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Measuring Food Safety Control in U.S. Hog Farms Using a Composite Indicator

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Abstract

Consumer demand for reliable food product quality and safety is growing. This trend, together with increased public regulation and attention to the legal liability of food processors and retailers creates derived demand for food safety assurance in farm production. In consequence, farms have adopted different measures, voluntarily or compulsorily, in their production practice to ensure reduced food safety risks from the farm product. Multiple individual indicators exist which reflect different facets of food safety practice. In fact, it is likely that production of a safer product is a result of several factors. However, little is known about what practices effect greater food safety control at the farm level, or how farms that take greater food safety control fare in comparison to other farms. This study develops a composite food safety control indicator by aggregating data from a set of individual indicators of food safety control and investigates the variation in food safety practices across farms. Moreover, we show how some relevant variables may influence farm food safety control, thus provide empirical evidence for the design of food safety-enhancing agricultural policy measures.

Keywords: food safety control, hog farm, composite indicator

Introduction

Consumer demand for reliable food product quality and safety is growing. This trend, together with increased public regulation and attention to the legal liability of food processors and retailers creates derived demand for food safety assurance in farm production. Both the public and private sectors are seeking better strategies to improve the safety of farm products and practices that will better assure safer product. While the responsibility for producing safe food product lies on the industry as a whole, ranging from production, processing, distribution, to retail, good manufacturing practices in farm is an important start for the whole chain. In consequence, farms have adopted different measures, voluntarily or compulsorily, in their production practice to ensure reduced food safety risks from the farm product.

Food-borne hazards consist of biological hazard, physical hazard, and chemical hazards (Horchner, et al. 2006; Reilly and Kaferstein, 1997), which can cause adverse health effects on human beings when consuming foods. Biological hazard includes microbiological and macrobiological hazards, such as microorganisms associated with animal disease or parasites. In hog production, *trichinae* and *Salmonella* are two important food safety pathogens (Unnevehr, Miller, and Gomez, 1999). Physical hazards include contaminates such as broken needles or lead shot (Horchner, et al. 2006). And chemical hazards include chemical or drug residues, such as hormones and antibiotics. Food safety hazards can occur at any points of production, including purchased feed, herd replacement, recycled materials (bedding, litter), water supplies, and environmental influences (birds, rodents, wildlife) (Mallinson, et al., 2001). However, on-farm control measures can prevent, reduce or eliminate those hazards. On-farm food safety control involves changes in both production systems and production practices. In contrast to changes in production systems that generally require fixed capital investment, production practices which influence variable costs of production are easier to change but require more continuous monitoring (Unnevehr, Miller, and Gomez, 1999). While taking food safety assurance practice may initially increase the cost to farmers, it reduces the risk resulting from unsafe food products that may cause more damage to farms, such as legal liability, cost related to recall, and sale reduction.

As production of a safer product is a result of several factors, multiple individual indicators exist which reflect different facets of food safety management. For policy makers, a comprehensive assessment based on the aggregation of available information is much of interest. Therefore, a construction of a composite indicator that combines the information from all facets of food safety control seems particular interesting in this context. Such indicator can provide information on how farms that take greater food safety control fare in comparison to other farms and what factors affect food safety control at the farm level. To authors' knowledge, there is no study on evaluation of farm food safety control by using a composite index. There are, however, some studies using a composite indicator in which sub-indicators are aggregated into one number to evaluate units performance in fields including human development (Mahlberg and Obersteiner 2001; Despotis 2005), quality of life **(**Hashimoto and Ishikawa 1993; Somarriba and Pena 2009; Zhu 2001**),** economic wellbeing (Murias, Martinez and De Miguel 2006), farm sustainability (Reig-Martinez, Gomez-Limon, and Picazo-Tadeo 2011), technology achievement (Cherchye et. al. 2008), and education quality (Murias, de Miguel and Rodriguez 2008). In this study, we develop a composite food safety control index by aggregating data from a set of individual indicators of food safety management and investigate the variation in food safety practices across farms. Moreover, we show how some relevant variables may influence farm food safety performance, thus provide empirical evidence for the design of food safety-enhancing agricultural policy measures. As food safety of meat products has emerged as a major public health issue, in this study, we focus on on-farm food safety control in swine production.

