Supply of Food Safety under Competing Inspection Schemes (Risk Mitigation Strategies)

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Introduction

In 1996, the mandatory Hazard Analysis Critical Control Point (HACCP) system in the US meat and poultry industry was implemented and now plays an important role in the supply of higher quality, safer meat and poultry products. The HACCP system relies greatly on a sampling inspection policy specified by the 1996 Pathogen Reduction (PR)/HACCP regulation. Most recently, Food Safety and Inspection Service (FSIS) issued new standards for Salmonella Verification Sampling Program and related activities for meat and poultry processors. The goal of these initiatives is to further increase the safety of meat and poultry products and reduce the number of foodborne illnesses.

In this paper, we investigate the relationship between competing sampling inspection schemes (risk mitigation strategies) and the uncertainty associated with imperfect information about food product safety. We assume that the uncertainty related to sampling inspection creates moral hazard on food safety and changes suppliers' incentives to deliver safer products. We assume that requirements of sampling inspection regulations (e.g., sample size and acceptance level), fines and losses associated with failing inspection or contaminated product reaching the market and causing harm, affect market participant risks. More specifically, we develop a principle-agent model to evaluate how the parameters of various sampling inspection schemes influence suppliers' willingness to deliver safety when buyers and the regulator have imperfect information about suppliers' efforts. In contrast to other, very limited work in this area of research, our model concentrates on multiple market suppliers and buyers and the possibility of repeated food safety failures that can affect suppliers reputation in the long run. We then apply this unique modeling approach to the 1996 PR/HACCP as well as the more recent FSIS raw meat and poultry salmonella sampling inspection standards.

The current economic literature on the use of food safety inspections is primarily based on analyses of the effects of inspections on producers' behavior and investment in product quality (addressing adverse selection problems) and on analyses of inspections as a policy tool to create incentives driving producers' efforts (addressing moral hazard problems).

In the studies that address adverse selection problems, agents have more information on the probabilities of risk than principals and the probabilities of risk are exogenous for principals. Therefore, the main question in this type of studies is: how risky is the agent? Examples of adverse selection studies include Akerlof 1970, Hennessy 1995, Chalfant et al. 1999, Starbird 1997 and 2000. Price-inspection type of incentives offered by principals, are not strong enough to make agents invest in higher quality (safer) products. The reason is sampling and measurement error. As mentioned earlier, the principal does not know how risky the agent is. Vertical integration and contracting that accounts for exogenous risk will remedy this problem.

In the studies that address the moral hazard problem, agents still have more information on the probabilities of risk but the probabilities depend explicitly on agents' efforts and are endogenous for principals. The main question in this type of studies is: how does the principal induce enough quality (safety) care from the agent? Examples of moral hazard studies include Milgrom and Roberts 1982, Bisin and Gottardi 1999, and

Starbird 2005. The authors show that inspections, internal and external failure costs have a significant impact on the price that the buyer is willing to offer and therefore the supplier's willingness to exert higher effort to ensure safety. They also show that changing the sample size or the acceptance rate of the sampling inspection policy might be as effective as increasing the expected failure costs (Starbird 2005).

In this paper, our research objective is to propose modeling techniques that build a comprehensive understanding of food safety inspections as a tool for creating economic incentives that impact risk levels. More broadly, our goal is to investigate how economic behavior and incentives influence risk levels in food markets.

Our research approach concentrates on specifying a dynamic Principal-Agent economic model for multiple market participants (principals and agents) whose economic objectives are also functions of food safety risks and agents' efforts to diminish them. Our dynamic model allows us for explicit consideration of agents' past performance ("history of reputation") in designing optimal price/inspection incentive schemes. In this setting, principals choose price/inspection incentive schemes that maximize their objectives (under different market structure conditions) subject to agents' optimal behavior under the incentive scheme and the participation constraint that agents' expected contamination control, inspection, and penalty costs cannot exceed. In each time period, agents choose a food safety control method and maximize their payoffs that also account for costs of safety controls, inspection, and penalties for current and/or past contamination levels that exceed standards set by principals. The optimal solution gives a steady state food safety control system for each reputation state and agent. Based on agent's performance history in controlling food risks, the incentive system determines sampling inspection parameters including frequencies, charges to the agent for testing, and penalties for substandard safety controls. Agent's choice of a food safety control system impacts current returns through the costs of food safety controls and through the probability of having a prevalence test below the required standard. Given a choice of a food safety control method, better reputation increases current expected returns by reducing sampling inspection costs and the expected penalties.

