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Markets and welfare effects of food fraud*

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This study develops a theoretical framework of heterogeneous consumers and producers and imperfectly competitive food companies to analyse the system-wide market and welfare effects of food fraud in the form of food adulteration and mislabelling. The results show that, while the price impacts of food fraud are product-specific with the equilibrium prices of high-quality and low-quality products moving in different directions, the equilibrium quantities depend on the relative magnitude of the demand and supply effects of food fraud. Regarding the welfare effects of food fraud, they are shown to be highly asymmetric across different consumers and producers. In addition to enabling the disaggregation of the welfare effects of food fraud, the explicit consideration of agent heterogeneity, asymmetries in the probability of fraud detection and the endogeneity of the producer quality choices also enables the derivation of a key result of this study; contrary to what is traditionally believed, both low-quality and high-quality producers can have economic incentives to commit fraud. The group that is more likely to cheat is determined by the social attitudes towards fraudulent behaviour, the enforcement policy parameters and the relative magnitude of the demand and supply effects of food fraud. A comparison of the market effects of mislabelling and food adulteration reveals that, while the equilibrium quantity of the high-quality product is higher in the presence of mislabelling, producers are more likely to mislabel than adulterate their products.

Key words: food fraud, heterogeneity, market and welfare effects.

1. Introduction

When you order seafood at a restaurant, do you get what you pay for? Scientists from Oceana, a nonprofit marine conservation organisation, conducted one of the largest seafood fraud investigations on 1,215 samples from 674 outlets in 21 states of the United States over the period 2010 to 2012 and found that there is, on average, a 33% probability that you do not actually get what you pay for. The share of mislabelled food was (a quite remarkable) 74% for seafood sold in sushi restaurants and 18% of seafood sold in grocery stores with mislabelled 'red snapper' and 'tuna' accounting for

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90% and 55% of the relevant tested products, respectively (Warner *et al.* 2013).

Food fraud became particularly prevalent in the middle ages when many merchants mixed cheap substitutes with expensive imported spices and sold them throughout Europe. During the 18th and 19th centuries, food fraud became widespread in the United States. Most common types of food fraud include milk being watered down and mixed with chalk, lead added to coffee and spices mixed with cheap substitutes (Laura 2014). Despite technological advancements that enable the detection of food fraud and consumers ranking authenticity and safety of food top among noneconomic issues (Grocery Manufacturers Association and Kearney 2010), food fraud still occurs with approximately 10% of the food on the grocery shelves in the United States being adulterated or mislabelled (Pimentel 2014).[1]

Food fraud is also quite prevalent in Europe. In one of the largest food fraud investigations launched by Interpol and Europol in 47 countries during the period December 2014 to January 2015, there were thousands of tons of adulterated food seized, including 31 tons of chemically treated seafood from Italy and 35 tons of counterfeit butter from Egypt (Oaklander 2015).

Concerns about authenticity and food safety have grown in recent years, given the presence of food fraud is understood to have global consequences. The 2008 Chinese milk scandal demonstrated the consequences of food adulteration at a global scale, affecting consumers and industries in multiple countries. The scandal involved selling watered-down milk as high-quality milk and adding melamine in milk to boost its protein content and pass nutritional tests (Mooney 2008). Due to this scandal, 290,000 babies around the world were affected by melamine contamination out of which 6 died and 52,000 were hospitalised (Grocery Manufacturers Association and Kearney 2010).

Food fraud is motivated by economic gains and is enabled by the fact that the information about the nature of the, increasingly prevalent in the food system, credence goods is normally asymmetric; while producers know whether a product is high quality or not, certain product attributes are not detectable by consumers through search or experience. While the introduction of certification and labelling can solve this information problem and ensure the presence of the high-quality products in the market (Giannakas 2002; Bonroy and Constantatos 2014; Roe *et al.* 2014; Zilberman *et al.* 2018), it can also create incentives for fraudulent behaviour by producers in the form

[1] A recent Washington Post investigation revealed that the Aurora Organic Dairy, one of the largest suppliers of organic milk in the United States, produced conventional milk and distributed it to the biggest grocery chains as organic (Whoriskey 2017). In another high-profile case, the Food and Drug Administration (FDA) found that Castle Cheese, a well-known Pennsylvania-based cheese company, was including wood pulp in their parmesan cheese marketed nationwide. In fact, based on Bloomberg News, this is a common practice with many well-known parmesan cheese brands using wood pulp while marketing their products as '100% Parmesan Cheese' (Lydia 2016).

of food adulteration and mislabelling. Such fraudulent behaviour is normally enabled by imperfect monitoring and enforcement systems and the fact that the ability and efforts of key actors in these markets (like firms and regulatory and enforcement agencies) may be unobservable by consumers (Sheldon 2017).

Despite the prevalence of food fraud and its, sometimes, devastating consequences for consumer well-being and the sectors involved, a systematic economic analysis of food fraud is virtually absent. Among the exceptions are the studies by Giannakas (2002) and Baksi and Bose (2007) that focus on causes and consequences of mislabelling. In particular, Giannakas (2002) develops a heterogeneous consumer model and examines the economic causes of mislabelling organic products and its consequences on consumer behaviour and welfare. He finds that consumer deception in the form of mislabelling decreases the value of labelling and can result in demand-side market failures. Baksi and Bose (2007) study efficient labelling policies for credence goods when producers can mislabel their products. They compare self and third-party labelling policies while assuming that only low-quality producers can engage in fraudulent behaviour. They show that costly third-party labelling by high-quality producers increases the price of high-quality products which, in turn, has two opposing effects: it increases the incentive of low-quality producers to cheat and decreases the market share of high-quality products.

While the aforementioned studies focus on the causes of mislabelling and its consequences for consumer behaviour and welfare, this research analyses the impacts of food fraud in the form of both food adulteration and mislabelling on all interest groups involved, that is consumers, producers and middlemen (e.g. food processors and retailers). Specifically, the main objective of this study is to analyse the system-wide market and welfare effects of food fraud, that is the effects of food adulteration and mislabelling on the equilibrium prices and quantities in the relevant food product markets and the welfare of consumers, producers and middlemen in the relevant supply channels. The case of no fraud (truthful labelling and no adulteration/mislabelling) is also analysed and serves as a benchmark for determining the market and welfare effects of food adulteration and mislabelling.