The paper is organized as follows. In the next section, on-farm food safety management is discussed. Then data and methodology are introduced. Results of farm food safety management evaluation are presented in the following section, followed by regression analysis of determinants of food safety management. Conclusions and discussions are presented at the end.

On-Farm Food Safety Management

On-farm food safety control involves every point of the production. There are, however, some practices which are important and frequently applied.

Pork Quality Assurance

Food safety is more easily ensured through hazard-preventing production practices (Unnevehr and Jensen, 1999). Like Hazard Analysis Critical Control Point (HACCP) which is used to ensure food safety by manufacturers of food products, Pork Quality Assurance (PQA) is a producer education and certification program that is used to improve food safety in pork by farmers. Antibiotic drug residues are an important food-safety attribute. PQA, which was developed by pork producers in 1989, mainly focuses on the reduction of the risk of violative animal health product residues in pork (National Pork Board or NPB website). With the success of PQA, PQA evolved to PQA Plus in 2007 by incorporating animal well-being to reflect customers' increasing interests in the way hogs are raised (NPB). PQA Plus is a three step program comprising education, farm site assessment, and third-party verification. The education provided by veterinarians, extension specialists or agriculture educators includes a conceptual training about 10 Good Production Practices that address food safety and animal well-being. As listed on the website of National Pork Board (NPB) which runs the PQA Plus program, 10 Good Production Practices are: "

1. Establish and implement an efficient and effective herd health management plan.

2. Use an appropriate veterinarian/client/patient relationship (VCPR) as the basis for medication decision-making.

3. Use antibiotics responsibly.

4. Identify and track all treated animals.

5. Maintain medication and treatment records.

6. Properly store, label and account for all drug products and medicated feeds.

7. Educate all animal caretakers on proper administration techniques, needle-use procedures, observance of withdrawal times and methods to avoid marketing adulterated products for human food.

8. Follow appropriate on-farm feed and commercial feed processor procedures.

9. Develop, implement and document an animal caretaker training program.

10. Provide proper swine care to improve swine well-being."

Producers receive PQA Plus certification after completing the education. On-farm assessment is a site assessment to track the welfare of on-farm animals. After the assessment which includes a review of records, facilities, equipment and animal care and well-being practices, the farm can get a PQA Plus Site Status (NPB). The third-party verification is used to analyze the success of the program by conducting and analyzing a survey to find out if the program can be improved.

Birds, Rodents, and Wild Life Control

While PQA Plus program can help ensure the residues in pork safe, other management practices are also needed to reduce the risk of introduction and spread of disease by protecting farms from entry of new pathogens and internal transfer among different areas of farms. Rodents, birds, and wild life can carry agents that cause E. coli, leptospirosis, atrophic rhinitis, rotaviral diarrhea, salmonellosis, swine dysentery, PRRS, *Streptococcus suis*, erysipelas, avian tuberculosis, Bordetella spp., classical swine fever, influenza, brucellosis, leptospirosis, trichinella, pseudorabies and transmissible gastro-enteritis (Food and Agriculture Organization of the United Nations, World Organization for Animal Health, World Bank). They can spread pathogens and diseases as they move from one farm to another and have close contacts with hogs. Those diseases not only cause economic loss to hog producers, some of them are also contagious to people who consume infected pork. For example, trichinosis infections in humans can be caused by consumption of raw or undercooked infected pork by trichinella. Controlling rodents, birds, and wild life access to production facilities or feed preparation areas can help reduce risk of disease transmission and improve food safety in hog operations. In addition, regular deworming of hogs is necessary to control internal parasites of swine (Myer and Walker).

Vehicles

Vehicles used to transport hogs represent a high risk for pathogens and disease transmission. Evidences have shown that contaminated vehicles can spread ASF, *Actinobacillus pleuropneumoniae*, TGE and *Streptococcus suis* (Food and Agriculture Organization of the United Nations, World Organization for Animal Health, World Bank). Cleaning and disinfecting vehicles before loading hogs, therefore is generally used to ensure no disease transferred though vehicles.

