



Effects of input capacity constraints on food quality and regulation mechanism design for food safety management[☆]



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ABSTRACT

Input capacity constraints means a firm cannot make its output decision based on the first - order optimal condition of profit maximization because it does not have enough inputs. Input capacity constraints have a significant effect on production quality and firm competition, especially on food safety management. This paper tries to provide a new perspective for quality operation in supply chain management. It also designs a new mechanism for quality regulation. After distinguishing between quantity-sensitive input capacity constraints and quality-sensitive input capacity constraints, this paper demonstrates a theoretical analysis about the impact of input capacity constraints on food quality and quality regulation by game theory. The results show that both kinds of capacity input constraints lead to a lower level of output, quality and consumer surplus, but a higher level of prices. In this study, we design a quality regulation to stimulate the growth of high quality food products. More importantly, this paper proves that reward is more effective in food quality guarantee programs than punishment or fine based programs. The conclusions are helpful for addressing food safety problems for both the supervisors and firms.

1. Introduction

Food safety has become a major issue for the central government of China and as a result the central government has taken up food safety issue as a key task in its No.1 central document in 2015 (<http://english.agri.gov.cn/>)¹. Food safety incidents happen regularly not only in China but throughout the world (Liu and Ma, 2016; Taylor et al., 2016). The first food contamination incident, recorded in the history, happened in the ancient Roman Empire (Kelth, 2012). Since then several foodborne illnesses have happened in Europe and other developed countries, such as the United States, during the 1900–1950 period. The number of food safety outbreaks peaked during the last half of the 20th century (Yang et al., 2009; Harrington, 2011). Interestingly, at the beginning of the 21st century, more food safety incidents have occurred in the developing countries, particularly, in Asia and Latin America (including China, Brazil, India). Based on the above information, we infer that

food safety outbreaks have something to do with the development of the economy and the issue should be investigated through the use of economic theory, such as input capacity constraints, as well as ethics and law disciplines.

Take the case of China, an increasing number of food safety incidents are being reported by the media, making food safety a focal point of major agricultural issues (Xue and Zhang, 2013). As a result studies have proposed ways to improve food safety (Li, 2009; Ni and Zeng, 2009; Handschuch et al., 2013; Chen et al., 2015b). These studies conclude that lack of laws, standards and regulations are the main reasons for food safety outbreaks. Few studies (see Lin et al., 2010; Lentz and Barrett, 2013; Geng et al., 2015) have used economic reasoning to understand the effects of regulations on food safety outbreaks. Recall that food quality is the foundation of food safety and material inputs inherently determine the quality of food. We know that inputs are scarce and scarcity could lead to input capacity constraints and

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¹ The No.1 central document is the first document of the central government of China announcing key responsibilities for agriculture during the subsequent years.

Nomenclatures

x_i	Quantity
q_i	Quality
α	Market size
γ	Product substitutability
U	Consumer utility
i	Firm index
p_i	Price
CS	Consumer surplus

π_i	Profits
c_i	Costs
θ	Transformation efficiency
R	Input capacity constraints boundary
n	Number of firms
p	Visited probability
m	Number of inspectors
c	Punishment fine
s	Reward fund

could lead to changes in the quantity and quality of output and other competitive decisions made by firms (Benjaafar et al., 2017; Jansen and Özalp, 2017; Cachon et al., 2017) and supply chains (Graves and Schoenmeyr, 2016). Additionally, input capacity constraints have significant influence on the food industry because firms under input capacity constraints are inclined to use lower quality of inputs or alternative inputs to produce the same product and to increase profit margins.

Food safety depends on production, handling, preparation, transportation and storage of food in ways that prevent foodborne illnesses. This includes routines that should be followed in order to avoid potentially severe health hazards. Any improper operation of the process, no matter intentional or unintentional, may result in food pollution or may even lead to food safety accidents/outbreaks. Food safety accidents can result from moral hazard behavior of food producers, based on asymmetric information, or from input capacity constraints. For example, quality of orange juice may be affected because only 80 oranges were used instead of 100, a case of input constraint, that were required in the production process. On the other hand, if a producer deliberately uses a wrong input, a case of moral hazard, in the food production process it could also compromise the food safety. Generally, quality motivation is employed for the latter and punishment is used for the former. Hence, different food safety problems need different regulations. Previous studies in the literature have focused on the moral hazard problem in food safety, however, only a few studies (see Lin, et al., 2010; Lentz and Barrett, 2013; Geng et al., 2015) have addressed the issue of input capacity constraints on food safety.