To analyse the system-wide economic impacts of food fraud, we develop an empirically relevant theoretical framework of food markets with heterogeneous consumers and producers (i.e. consumers differing in their preferences and perfectly competitive agricultural producers differing in their efficiency/costs of production) and imperfectly competitive middlemen. The explicit consideration of consumer and producer heterogeneity allows us to model the asymmetries in the probability of fraud detection for low- and high-quality producers and enables the determination and disaggregation of the welfare effects of food fraud on the interest groups involved.

In addition to enabling the disaggregation of the welfare effects of food fraud, the explicit consideration of agent heterogeneity, asymmetries in the probability of fraud detection and the endogeneity of the producer quality choices enables the derivation of a key result of this study, contrary to what is traditionally believed, both low-quality and high-quality producers can have economic incentives to commit fraud. The group that is more likely to cheat is shown to be determined by the social attitudes towards fraudulent behaviour, the enforcement policy parameters, and the relative magnitude of the demand and supply effects of food fraud.

The rest of the paper is organised as follows. The second section presents a simple model of heterogeneous consumers and producers and derives the equilibrium quantities, prices and welfare of the relevant groups involved when there is no fraud in the market. The third section derives the equilibrium conditions under food adulteration and determines the market and welfare effects of this type of food fraud. The fourth section focuses on mislabelling and compares its market and welfare effects to those of food adulteration. Alternative scenarios on the group that is engaged in fraudulent activity and incurs liability costs are considered before the final section summarises and concludes the paper.

2. Benchmark case: no food fraud

In the benchmark model, it is assumed that there is no food fraud in the market; that is, producers do not deliberately mislabel or adulterate food products for economic gain.

2.1 Consumer problem

Consider a standard market for vertically differentiated products where two types of a food product, high quality (h) and low quality (l), are segregated and marketed separately (Giannakas 2011). Consumers are able to distinguish between the two products and agree on what constitutes high quality (i.e. they agree that extra virgin olive oil, for instance, is higher quality than virgin olive oil). While consumers agree on the relative quality (and, thus, utility) ranking of the two products, they differ in their valuation of the perceived quality differences between the low- and high-quality products. Let the parameter $\alpha \epsilon [0,1]$ be the consumer differentiating attribute (i.e. preferences), and, for simplicity and without loss of generality, consumers be uniformly distributed between the polar values of α.[2] Assuming that consumers have the choice between a unit of the high-quality product, the low-quality product and a substitute product, and that their consumption decision represents a small share of their income, their utility function can be written as:

[2] The implications of relaxing this assumption to allow for a concentration of consumers at the ends of the spectrum (i.e. 0 and 1) are straight forward and discussed at the end of this section.

$$
\begin{aligned}
U_h &= U - P_h^c + \lambda_h \alpha \text{ if a unit of the high-quality product is consumed} \\
U_l &= U - P_l^c + \lambda_l \alpha \text{ if a unit of the low-quality product is consumed} \\
U_a &= U \text{ if a unit of the substitute product is consumed}
\end{aligned} \tag{1}
$$

where U_i is the utility associated with a unit consumption of product i ($i = h,l, \alpha$); P_h^c and P_l^c are the prices of the high and low-quality products, respectively; U is the per unit base level of utility which is common across consumers and greater than P_h^c and P_l^c; and λ_h and λ_l are non-negative utility enhancement factors associated with the consumption of the high and low-quality products, respectively. In this context, $U + \lambda_h \alpha$ and $U + \lambda_l \alpha$ represent the maximum consumer willingness to pay (WTP) for a unit of the high-quality and low-quality products, respectively. Subtracting the corresponding prices from these WTP values provides estimates of the consumer surplus associated with the consumption of these products. To allow positive market shares of all quality-differentiated food products, it is assumed that the price of the high-quality product is greater than that of the low-quality product (i.e. $P_h^c > P_l^c$) and the valuation of the quality difference between the two products exceeds the price premium of the high-quality product for all consumers (i.e. $\lambda_h - \lambda_l > P_h^c - P_l^c$). For simplicity and tractability of the model, it is assumed that U_α, the utility associated with the consumption of the substitute product, is equal to the base level of utility U.

The consumer purchasing decision is determined by comparing the utilities associated with the consumption of the different products. In this context, the equality of U_h and U_l determines the differentiating attribute of the consumer who is indifferent between consuming a unit of the high-quality product and a unit of the low-quality product, α_l, that is:

$$
\alpha_l : U_h = U_l \Rightarrow \alpha_l = \frac{P_h^c - P_l^c}{\lambda_h - \lambda_l} \tag{2}
$$

Similarly, the equality of U_l and U_a determines the differentiating attribute of the consumer who is indifferent between the low-quality product and the substitute product, α_α, that is:

$$
\alpha_a : U_l = U_a \Rightarrow \alpha_a = \frac{P_l^c}{\lambda_l} \tag{3}
$$

Consumers with differentiating attribute $\alpha \epsilon [0, \alpha_\alpha)$ prefer the substitute product, consumers with differentiating attribute $\alpha \epsilon (\alpha_a, \alpha_l)$ prefer the low-quality product, while consumers with strong preference for quality (i.e. consumers with $(\alpha_l, 1]$) prefer the high-quality product. With normalisation of the mass of consumers to unity, the consumer demands for the low-quality product and the high-quality product (denoted by x_l and x_h, respectively) are:

$$x_l = \alpha_l - \alpha_a = \frac{\lambda_l P^c_h - \lambda_h P^c_l}{\lambda_l(\lambda_h - \lambda_l)} \tag{4}$$

$$x_h = 1 - \alpha_l = \frac{(\lambda_h - \lambda_l) - (P^c_h - P^c_l)}{(\lambda_h - \lambda_l)} \tag{5}$$

Equations (4) and (5) show that the demand for low (high)-quality food decreases with an increase in its own price and/or an increase (fall) in the consumer valuation of the quality difference between the high- and low-quality products. If the price premium of the high-quality product is greater than the valuation of the quality difference between two food products for all consumers (i.e. $P^c_h - P^c_l > \lambda_h - \lambda_l$), the high-quality product will be driven out of the market.