All-In/All-Out System

An all-in/all-out (AIAO) system keeps animals that are in same range of age and weight together in a group. The group is moved into next phase of production together. Then the building is completely emptied and sanitized. The AIAO system is different from the traditional continuous flow system as in a continuous flow system, pigs are not grouped by age or weight and they move as individuals. Thus the facility in a traditional continuous flow system is never emptied (Floyd, Owsley, and Van Dyke). The advantages of AIAO system over the traditional continuous flow system include reduction of disease transmission and improvement in sanitation as well as improved environment control, record keeping and pig performance (Food and Agriculture Organization of the United Nations, World Organization for Animal Health, World Bank, 2010; Floyd, Owsley, and Van Dyke). AIAO is able to reduce disease transmission by separating a group of hogs which are at same age and have similar immunities from other groups. By preventing nose-to-nose contact between pigs in different groups, AIAO can limit spread of respiratory disease (pneumonia) (Floyd, Owsley, and Van Dyke). In addition, the facilities are completely cleaned and disinfected after the group moves out of the facility which can prevent disease transmission to next groups.

Biosecurity Plan

A biosecurity plan is defined by the Terrestrial Code as: "*a plan that identifies potential pathways for the introduction and spread of disease in a zone or compartment, and describes the measures which are being or will be applied to mitigate the disease risks, if applicable, in accordance with the recommendations in the Terrestrial Code*" (World Organization for Animal Health, 2008). It aims to prevent the introduction of a new pathogen to farms, reduce the spread of disease among hogs on premises, and prevent the spread of pathogens present on farms to another population of animals (Technical Committee on Biosecurity/Canadian Swine Health Board, 2010). There are many extension articles discussing what should be included in a biosecurity plan (e.g., Owsley, 2002; Shulaw and Bowman, 2001). Generally, animal contact controlling and traffic controlling (including movement of people, animals, and equipment) are deemed necessary in an on-farm biosecurity plan. In animal contact controlling, the isolation of new hogs brought to the farm and sick animals, segregation of hogs (AIAO), and control of wildlife, rodents, and birds, are related issues. Bringing new animals that might be exposed to infected animals to farms can present a great risk. In traffic controlling, besides asking visitors to wear clean outwear and footwear, additional disinfection and restricted access to certain areas for some visitors, especially those having close contacts with animals and their bodily discharges, are recommended. In addition, vehicles or equipment dirty with mud or manures can cause contamination and transmit pathogens. They must be cleaned before entering or leaving farms.

Data

The data used in this study is from 2009 Phase III Agricultural Resource Management Survey (ARMS), Hogs Production Practices and Costs and Returns Report. Covering a cross-section of U.S. hog operations, the survey collects information on farm operators and farm financial characteristics as well as on production practices and facilities. Hog farms were chosen from a list of farm operations maintained by USDA's National Agricultural Statistics Services (NASS). The survey data includes 1,198 responses from 19 states. One important difference between the 2009 Phase III ARMS Hogs Production Practices and Costs and Returns Report and those in previous years is that 2009 report has information on hog farms management practices on food safety. As there are broad differences in production techniques among different types of hog operations, we limit our study to feeder pig-to-finish hog operations.

In the 2009 Phase ARMS Hogs Production Practices and Costs and Returns Report, producers are asked to answer some questions regarding food safety. For PQA Plus, the survey asks: 1) "Did you have PQA Plus certification status during 2009?" 2) "Did all employees involved with hog production have PQA Plus certification status during 2009?" And 3) "Were your premises PQA plus site assessed for 2009?" The survey also asks questions concerning wildlife, rodent, and bird control: 1) "Did cats or wildlife have access to production facilities or feed preparation areas during 2009?" 2) "Did you have a routine rodent control program in and around hog production facilities during 2009?" and 3) "Were you production facilities 'bird proofed' with screening during 2009?" In addition, there are questions on vehicles, "Were the vehicles used to transport hogs during 2009, including those to market, cleaned and disinfected before loading the hogs?", and bio-security plan, "Did you have a written bio-security plan during 2009?" Other questions regarding food safety include 1) Was an AIAO system used in 2009 for the facilities? And 2) "Did you deworm growing-finishing hogs during 2009?"