We adopt and utilize MATLAB programs developed by Miranda and Fackler (2002) to solve agents' stochastic discrete time and state of nature dynamic programming problem for a given set of parameters and under competing incentives schemes. We also obtain the optimal values of the incentive scheme parameters for principals using the same methods of estimation. We consider varying principal objectives under varying market structure conditions. In this sense we extend the work by King et al. (2007) who applied similar methods to evaluate salmonella control in pork production in the Netherlands. We use cost estimates and FSIS raw meat and poultry salmonella sampling inspection parameters to evaluate current and proposed food safety inspection schemes in the United States.

The remainder of the paper is structured as follows: the next section describes raw meat and poultry salmonella sampling inspection schemes used in the United States. Section three presents the details of the dynamic principal-agent economic model and section four sets out estimation procedures of the model and the expected results. The final section of the paper provides concluding remarks. We expect that our paper will generate interest among conference participants given a very current and unique policy topic as well as new modeling and estimation methods.

Raw Meat and Poultry Salmonella Sampling Inspection Schemes in Slaughter Plants in the United States

In 1996, FSIS established PR/HACCP to verify that plants follow consistent process control for preventing the contamination of raw meat and poultry products with salmonella, by setting salmonella performance standards that slaughter plants should meet. Raw products with established performance standards include: carcasses of cows/bulls, steers/heifers, market hogs, broilers, and turkey. The performance standards are based on the prevalence of salmonella and are determined based on FSIS nationwide microbiological baseline studies conducted prior to PR/HACCP implementation. The performance standards are presented in terms of the maximum number of salmonella positive samples acceptable per given sample set. The number of samples in a sample set varies by product type, and the maximum number of positive samples acceptable in a set provides an 80% probability of a slaughter plant passing the inspection when it is operating at the standard.

Before 2006, there were two phases of the sampling inspections for salmonella in raw meat and poultry: non-targeted and targeted testing. Non-targeted set tests were collected at plants randomly selected from the population of all federally inspected plants, with a goal of scheduling every plant at least once a year. Targeted testing represented sample sets collected from plants targeted for follow up testing following a failed set.

In February 2006, FSIS issued new standards for Salmonella Verification Sampling Program. Through this program, slaughter plants have been scheduled for inspections based on food safety risk criteria therefore, FSIS increased testing frequency in plants with the most salmonella positive samples and the greatest number of samples with serotypes most frequently associated with human salmonellosis, as defined by CDC. Slaughter plants are grouped into one of three categories. Category 1 includes plants with two most recent salmonella set results equal to or less than 50% of the performance standard. FSIS considers these plants to demonstrate consistent process control. Category 2 includes plants where at least one of their two most recent set results was greater than 50% of the performance standards without exceeding it. These plants are considered to have variable salmonella process control. Category 3 includes plants where most recent salmonella set results exceeded the performance standards for its product class. FSIS considers these plants having highly variable process control.

Dynamic Principal-Agent Economic Model

The dynamic Principal-Agent model utilized in this paper allows us to estimate optimal levels of food safety inspection parameters as well as Nash equilibrium economic incentive parameters for a two tier supply chain of livestock suppliers (agents) and federally inspected slaughter plants (principals) in the US raw meat and poultry market. We choose and examine two alternative market structure scenarios on the slaughter plant side (principal side), perfectly competitive as well as symmetric Cournot oligopoly with all plants selecting the same equilibrium quantity with a Cournot oligopoly equilibrium price, and its impacts on the salmonella sampling inspection parameters and the economic incentives parameters.