Figure 1 shows the consumer decisions in the consumer utility space when $(\lambda_h - \lambda_l) > \left(P^c_h - P^c_l\right)$ and the three products coexist in the market. The upward sloping U_l and U_h curves show the utility associated with the unit consumption of the low-quality product and the high-quality product, respectively, for different levels of the differentiating attribute α. The horizontal curve U_a graphs the utility derived from the consumption of the substitute product. Figure 1 also shows that an increase in the price of the high-quality product will shift the U_h curve downward and decrease x_h (i.e. $\frac{\partial x_h}{\partial P^c_h} < 0$), while an increase in the price of the low-quality product will increase x_h (i.e. $\frac{\partial x_h}{\partial P^c_l} > 0$). Also, an increase in the utility enhancement factor associated with the consumption of the high-quality product will rotate the U_h curve to the left, resulting in increased market share of the high-quality product. The shaded area CG_{nf} depicts the consumer welfare gain from the presence of the high-quality product in the market.

Since equation (1) measures the consumer surplus associated with the consumption of the high-quality, low-quality and substitute products, the area under the dashed kinked line shows the welfare of the different consumer

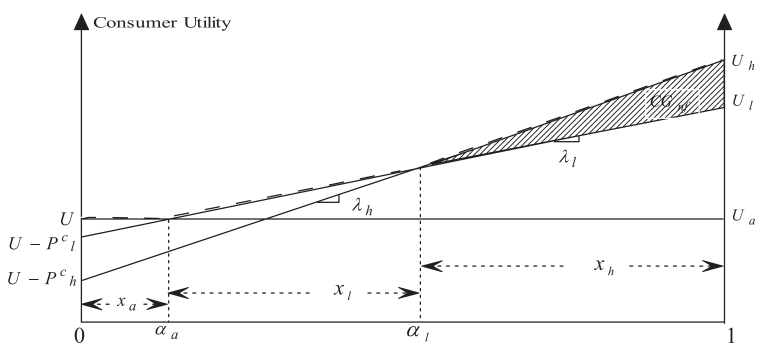

Figure 1 Consumption decisions and welfare effects under no fraud.

groups. Mathematically, the surpluses of consumers of low-quality and high-quality products are as follows:

$$CS_l = \int_{\alpha_a}^{\alpha_l} U_l d\alpha = \frac{\left(\lambda_l P_h^c - \lambda_h P_l^c\right)\left[2U(\lambda_h - \lambda_l) + \lambda_l P_h^c - \lambda_h P_l^c\right]}{2\lambda_l(\lambda_h - \lambda_l)^2} \tag{6}$$

$$CS_h = \int_{\alpha_l}^{1} U_h d\alpha = \frac{\left[(\lambda_h - \lambda_l) - \left(P_h^c - P_l^c\right)\right]\left[2U(\lambda_h - \lambda_l) - P_h^c(\lambda_h - 2\lambda_l) - \lambda_h\left\{P_l^c - (\lambda_h - \lambda_l)\right\}\right]}{2(\lambda_h - \lambda_l)^2} \tag{7}$$

Before concluding this section, it is important to note that if the distribution of consumers is not uniform but is, instead, skewed to the left (i.e. the probability mass is shifted towards one), the greater is the number of consumers with relatively strong preference for the high-quality product, the greater is the market share of this product, and the greater the welfare of the high-quality product consumers.

2.2 Producer problem

A producer's production decision depends on the net returns associated with the production of the high-quality, low-quality and alternative products. Let $A\epsilon[0,1]$ denote the producer differentiating attribute (i.e. efficiency), and producers be uniformly distributed between the polar values of A.[3] The greater the value of A, the greater the costs of production and the lower the producer efficiency. A producer with attribute A has the following net returns function:

$$\begin{aligned} &pi_h = P_h^f - w_h - \delta A \quad \text{if a unit of the highquality product is produced.} \\ &\pi_l = P_l^f - w_l - \gamma A \quad \text{if a unit of the lowquality product is produced.} \\ &\pi_a = 0 \quad \text{if a unit of an alternative product is produced} \end{aligned} \tag{8}$$

where π_i are the net returns associated with unit production of product i (i = h,l,a); P_i^f is the producer price of product i; w_i is the production cost of product i which is outside the control of producers; and δ and γ are the cost enhancement factors associated with the production of the high-quality and the low-quality products, respectively. To capture the higher production cost associated with the production of the high-quality product (as compared to

[3] The implications of relaxing this assumption to allow for a concentration of producers at the ends of the spectrum (i.e. 0 and 1) are straight forward and discussed throughout this section.

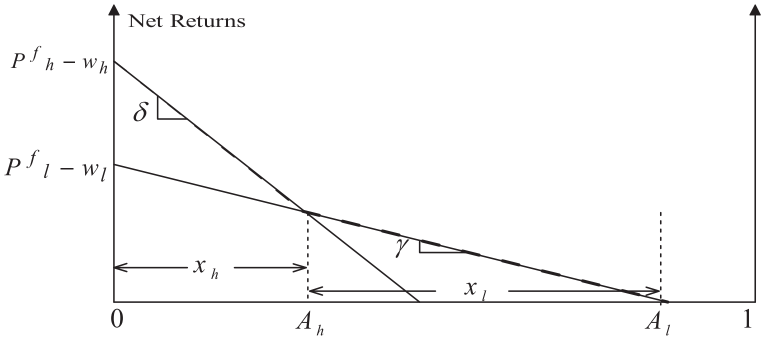

Figure 2 Producer decisions and welfare effects under no fraud.

that of the low-quality product), it is assumed that $w_h > w_l$ and $\delta > \gamma$. The terms δA and γA capture the heterogeneity of producers in terms of their costs of (and efficiency in) producing the high-quality product and the low-quality product, respectively.[4] The high-quality product receives a price premium but its production cost is higher than that of the low-quality product (i.e. $P^f_h > P^f_l$ and $w_h > w_l$). To allow positive supply of all products in the market, it is assumed that $\left(P^f_h - w_h\right) > \left(P^f_l - w_l\right)$.