As some of the total 10 questions related to food safety questions listed above in the survey may be closely correlated, we use principal component analysis (PCA) to transform the data into a set of uncorrelated variables which can be used in the DEA approach. The PCA can also reduce the data dimensionality with resulting principal components still able to account for most of the variance. Both eigenvalue-one criterion, also known as Kaiser criterion (Kaiser, 1960), and the scree test (Cattell, 1966) are used to decide which components are retained in the PCA. With eigenvalue-one criterion, any components with an eigenvalue greater than 1.00 were retained for rotation. And with the scree test, the components that appear before the break on the plot of eigenvalues are assumed to be meaningful and are retained.

Methodology

To construct the composite index for food safety control, we use Data Envelopment Analysis (DEA). DEA is a widely used non-parametric approach based on mathematical programming that allows us to benchmark the performance of individual decision making units (DMUs) against frontiers of best practices based on the observed behavior of other units (Cooper et al, 2007). It is particularly well suited to determining relative levels of food safety controls because it can easily deal with multi-faceted attributes of DMUs, operating an endogenous procedure to the computation of weights for each of these attributes.

Measuring Food Safety Control via DEA

The basic DEA model for evaluating DMUs (e.g., Cook and Seiford, 2009; Despotis, 2005) are set up as:

$$\begin{aligned}
&\max S_{k0} = \sum_{r=1}^{R} \omega_r I_{rk0} \\
&\text{subject to} \\
&\sum_{r=1}^{R} \omega_r I_{rk} \leq 1, \text{ for any farm k} \\
&\omega_r \geq \varepsilon
\end{aligned} \tag{1}$$

Where S_{k0} is the score for the evaluated farm k0; and ω_r is the weight that maximizes the weighted sum of food safety elements for the evaluated farm k0. The weight ω_r is restricted to be greater than a positive infinitesimal ε. I_{rk} is the value of element *r* for unit *k.* The weighted sum of the elements is constrained to be less than or equal to 1 for all farms. This model is equivalent to an input-oriented constant-returns-to-scale DEA model (Despotis 2005) with R outputs and one dummy input for all farms[1]. Table 1 presents the scores of hog farms on the food safety performance obtained from model (1). Farms that have a score of S_{k0} equal to 1 are "best practice" farms in terms of actions on food safety, while farms that have a low score of S_0 show poor performance on food safety.

As the conventional DEA scores are not calculated based on common eights (the weights in DEA model is chosen for each unit to maximize the unit's performance), they cannot be used to rank the farms in terms of food safety management. In addition, while a conventional DEA

[1] A single dummy input has been interpreted as a ''helmsman'' by Koopmans (1951) and Lovell and Pastor (1995), a collective decision-making apparatus for every DMU (Murias et. al. 2008). The DEA model with a unity input vector has been employed in Lovell and Pastor (1995), Reig-Martinez et al (2011), and Mahlberg and Obersteiner (2001).

model is strong in identifying the inefficient units, it is weak in discriminating among the efficient ones (Despotis, 2002). In order to improve the discriminating power of DEA and obtain a complete ranking of individual farms, a common weight approach (Despotis, 2002, 2005) is used to estimate the efficiency scores for farms. Following Despotis (2005), the model is set up as

$$\begin{aligned} & Min_{d_k,\omega_r,z}\ t\frac{1}{K}\sum_{k=1}^{K} d_k + (1-t)z \\ & subject\ to: \sum_{r=1}^{R} \omega_r I_{rk} + d_k = S_k \qquad k = 1,\dots,K \\ & \qquad d_k - \mathrm{z} \le 0 \qquad k = 1,\dots,K \\ & \qquad d_k \ge 0 \qquad k = 1,\dots,K \\ & \qquad \omega_r \ge \varepsilon \\ & \qquad \mathrm{z} \ge 0 \end{aligned} \tag{2}$$

Where the first item of the objective function represents the mean deviation between the DEA-efficiency scores and the adjusted global efficiency scores for all farms; and the second term represents the maximal deviation between the DEA-efficiency scores and the adjusted global efficiency scores for all farms. S_k is the DEA-efficiency score for unit *k*, I_{rk} is the value of indicator *r* for unit *k*, and ω_{ri} is the weight of indicator *r* in the assessment of food safety of DMU_i.

