



# Modeling a Government-Manufacturer-Farmer game for food supply chain risk management



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## ABSTRACT

Farmers may add chemical additives to crops to enhance their appearances/tastes or decrease their costs, which may also increase the food demand and sales profits. Manufacturers buy products from farmers and sell them to consumers, where the government benefits from tax income based on sales revenues. However, once the contaminated food is consumed, customers could get sick. The government would, thus, be partially responsible for society's health risks from the chemical additives. The punishment policies are set up by the government to regulate and deter farmers' and manufacturers' risky behavior, balancing tax income, punishment income, and society's health risks. Based on the observation of government regulations, the farmers strategically choose the optimal level of chemical additives, and manufacturers pay the appropriate price to farmers. To our knowledge, little work has studied the strategic interactions among the regulating government, manufacturers, and farmers with endogenous customer demand. This paper fills this gap by building a Government-Manufacturer-Farmer model with three decentralized and centralized sub-models. The models are validated and illustrated through applying the 2008 Sanlu food contamination data. Our results show that (a) the higher the food price is, the higher the punishment is needed to deter the use of chemicals; (b) the optimal chemical level increases in the payment to the farmer when it is low and decreases in the government punishment; (c) the manufacturer's payment to the farmer decreases in the government punishment; (d) the chemical level is significantly higher in the centralized model than in the decentralized model especially when the food price and slope for sales amount are high, or the base sales demand, tax rate, and chemical cost are low; and (e) the decentralized model leads to the lowest chemical level at equilibrium. This paper provides some novel policy insights for food supply chain risk management.

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## 1. Introduction

In the field of food supply chain research, there is literature focusing on health and safety. The consumers' perception of potential (food) risks is analyzed in (Liu, Pieniak, Verbeke, 2013; Liu, Pieniak, Verbeke, 2014; Sparks and Shepherd, 1994). Chemical additives are normally added in many processes along the food supply chain by farmers and manufacturers. The food additives are used for a number of purposes, generally for preservation, provision of vitamins or minerals, and enhancement of the food texture, appearance, and flavor. However, food additives could also be harmful. For example, there were more than 100 pet deaths among nearly 500 cases of kidney failure due to a contaminated food

additive, “wheat gluten” (which was adulterated with melamine to increase the apparent protein level) in animal food in 2007, involving three companies *Americas Choice*, *Preferred Pet* and *Authority* (Associated Press, 2007; U S Food and Drug Administration and U S Department of Health & Human Service, 2008). At least six infants were killed due to kidney stones, and the kidneys of 300,000 infants were damaged by industrial chemical melamine in 2008 after using the milk products from Sanlu company (Branigan, 2008). Some children have experienced growth problems due to the contaminated chemical additive 2-ethylhexyl phthalate (DEHP) in food and drinks from 47 Taiwanese companies in 2011 (Galarpe, 2011). The German company, *Harles and Jentzsch*, contaminated 150,000 tons of feed for chickens, turkey, and swine with the cancer-causing additive Dioxin in 2011 (Spiegel Online, 2011).

There are many other cases that follow the same pattern in China. There has been a longstanding concern about farmers using toxic pesticides on vegetables, rice, and other crops in China, where

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the pesticides is meant to kill pests or keep the product fresh (Mail, 2012). Another issue is that the use of poisonous chemical malachite green, which was used for raising mandarin fish to avoid them ill and was found in Hong Kong. It is said that this chemical is harmful for human health risk (CSR C, 2006). About 60 farms in Henan province fed pigs with illegal ractopamine to make more profit, where the ractopamine can speed up the process of muscle building and fat burning to produce leaner pork (Post, 2011).

Multi-stage supply chains in modern economies give anonymity to actors at different stages. The limited transmission of information from suppliers to consumers gives suppliers opportunity to introduce harmful or fraudulent chemicals that raise their profits while harming or defrauding consumers without their knowledge. This strategy benefits individual suppliers in the short run at the expense of consumers. However, market failure similar to a “market for lemons” scenario occurs when consumers become aware of the risk and have no means of gathering reliable information on products. Regulators can gain insights about how to preserve a healthy market by considering the strategic behavior of different actors in the supply chain.