In this context, the production choice of a producer is determined by the relationship between π_h, π_l, and π_a. The equality of π_h and π_l determines the differentiating attribute of the producer who is indifferent between producing the high-quality and the low-quality products, A_h, that is:

$$A_h : \pi_h = \pi_l \Rightarrow A_h = \frac{(P^f_h - P^f_l) + (w_l - w_h)}{(\delta - \gamma)} \tag{9}$$

Similarly, the equality of π_l and π_a determines the differentiating attribute of the producer who is indifferent between low-quality product and the alternative product, A_l, that is:

$$A_l : \pi_l = \pi_a \Rightarrow A_l = \frac{P^f_l - w_l}{\gamma} \tag{10}$$

More efficient producers (i.e. producers with differentiating attribute $A \in [0, A_h]$) find it optimal to produce the high-quality product while less efficient producers (i.e. producers with differentiating attribute $A \in (A_h, A_l]$) produce the low-quality product. By normalising the mass of producers to unity, the supplies of the high-quality and the low-quality products are given as:

[4] Producers differ in the cost associated with the production of a food product due to differences in age, level of education, experience, geographic location, management, technical skills, quality of land, etc.

$$x_h = A_h = \frac{(P_h^f - P_l^f) + (w_l - w_h)}{(\delta - \gamma)} \tag{11}$$

$$x_l = A_l - A_h = \frac{\delta(P_l^f - w_l) - \gamma(P_h^f - w_h)}{\gamma(\delta - \gamma)} \tag{12}$$

Figure 2 shows the producer decisions when the prices and cost parameters are such that the three products enjoy positive production shares with the area under the kinked dashed line in Figure 2 capturing the welfare of the different groups of producers. Mathematically, the surpluses of the producers of the high and low-quality products are as follows:

$$PS_h = \int_0^{A_h} \pi_h dA = \frac{\left[(P_h^f - w_h)(\delta - 2\gamma) + \delta(P_l^f - w_l)\right]\left[(P_h^f - w_h) - (P_l^f - w_l)\right]}{2(\delta - \gamma)^2} \tag{13}$$

$$PS_l = \int_{A_h}^{A_l} \pi_l dA = \frac{\left[\delta(P_l^f - w_l) - \gamma(P_h^f - w_h)\right]^2}{2\gamma(\delta - \gamma)^2} \tag{14}$$

If the distribution of producers is not uniform but is, instead, skewed to the right (i.e. the probability mass has shifted towards zero), the greater is the number of more efficient producers, the greater is the production share of the high-quality food product, and the greater the welfare of producers of this product.

2.3 Equilibrium conditions

Having determined the demand and supply functions of the high-quality and low-quality products, this section determines the market outcome of the benchmark model. To capture the increased concentration and imperfect competition among food manufacturers and retailers (Sexton 2000, 2013; McCorriston 2002), our study allows middlemen to exercise market power both when procuring the farm product from producers and when selling the final product to consumers. Facing the demand and supply schedules derived in the previous sections, the profit maximising middlemen produce the quantity determined by the equality of the relevant marginal revenue and marginal outlay schedules. Once the optimal quantity is determined, the profit maximising middlemen charge the maximum price consumers are willing to pay for this quantity and offer the minimum price that will induce producers to supply the necessary quantity of the food product.

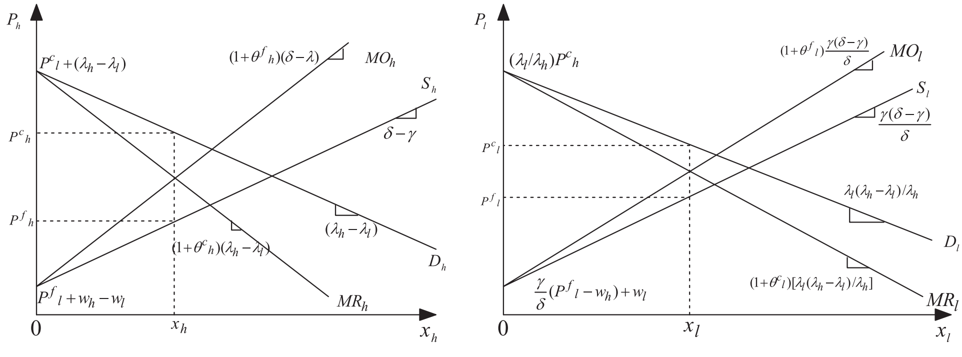

Figure 3 Equilibrium conditions of the high-quality (h) and the low-quality (l) products under no fraud.

Figure 3 depicts the equilibrium quantities, prices and profits in the markets for the high- and low-quality products when there is no fraud in the agri-food marketing system. It should be noted that the parameters θ_i^c and θ_i^f $(i = h, l)$ are conjectural variation elasticities that capture the degree of market power of middlemen when selling the processed food product to consumers and when buying the food product from producers, respectively (Perloff, Karp and Golan, 2007). The derivation and mathematical expressions of the equilibrium conditions are provided in Appendix S1.[5]

3. Food fraud: food adulteration

This section considers the case where food fraud is in the form of food adulteration that results in the probability of a health hazard if consumers consume the adulterated food product. For simplicity, it is assumed that dishonest producers use various adulteration methods to reduce the cost and/or increase the shelf life of their product, and then market it as the high-quality product.[6]

3.1 Consumer problem

In the presence of food adulteration, consumers have the choice between the product marketed as high-quality, the low-quality product and the substitute good. It should be noted that, in this study, the high-quality product refers to

[5] The parameter θ takes values from zero to one. When $\theta = 1$ the market structure is monopoly/monopsony, while when $\theta = 0$ the market structure is either perfectly competitive or oligopolistic with firms involved in a Bertrand price competition (Perloff, Karp and Golan 2007). The greater is the value of θ, the greater the market power of middlemen (for the use of the conjectural variation elasticity in equilibrium displacement models, see Holloway (1991) and Sexton (2000)).

