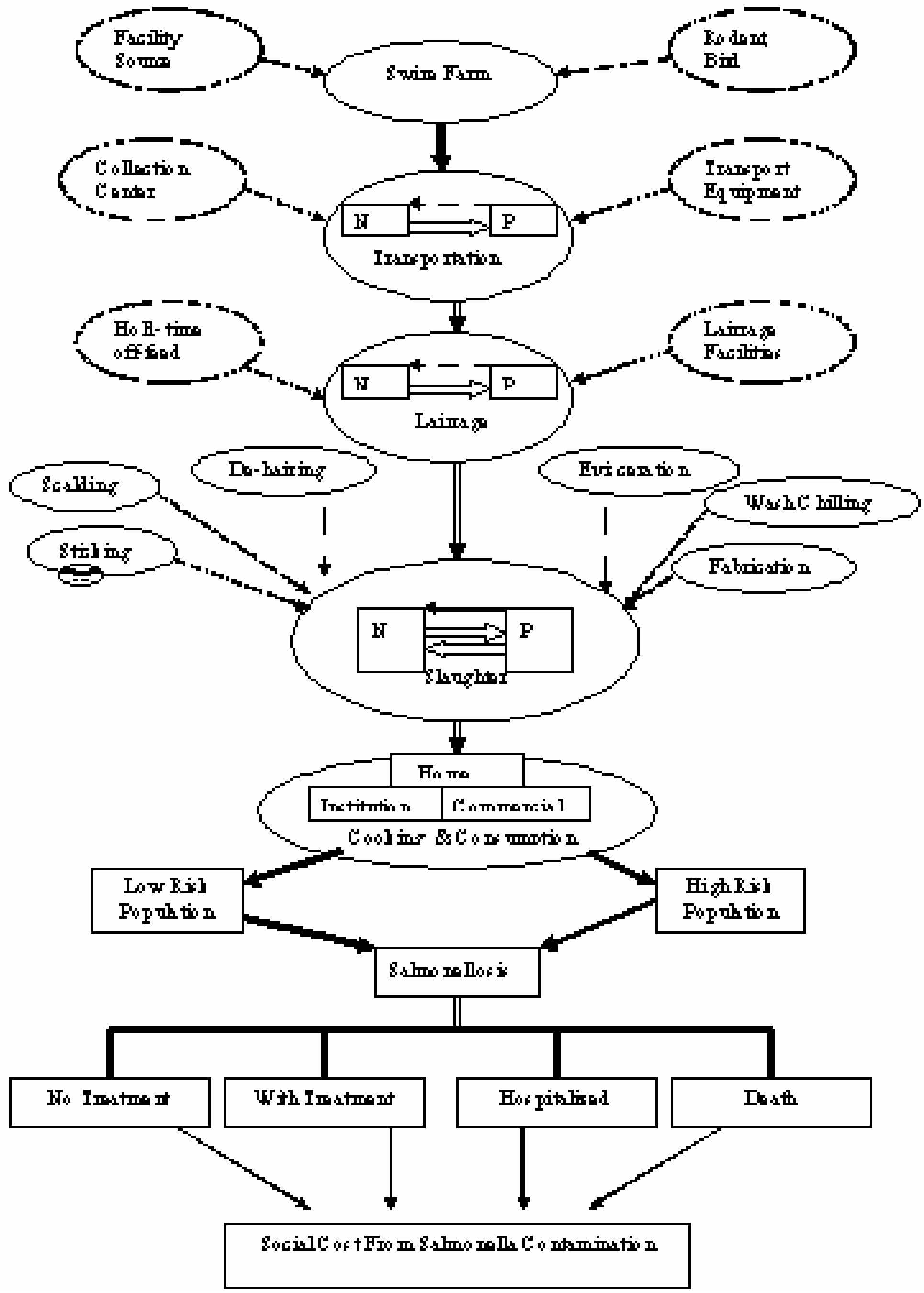

Figure 3. Cost of Illness Estimate for Salmonellosis Attributable to Pork