We assume that livestock suppliers (agents) operate in a competitive market and that they are homogenous (except for effort to ensure product safety and related to effort costs). Therefore, it is enough to set the objective function and the constraints for one representative agent. All the obtained parameters of interest can be used for all of the agents. In each time period, agents choose a contamination control system and maximize their payoffs that include costs of safety controls, testing, and a penalty for current and/or past contamination levels that exceed standards set by slaughter plants (principals). In this paper, we focus on federally inspected slaughter plants and the salmonella sampling inspection standards are set in this case by FSIS. The optimal solution of the model gives a steady state control system for each reputation state and agent.

In our model, we also assume that principals can be private or public and their objectives can also be private or public (e.g., maximize profits in competitive or oligopoly markets, social welfare, etc.). Principals choose a price/testing incentive schemes that maximize their objectives subject to agents' optimal behavior under the incentive scheme and the participation constraint that agents' expected contamination control, testing, and penalty costs cannot exceed. Our model allows for explicit consideration of agents' past performance ("history of reputation") in designing price/testing incentive schemes.

Agents' maximize current expected returns under cumulative reputation inspection scheme (see equations below where γ- represents monthly discount rate, x-represents contamination control method, R-represents reputation level). Agents' choice of contamination control systems, x, impacts current returns through control costs and through the probability of having prevalence tests below the required standard. Given a choice of x, better reputation increases current expected returns by reducing inspection costs and the expected penalties. The structure of this reputation based sampling inspection scheme is similar to auto insurance rates where customers pay lower premiums as the number of consecutive time periods without accidents increases.

$$\max \sum_{t=0}^{\infty} \gamma^{t} f_{1}(x_t, R_t)$$

$$s.t$$

$$R_{t+1} = \begin{cases} \min((R_{t+1}), 12) & if \; Test_t Fail_t = 0 \\ 1 & if \; Test_t Fail_t = 1 \end{cases}$$

$$where$$

$$f_t(x_t, R_t) = PP - PC - c(x_t) - \alpha_{11} p(R_t) TC - \alpha_{12} p(R_t)(1 - p(x_t))$$

$$and$$

$$p(R_t) = \max((\alpha_{13} e^{-\alpha_{14}(R_t - 1)}), \alpha_{15}).$$

The notations used in the equations above are as follows:

Test-is a binary variable equal to 1 if products are tested in period t and 0 otherwise.

Fail-is a binary variable equal to 1 if products have a prevalence test in period t above the allowable standard and 0 otherwise.

R-is the number of consecutive months (up to 12 in this case), without failing the inspection.

p(R)-is probability that the agents' products will be tested, it declines as R increases, the last equation shows the relationship.

α_{11}-is a parameter, share of the expected testing costs paid by the agent.

α_{12}-is the size of the penalty per product.

α_{13} α_{14} α_{15}-are parameters related to the probabilities of being tested (maximum probability of being tested, reduction in the probability of being tested, and the minimum probability of being tested, respectively).

PP-is the product price.

PC-represents (non-contamination control) production cost.

C(x)-represents contamination control cost.

TC-represents testing cost.

Agents' good reputation can help principals to relax incentive compatibility constraints and lead to less frequent inspections, less testing. An incentive compatibility constraint requires that expected agents' payoffs under high effort are greater than under low effort. In addition, incentive compatibility constraints have to be binding because when they are not binding, agents' compensation prices are constant and independent of the effort to ensure safety. It is also worth nothing that with perfect information about agents' effort (hence product safety), principals select the price and agents' effort. On the other hand, with asymmetric information, principals choose the price and agents choose the level of effort.