### 1.1. Risky behavior in food supply chain

A food supply chain process is illustrated in Fig. 1, where raw materials such as raw milk are initially produced by farmers (representing suppliers of raw commodities to manufacturers which include farmers and traders). The raw food is then bought and processed by the manufacturers, and eventually consumed by customers. The government receives the tax income through the manufacturer's sale profit. During the supply chain process, chemical additives could be added by the farmers or manufacturers to preserve the product's freshness or improve its appearance. (In 2008, the contamination of melamine in the aforementioned Sanlu case actually is considered food fraud, and even a food crime, where the farmer added melamine to the raw milk.) The consumers may get sick by consuming the contaminated food. The government inspects and punishes the risky behavior by farmers or manufacturers in the food supply chain and may be considered partially responsible for the societal impacts. The government agencies responsible for inspection and punishment include the U.S. Food and Drug Administration, the European Food Safety Authority, and the Chinese Institute of Food Safety Control and Inspection. This paper focuses on the risky behavior of the farmers, who could be motivated by the low selling profits from manufacturers (Gale & Hu, 2009).

### 1.2. Motivation for risky behavior by manufacturers or farmers

Chemical additives could preserve the freshness of food and make it more attractive, which is helpful for selling products. Due to considerable sales profits, the manufacturers or farmers may use food additives even though they are harmful (Harrington, 2011). Inspection and punishment policies could deter the manufacturers or farmers' risky behavior. In the Sanlu case, due to low or even no

profits from the Sanlu company, farmers had to add melamine to produce milk with high protein, reduce the production costs, and satisfy the demand for the Sanlu company, who was aware of such risky behavior (DeLaurentis, 2009). Appendix provides the influence diagram for the manufacturer's or farmer's risky behavior.

### 1.3. Motivation for punishment policy by government

The government encourages the sales demand for the manufacturers and farmers (who may add high level of chemicals), which could yield considerable tax incomes from an economic perspective. A conflict tradeoff is generated for the government on how to control the risky behavior. We consider the government as the first mover who sets up punishment, and the farmers or manufacturers as the followers who observe the punishment policy and strategically add chemical additives. The government takes the optimal punishment strategy considering the farmers' and manufacturers' strategic responses, to farmers and manufacturers, respectively. Appendix provides the influence diagram for the government's punishment policy.

### 1.4. Literature review and contribution

Food contamination incidents could derive from the government's lack of regulations, punishments, and resources to enforce food safety (Ellis & Turner, 2010; Ming, 2006; Zacha, Doyleb, Bierc, & Czuprynski, 2012). For the safety of the (food) supply chain, many suggestions on government regulations are proposed: (a) the joint use of liability and safety regulation (Shavell, 1984); (b) fines and corrective taxes (Kambhu, 1990); (c) a higher inspection accuracy and stronger enforcement (Cheung & Zhuang, 2012; Oh, 1995); (d) the imposition of liability for damages (Segerson, 1999); (e) transferring costs and benefits from the government to the manufacturers using penalty contracts (Hobbs & Kerr, 1999); and (f) transferring safety failure costs from the government to the manufacturers (Chen, 2009). This paper focuses on the government's punishment and taxes.

There exists strategic interactions between companies and the regulating government in the existing literature (Tompkin, 2001). For example, (Rose-Ackerman, 1991) suggests direct regulation and product liability that can make incentives for companies to control food quality. (Henson & Caswell, 1999) points out that the expected economic benefits and costs affect a firm's response to the government regulation. The companies' benefits and costs are measured for improving food quality and safety in quality management systems in (Caswell, 1998). (Fares & Rouviere, 2010) finds that the company's decision of using additives depends on its own costs (e.g., food spoilage and risks) and benefits (e.g., productivity enhancement), with or without facing the government regulation.

Strategic interactions between companies and the government are not new, e.g., (Pouliot & Sumner, 2008) analyzes the food safety and quality issues from the perspective of traceability in a marketing chain composed of farmers, marketers and consumers.

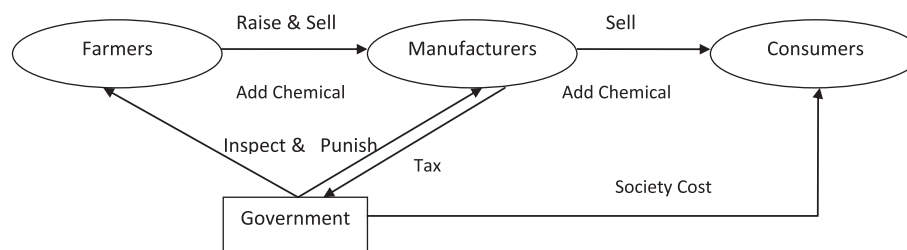


Fig. 1. Risky behavior from the farmers and manufacturers in food supply chain, under potential government regulation, inspection, and punishment.

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