[6] While dishonest producers can market the adulterated product as the low-quality product to increase profits when the production cost of the adulterated product is lower than the production cost of the low-quality product, the qualitative nature of our results does not change by assuming that both the high and low-quality products are adulterated.

a truthfully labelled high-quality product while the product marketed as high quality includes both high-quality and adulterated products. Therefore, when food adulteration occurs in a market, consumers assign a probability that the product marketed as high quality is adulterated and a probability of a health hazard from consuming adulterated product. This uncertainty reduces the consumer valuation of (and willingness to pay for) the product marketed as high quality, with the utility associated with its consumption in the presence of food adulteration given by:

$$\begin{aligned} U_{h,d} &= \mu\Big(U - P^c_{h,d} + \lambda_h\alpha\Big) + (1-\mu)\Big(U - P^c_{h,d} - \epsilon\psi\Big) \\ &= U - P^c_{h,d} + \mu\lambda_h\alpha - (1-\mu)\epsilon\psi \end{aligned} \tag{15}$$

where $U - P^c_{h,d} + \lambda_h\alpha$ is the utility associated with the consumption of the high-quality product and $U - P^c_{h,d} - \varepsilon\psi$ is the utility associated with the consumption of adulterated product. The parameter μ is the probability that the food product is high quality, which makes $(1-\mu)$ the probability that the food product is adulterated (i.e. probability of food adulteration). The parameter ϵ is the probability of getting sick when consuming the adulterated product and the parameter ψ is the total cost of receiving medical treatment, making $(1-\mu)\varepsilon\psi$ the expected cost of getting sick when consuming the adulterated product.

In this context, the consumer utility function in the presence of food adulteration can be written as:

$$\begin{aligned} U_{h,d} &= U - P^c_{h,d} + \mu\lambda_h\alpha \\ &\quad - (1-\mu)\varepsilon\psi \text{ if a unit of the product marketed as high-quality is consumed} \\ U_{l,d} &= U - P^c_{l,d} + \lambda_l\alpha \text{ if a unit of the low-quality product is consumed} \\ U_{a,d} &= U \text{ if a unit of the substitute product is consumed} \end{aligned} \tag{16}$$

where $U_{i,d}$ is the utility associated with the unit consumption of food product i $(i = h, l, a)$ in the presence of food adulteration. All other variables are as previously defined. The equality of $U_{h,d}$ and $U_{l,d}$ determines the differentiating attribute of the consumer who is indifferent between consuming a unit of the product marketed as high-quality and the low-quality product, $\alpha_{l,d}$, that is:

$$\alpha_{l,d} = \frac{P^c_{h,d} - P^c_{l,d} + (1-\mu)\varepsilon\psi}{(\mu\lambda_h - \lambda_l)} \tag{17}$$

Similarly, the equality of $U_{l,d}$ and $U_{a,d}$ determines the differentiating attribute of the consumer who is indifferent between consuming a unit of the low-quality product and a unit of the substitute product in the presence of food adulteration, α_a, that is:

$$\alpha_{a,d} = \frac{P^c_{l,d}}{\lambda_l} \tag{18}$$

Following the process developed earlier, we can derive the consumer demands for the low-quality product and the product marketed as high quality as:

$$x_{l,d} = \alpha_{l,d} - \alpha_{a,d} = \frac{\lambda_l P^c_{h,d} - \mu\lambda_h P^c_{l,d} + \lambda_l(1-\mu)\varepsilon\psi}{\lambda_l(\mu\lambda_h - \lambda_l)} \tag{19}$$

$$x_{h,d} = 1 - \alpha_{l,d} = \frac{(\mu\lambda_h - \lambda_l) - \left(P^c_{h,d} - P^c_{l,d}\right) - (1-\mu)\varepsilon\psi}{(\mu\lambda_h - \lambda_l)} \tag{20}$$

3.2 Producer problem

Consider now the producer decisions and welfare in the presence of food adulteration. The producer net returns function in the presence of food adulteration is:

$$\begin{aligned}
&\pi_{h,d} = P^f_{h,d} - w_h - \delta A \ \text{ if a unit of the high-quality product is produced.}\\
&\pi^{ch}_{h,d} = P^f_{h,d} - \beta(w_h + \delta A) - \phi(A)\rho \ \text{ if a unit of the adulterated product is produced.}\\
&\pi_{l,d} = P^f_{l,d} - w_l - \gamma A \ \text{ if a unit of the low-quality product is produced.}\\
&\pi_{a,d} = 0 \ \text{ if a unit of an alternative product is produced}
\end{aligned} \tag{21}$$

where $\pi^{ch}_{h,d}$ are the expected net returns associated with the unit production of adulterated product and the term $\beta(w_h + \delta A)$ represents the cost of producing the adulterated product (where $0 < \beta < 1$). The cost savings/producer benefits from food adulteration are, then, given by $(1-\beta)(w_h + \delta A)$. The parameter ϕ is the probability of food adulteration being detected, and ρ is the penalty for detected food adulteration, which includes fines, legal costs, relevant liabilities and other costs associated with being caught cheating. All other variables are as previously defined.