When t=0, the first term in the objective function disappears and equation (2) becomes

$$\begin{aligned} & Min\ \mathrm{z} \\ & subject\ to: S_k - \sum_{r=1}^{R} \omega_r I_{rk} - z \le 0 \qquad k = 1,\dots,K \\ & \qquad \omega_r \ge \varepsilon \\ & \qquad \mathrm{z} \ge 0 \end{aligned} \tag{3}$$

When $t = 1$, the second term in the objective function disappears and the model becomes:

$$
\begin{aligned}
&Min_{d_k,\omega_r,z}\ t\frac{1}{K}\sum\nolimits_{k=1}^{K} d_k \\
&subject\ to: \sum\nolimits_{r=1}^{R} \omega_r I_{rk} + d_k = S_k \qquad k = 1,\dots,K \\
&\qquad d_k \geq 0 \qquad\qquad\qquad\qquad k = 1,\dots,K \qquad (4) \\
&\qquad \omega_r \geq \varepsilon
\end{aligned}
$$

And when $0 < t < 1$, model (2) is solved repeatedly for different values of *t* to find different sets of common weights that minimize both the mean and maximal deviation.

By solving the models above, global efficiency scores of food safety can be computed for each farm. Then farms can be ranked according to the factor $b_j + S_j$, where b_j is the number of times a farm *j* achieves efficient score and S_j is the farm's average global efficiency score.

Determinants of the Rank of Food Safety Control

After we rank the food safety control for farms, it is interesting to investigate what exogenous factors affect the performance of farm food safety control. The most used approach to modeling the DEA scores against exogenous variables is tobit regression (Aly et al., 1990; Stanton, 2002; Dietsch and Weill, 1999) and naïve bootstrap (Xue and Harker, 1999; Hirschberg and Lloyd, 2002). Such approaches, however, as demonstrated by Simar and Wilson (2007), are inappropriate as either no coherent description of a data-generating process is provided or the efficiency scores obtained from the DEA approach are correlated with the explanatory variables. Consequently, the results are insensible or inconsistent.

The procedure proposed by Simar and Wilson (2007) is a statistical model (coherent data-generating process) based on truncated regression and bootstrapping techniques. It is logically consistent with regressing DEA estimates on covariates that are different from the inputs in the DEA. The equation used to analyze determinants of food safety performance is as follows:

$$S_i = \alpha_0 + X_i\beta + \varepsilon_i \quad (5)$$

Where S_i is the score obtained from the DEA analysis for the *i*th farms and X_i is a row vector of independent variables for farm *i*. Table 2 reports dependent and independent variables along with their summary statistics. As sampling weights were used to account for the survey design, survey population means instead of sample means are reported. Among independent variables, the size of the hog farms is categorized into four groups: Size 1 with less than 500 hogs through Size 4 with 5,000 or more hogs. The dummy variable for each size group (*Size1*, *Size2*, *Size3*, and *Size4*) is equal to 1 if the operation has the corresponding number of hogs and 0 otherwise. We divided the hog operation locations into five geographical regions: *East* (including North Carolina), *South*, *North*, *West*, and *Midwest* (including Iowa). *College* is used to indicate operator's education level and takes value of 1 if the operator had 4-year college or above degree and zero otherwise. *Off-farm* has value 1 if the operator worked off farm for wages or a salary at least half time in 2009. *Organic* denotes if the farm is a certified organic hog operation and *exit* denotes if the farm will exit the business in 5 years (taking value of 1) or not (taking value of 0). *Facility Age* indicates the average age of the hog operation's housing facilities/buildings since last remodeled. And *Contract* indicates if hogs were produced under production contract.

Conclusions and Discussions

In this study, we use DEA to analyze the relative performance of food safety management for hog farms. To authors' best knowledge, there have been no studies on ranking individual farms food safety control using DEA models with global common weights. The advantage of this method is that the weights in the DEA process are less contestable and the composite index obtained from the optimization process can be used to rank farms in terms of food safety control rather than just identify the "inefficient" ones. In addition, the Simar-Wilson method is used to identify factors that affect farm food safety control. The composite food safety management index we use in this study can offer substantial insight into the empirical assessment of food safety control at the farm level, which is crucial for producing safer agricultural food products as farm production is the first step in food production.

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