Therefore, the objective of this study is to assess the impact of input capacity constraints on food safety and how to make quality regulation more successful. Specifically, we address the issue of quantity- and quality-sensitive input constraints in the food industry. A major issue about input capacity constraints is how it could lead to a decrease in the quality of food products and food safety standards. This study contributes to the literature in several ways. First, this paper aims to model the impact of input capacity constraints on food quality and food safety using game theory. Second, we show differential impacts of quality-sensitive and quantity-sensitive input capacity constraints on the food industry. Third, we design an effective quality regulation mechanism in order to reduce food safety problems. The results of this study should be helpful in designing and reducing input capacity constraints and in developing regulations. Finally, we offer a new perspective in solving food safety issues for agri-food markets and food supply chain management.

We classify input capacity constraints into quantity-sensitive and quality-sensitive constraints. A quantity-sensitive input capacity constraint means that the constrained input has a major impact on the quantity of the output, while a quality-sensitive input capacity constraint has a significant impact on the quality of the output produced. Lastly, we compare the differences in quality and quantity as well as in consumer surplus among the three different scenarios, based on symmetric Cournot competition.

The rest of this article is organized as follows. The next section sets up the basic model. In Section 3, we derive the unique equilibrium of

our game. In this section, equilibrium analyses are offered under three different scenarios, namely, no-constraints, quantity-sensitive and quality-sensitive input constraints. Some major Propositions are outlined after comparing the analyses. Section 4 develops a quality regulation mechanism based on Basu and Dixit's "Too Small to Regulate" theory and some significant Propositions are presented in this section. The last section of the paper provides conclusions and implications of the study. Here we also provide the major limitations of our study and avenues for future research. Finally, all omitted proofs are presented in the Appendix.

2. Literature review

Food safety outbreaks is not only a problem in the developing countries but across the world, even developed countries such as the United States cannot be excluded. Recently, Rieger et al. (2016) investigated food scandal in the German meat industry and found that consumption habits and media usage behaviors impact households' responses to food safety outbreaks. In another study, Liu and Ma (2016) analyzed food scandals in China and found that media exposure was helpful in securing food safety. Food safety risks could exist in any part of the food supply chain. But the vast majority of food safety outbreaks occur during the food production and processing, or due to producing with inferior inputs. Additionally, illegal additives could lead to outbreaks in food safety. For example, Wang et al. (2015) concluded that scarcity in raw milk played a significant role in the 2008 milk scandal in China. Several studies (Chen et al., 2017; Lu et al., 2015; Zhang et al., 2015) have investigated the impact of soil and water pollution on food safety. In each case the authors found that water and soil pollutions are major factors affecting food safety in China. Finally, a study (Karp et al., 2016) investigated the influence of agricultural practices on food safety and found a positive and significant relationship between agricultural practices and food safety.

Food production and safety standards are widely used in the food industry, therefore, a plethora of studies, especially in developing countries, have investigated the impact of food safety standards on food safety. For instance, Jongwanich (2009) concluded that food safety standards of developed countries have a significant influence on the food safety standard in the developing countries, and that developing countries benefit from those standards. The food safety standards stimulate firms in the developing countries to raise their food quality standards. Similarly, Handschuch et al. (2013) examined the effects of food safety and quality standards on the growth of small farms in the developing countries. The authors found that food standards have a positive and significant effect on small farms' quality performance and income. Finally, Hou et al. (2016) investigated the impacts of food safety standards on international supply chain organization (ISCO) and concluded that ISCO benefits from food safety standards. Standards, ethics and law play a critical role in the food safety problem (Fagotto, 2015; Sperling, 2010); food safety laws are ameliorating due to food safety problems (Geng et al., 2015).

Regulations, especially quality control regulations, are needed to enhance food safety in any economy. For example, Dou et al. (2015)

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