The probability of detection takes values between zero to one, and it is assumed to be a linear function of the efficiency of producers, that is: $\phi(A) = \phi_0 + \phi_1 A$. This formulation of detection probability captures the idea that the more efficient are producers (due to better education, experience, management skills, technology adopted, etc.), the better able they are to cover their fraudulent behaviour, and the lower is the probability that their fraudulent activity will be detected. While the probability of fraud detection falls with the level of producer efficiency, all producers face a strictly positive detection probability (i.e. the detection probability of the most efficient producer with differentiating attribute $A = 0$ is $\phi_0 > 0$). In addition to being strictly positive, the intercept of the detection probability function, ϕ_0, is exogenous to producers as it represents the probability that producers will be detected if they adulterate irrespective of their level of efficiency and efforts. The parameter ϕ_0 depends on the traceability system in place, the observability of producers' illegal actions by third parties (e.g. media, former employees, other firms/business partners,[7] etc.) and social attitudes towards food fraud (i.e. the likelihood that a third party that observes the illegal actions of producers will report them to the enforcing authorities). The slope of the detection probability function, ϕ_1, reflects the audit probability given by the number of producers that are audited over the total number of producers. To capture the superiority of this audit strategy (see Townsend (1979), Mookherjee and Png (1989), and Dionne *et al.* (2009)) and FDA policies (IMNRC 2010), audits are assumed to be random – that is, the enforcement agency decides on the total number of producers that will be audited, and the identities of those audited are determined randomly.

According to Kurtzweil (1999), it is not always easy to detect illegal actions of producers during auditing because adulterators tend to develop unique ways of covering their illegal actions. For instance, one popular orange juice company was mixing liquid beet sugar in their orange juice. FDA investigators did not observe this illegal action during their auditing because this company hid its supply of liquid beet sugar in a secret room and used pipelines hidden in the ceiling to transport the liquid beet sugar to the production area. The FDA investigators caught this illegal action only after receiving explicit directions to that secret room from a former employee of this orange juice company.[8] This third-party monitoring is captured by the parameter ϕ_0 in this model. FDA also states that it can also be difficult to detect illegal actions of producers even when proper scientific tests exist because some producers can be very effective in developing unique ways to concoct mixtures that closely resemble the real thing. For example, they add chemicals to their product that, when tested, resemble closely the chemical profile of the natural product. The key characteristics involved in these examples are consistent with the formulation of the detection probability function.

Regarding the producer decisions, a producer with differentiating attribute A will engage in fraudulent behaviour when the gains from food adulteration (i.e. $(1-\beta)(w_h + \delta A)$) exceed the expected penalty (i.e. $(\phi_0 + \phi_1 A)\rho$). In assessing the market and welfare effects of food fraud, we consider all possible cases regarding the relationship between the net expected benefit of

[7] As pointed out by an anonymous reviewer, when middlemen are responsible for liability costs associated with food adulteration, they can be expected to increase their monitoring efforts, increasing, this way, the detection probability faced by producers.

[8] The Washington Post investigation mentioned earlier is another example of third-party monitoring.

fraudulent behaviour and the efficiency of producers. In particular, we analyse (a) the case where the net expected benefit of fraudulent behaviour increases with the efficiency of producers (i.e. $(1-\beta)w_h > \phi_0\rho$ and $(1-\beta)\delta < \phi_1\rho$; termed scenario 1); (b) the case where the net expected benefit of fraudulent behaviour decreases with the efficiency of producers (i.e. $(1-\beta)w_h < \phi_0\rho$ and $(1-\beta)\delta > \phi_1\rho$; scenario 2); (c) the case where the net expected benefit of fraudulent behaviour is positive for all producers (i.e. $(1-\beta)w_h \geq \phi_0\rho$ and $(1-\beta)\delta \geq \phi_1\rho$; scenario 3A); and (d) the case where the net expected benefit of fraudulent behaviour is negative for all producers (i.e. $(1-\beta)w_h \leq \phi_0\rho$ and $(1-\beta)\delta \leq \phi_1\rho$; scenario 3B).

3.2.1 Scenario 1: The net expected benefit of fraudulent behaviour increases with the efficiency of producers

The equality of $\pi_{h,d}$ and $\pi_{l,d}$ determines the producer with differentiating attribute $A_{h,d}$ who is indifferent between producing a unit of the high-quality product and a unit of the low-quality product, where:

$$A_{h,d} = \frac{(P^f_{h,d} - P^f_{l,d}) + (w_l - w_h)}{(\delta - \gamma)} \tag{22}$$

As noted earlier, however, not all foods marketed as high quality are actually high quality in the presence of food adulteration. The equality of $\pi_{h,d}$ and $\pi^{ch}_{h,d}$ determines the producer with $A^{ch}_{h,d}$ who is indifferent between producing a unit of the high quality and a unit of the adulterated product, where:

$$A^{ch}_{h,d} = \frac{w_h - \beta w_h - \phi_0\rho}{\{(\beta\delta + \phi_1\rho) - \delta\}} \tag{23}$$

Similarly, the equality $\pi_{l,d}$ and $\pi_{a,d}$ determines the differentiating attribute of the producer who is indifferent between producing a unit of the low-quality product and a unit of alternative product, $A_{l,d}$. The supplies of the high-quality, adulterated and low-quality products are then given by:

$$x^{tl}_{h,d} = A_{h,d} - A^{ch}_{h,d} = \frac{\{(\beta\delta + \phi_1\rho) - \delta\}\left(P^f_{h,d} - P^f_{l,d} + w_l\right) - \{(\beta\gamma + \phi_1\rho) - \gamma\}w_h + (\delta - \gamma)\phi_0\rho}{(\delta - \gamma)\{(\beta\delta + \phi_1\rho) - \delta\}} \tag{24}$$

$$x^{ch}_{h,d} = A^{ch}_{h,d} = \frac{w_h - \beta w_h - \phi_0\rho}{\{(\beta\delta + \phi_1\rho) - \delta\}} \tag{25}$$

$$x_{l,d} = A_{l,d} - A_{h,d} = \frac{\delta\left(P^f_{l,d} - w_l\right) - \gamma\left(P^f_{h,d} - w_h\right)}{\gamma(\delta - \gamma)} \tag{26}$$