In a dynamic setting, principals spread agents' rewards and punishments between the current and future periods therefore good agents' performance today gives a greater continuation payoff in the future. Given the assumptions discussed earlier, the optimal incentive system parameters and the agents' optimal contamination control systems represent a Nash equilibrium. Neither the principals nor the agents can be made better off by deviating from their optimal solution.

In our model, policy makers can impact indirectly food safety outcomes through internal and external failure costs, as well as through sampling inspection parameters (e.g., sample size, acceptance rate). Sample size has a large impact on expected internal and external failure cost through the probability of acceptance and rejection, and the likelihood ratio, that is the ratio of the probability of acceptance of an unsafe (low effort) product to the probability of acceptance of a safe (high effort) product. The likelihood ratio is a measure of the precision of the inspection policy. When the likelihood ratio is zero then the inspection is perfect and there is no chance of accepting unsafe (low effort) products. The accuracy of the inspection policy has a direct impact on the willingness of agents to deliver safer products and therefore on the price that principals must offer to get safer products.

Acceptance rates of sampling inspections can have even larger impact than sample sizes on expected internal and external failure costs also through the probability of acceptance and rejection, and the likelihood ratio. This is because when we decrease the acceptance rate (number), the decrease in the probability of acceptance of an unsafe product is larger than the decrease in the probability of acceptance of a safe product and this is why changing the acceptance rate has even a larger overall impact on food safety outcomes.

Estimation Procedures of the Model and Expected Results

We adopt MATLAB programs developed by Miranda and Fackler (2002) to solve agents' stochastic discrete time and state of nature dynamic programming equations for a given set of parameters and under competing inspection schemes. We also obtain the optimal values of the incentive scheme parameters for principals using the same methods of estimation. Our discrete time, discrete state decision model has the following structure, in every time period agents observe the state of an economic and a biological system, take an action, and get payoffs that depend on both the state of the system and the action taken. The agents seek a sequence of policies that yield the specific action that should be taken in any given state and time period to maximize the present value of current and expected future payoffs over a selected time horizon. As Bellman (1957) describes "Dynamic programming is based on the principle of optimality which has the property that whatever the initial state and decisions are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision."

The computer program that we design for our specific model uses policy iteration to identify an optimal steady state control policy (e.g., the optimal salmonella control method for the considered reputation state). In addition, we obtain a long-run probability for each possible state under the optimal policy. We then use this information to calculate expected control costs, testing cost, penalties, and prevalence levels for a representative agent operating under the optimal policy.

The next step is to solve slaughter plants optimization problems that depend on selecting optimal sets of economic incentive parameters. These optimal parameters define then a Nash equilibrium since the livestock producers and slaughter plants are responding optimally to each other choices. As mentioned earlier, we consider two market structure scenarios on the slaughter plant side, perfectly competitive and symmetric Cournot oligopoly with all plants selecting the same equilibrium quantity with a Cournot oligopoly equilibrium price.

Model parameters for the analysis set up in this paper will be based on current conditions for meat and slaughter plant operations in the United States. We will obtain the data on non-contamination agents' production costs, prices and outputs, cost of sampling inspections (e.g., salmonella testing), inspection failure penalty costs, sampling inspection parameters including sample sizes and acceptance rates, as well as contamination prevalence data obtained from inspections. Due to time constraints, the results of the estimated model are not available at this time and will be obtained in the next two months, before the conference presentation.

Concluding Remarks

In this paper we present a dynamic principal-agent model for salmonella control in the US raw meat and poultry market. We provide methods that allow for integrated analyses of the economic incentives system and the biological salmonella control system. Higher level of model complexity creates the need to use numerical methods of estimation but at the same time gives more useful real world results for policy analysis. The methods are also useful in private contract design. Our approach allows us to arrive at more precise analysis of sampling inspection schemes and economic behavior. This information is crucial to the design of more effective food safety and inspection programs. As it is apparent from our work, economic and biological systems jointly determine the level of risk and the optimal mix of food safety controls. Therefore, more work is needed to evaluate the effects of various linkages between economic behavior and biological risk.

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