Figure 4a,b shows the supply curves of the product marketed as high-quality and the low-quality product, respectively, under scenario 1 in the familiar price-quantity space. The total production of the product marketed as high quality, $x_{h,d}$, is determined by the intersection of the net returns curves associated with the production of the high-quality and low-quality products. However, not all producers with differentiating attribute $A \in [0, A_{h,d}]$ produce the high-quality product. The dashed line in the lower panel of Figure 4a represents the supply curve of the high-quality product while the dotted line represents the supply curve of the adulterated product. (The dashed line is the supply of high-quality product when both the high- and low-quality products coexist in the market, while the dotted line is the supply of adulterated product when all producers adulterate their product). The intersection of the net returns curves associated with the production of the adulterated and high-quality products determines the total quantity of adulterated product $x^{ch}_{h,d}$, making the actual quantity of the high-quality product in the market equal to $x_{h,d} - x^{ch}_{h,d}$. Producers with $A \in \left[0, A^{ch}_{h,d}\right]$ choose to produce the adulterated product and market it as the high-quality product, while producers with $A \in \left(A^{ch}_{h,d}, A_{h,d}\right]$ produce the high-quality product, making the solid kinked line in the lower panel of Figure 4a the supply curve of the product marketed as high quality

3.2.2 Scenario 2: The net expected benefit of fraudulent behaviour decreases with the efficiency of producers

The equality of the net returns functions $\pi_{l,d}$ and $\pi^{ch}_{h,d}$ determines the differentiating attribute of the producer who is indifferent between producing a unit of the high-quality product and a unit of the low-quality product, $A_{h,d}$, that is:

$$A_{h,d} = \frac{\left\{P^f_{h,d} - (\beta w_h + \phi_0 \rho)\right\} - \left(P^f_{l,d} - w_l\right)}{\{(\beta\delta + \phi_1 \rho) - \delta\}} \tag{27}$$

As noted earlier, in the presence of food adulteration, the product marketed as high quality includes both high-quality and adulterated products. The equality of the net returns functions $\pi_{h,d}$ and $\pi^{ch}_{h,d}$ determines the differentiating attribute of the producer who is indifferent between producing a unit of the high-quality product and a unit of the adulterated product, $A^t_{h,d}$, where:

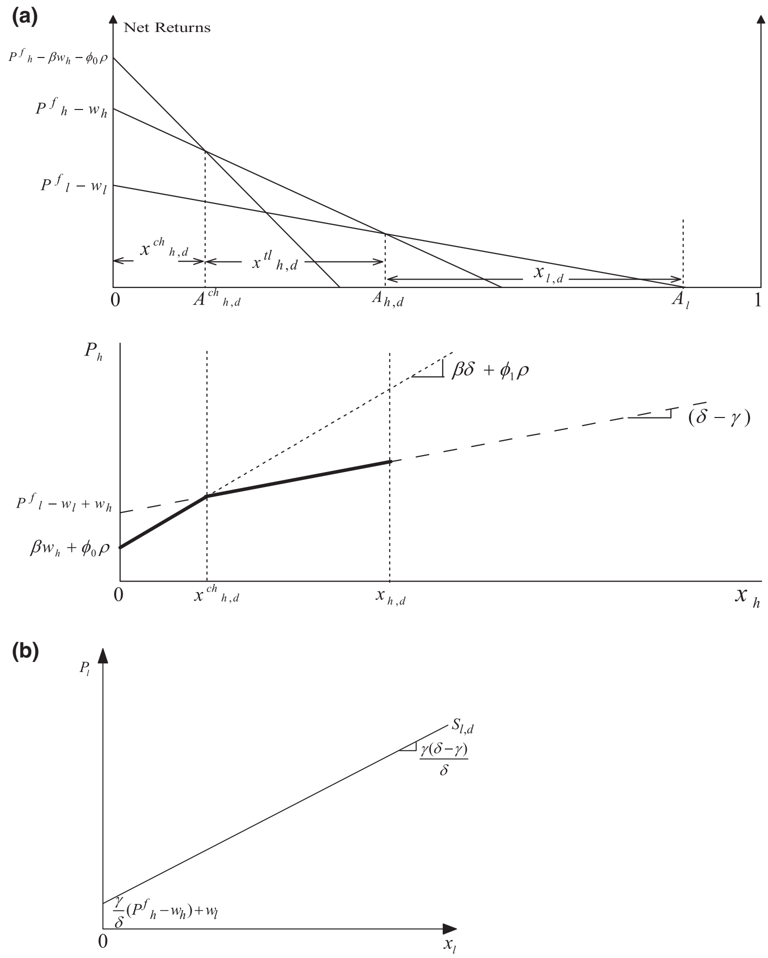

Figure 4 (a) Supply of the product marketed as high-quality under food adulteration scenario 1 (kinked bold line of lower panel). (b) Supply of the low-quality product under food adulteration scenario 1.

$$A^{t}_{h,d} = \frac{\{(\beta w_h + \phi_0 \rho) - w_h\}}{\{\delta - (\beta\delta + \phi_1 \rho)\}} \tag{28}$$

Finally, the producer with differentiating attribute $A_{l,d}$ is indifferent between producing a unit of the low-quality product and a unit of alternative product. The supplies of high-quality, adulterated and low-quality products are given as:

$$x^{tl}_{h,d} = A^{tl}_{h,d} = \frac{\{(\beta w_h + \phi_0 \rho) - w_h\}}{\{\delta - (\beta\delta + \phi_1 \rho)\}} \tag{29}$$

$$x^{ch}_{h,d}=A_{h,d}-A^{t}_{h,d}$$
$$=\frac{\{\delta-(\beta\delta+\phi_1\rho)\}\left[P^{f}_{h,d}-(\beta w_h+\phi_0\rho)-P^{f}_{l,d}+w_l\right]-\{(\beta\delta+\phi_1\rho)-\gamma\}[(\beta w_h+\phi_0\rho)-w_h]}{\{(\beta\delta+\phi_1\rho)-\gamma\}\{\delta-(\beta\delta+\phi_1\rho)\}} \tag{30}$$

$$x_{l,d}=A_{l,d}-A_{h,d}=\frac{(\beta\delta+\phi_1\rho)\left(P^{f}_{l,d}-w_l\right)-\gamma\left\{P^{f}_{h,d}-(\beta w_h+\phi_0\rho)\right\}}{\gamma\{(\beta\delta+\phi_1\rho)-\gamma\}} \tag{31}$$

Like scenario 1, not all product marketed as high quality is actually high quality. Therefore, the supply curve of the product marketed as high quality under food adulteration scenario 2 is also kinked. However, unlike scenario 1 where (some) high-quality producers find it optimal to engage in fraudulent behaviour, under scenario 2 both high- and low-quality producers find it optimal to engage in fraudulent behaviour (see Appendix S3).

3.2.3 Scenarios 3A and 3B: The net expected benefit of fraudulent behaviour is positive (negative) for all producers under scenario 3A(3B)

Scenario 3A arises when the enforcement policy is unable to deter food adulteration. Since the net expected benefit of fraudulent behaviour is greater than the expected penalty for all producers, the product marketed as high quality includes only adulterated product under this scenario. Consumers are not willing to pay a premium for the product marketed as high quality and, at equilibrium, only the low-quality product is supplied to the market. The ineffectiveness of the enforcement policy drives the high-quality product out of the market. Scenario 3B, on the other hand, arises when the enforcement policy is perfect. Under this scenario, no producer has incentive to adulterate food since the net expected benefit of fraudulent behaviour is negative regardless of the efficiency of producers. Thus, there will be no food fraud in the market.

Due to the lack of coexistence of truthfully labelled high-quality and adulterated products under scenarios 3A and 3B, the rest of this study focuses on the more interesting cases of the interior solutions; that is, scenarios 1 and 2 where a part of food supply is adulterated.

3.3 System-wide market and welfare effects of food adulteration

This section presents the system-wide effects of food adulteration in the agri-food marketing system. The heterogeneous agent framework outlined above is used to determine the changes in market conditions and aggregate consumer and producer welfare due to food adulteration.

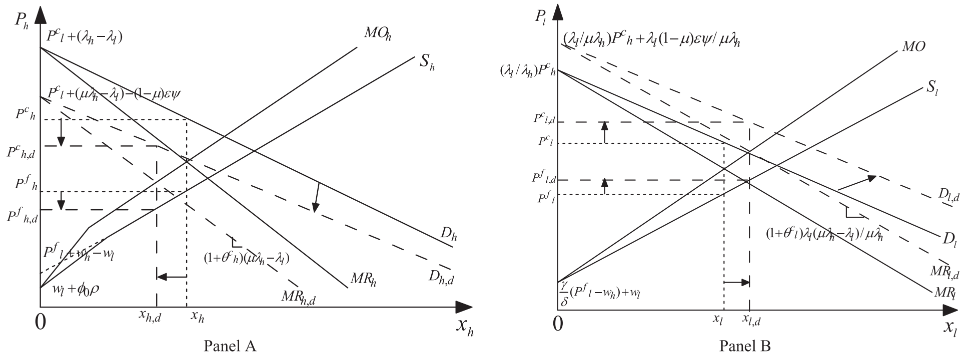

Figure 5 Equilibrium conditions under food adulteration (scenario 1).

3.3.1 Market effects of food adulteration

Result 1: When the net expected benefit of fraudulent behaviour increases with the efficiency of producers (i.e. scenario 1), food adulteration causes (a) a reduction in the consumer price, the price received by producers, and the quantity of the product marketed as high quality, and (b) an increase in the consumer and producer prices, and the quantity of the low-quality product.

Consider the equilibrium conditions under scenario 1. Since food adulteration creates uncertainty about the nature of the product marketed as high-quality, consumer demand for the high-quality product decreases. In particular, the demand curve for the high-quality product shifts from D_h to $D_{h,d}$ in the presence of food adulteration (see Figure 5, panel A). Regarding the supply curve of the product marketed as high quality, S_h, it is kinked since the supply of the product marketed as high quality includes both the supply of high-quality and adulterated products. The equilibrium quantity, consumer price, and price received by producers of the high-quality product are x_h, P_h^c, and P_h^f, respectively, in the absence of food fraud. The presence of food adulteration results in reduced equilibrium quantity (from x_h to $x_{h,d}$), consumer price (from P_h^c to $P_{h,d}^c$), and price received by producers (from P_h^f to $P_{h,d}^f$) of the product marketed as high quality (see Figure 5 panel A).

The uncertainty about the nature of the product marketed as high quality in the presence of food adulteration increases the consumer demand for the low-quality product; therefore, the demand curve for the low-quality product shifts from D_l to $D_{l,d}$ (see Figure 5, panel B). The presence of food adulteration results in increased equilibrium quantity (from x_l to $x_{l,d}$), consumer price (from P_l^c to $P_{l,d}^c$), and price received by producers (from P_l^f to $P_{l,d}^f$) of the low-quality product.

Result 2: When the net expected benefit of fraudulent behaviour decreases with the efficiency of producers (i.e. scenario 2), food adulteration causes (a) a reduction (increase) in the consumer price and price received by producers of the product marketed as high quality (low-quality), and (b) a reduction (increase) in the quantity of the product marketed as high quality and an increase (reduction) in the quantity of the low-quality product when the demand (supply) effect dominates the supply (demand) effect of food adulteration.

Under scenario 2, the demand curve for the high-quality product also shifts to the left (to $D_{h,d,2A}$ and $D_{h,d,2B}$ in panel A of Figures 6a,b, respectively) which reflects lower demand for the high-quality product. Unlike scenario 1, when the net expected benefit of fraudulent behaviour decreases with the efficiency of producers, not only (some) high-quality producers but also (some) low-quality producers find it optimal to produce the adulterated product and market it as the high-quality product, which results in increased supply of the product marketed as high quality. Therefore, the (kinked) supply curve of the product marketed as high-quality shifts to the right (to $S_{h,d,2A}$ and $S_{h,d,2B}$ in panel A of Figures 6a,b, respectively).

Since a decrease in the demand causes the equilibrium quantity to fall while a supply increase causes it to increase, the impact of food fraud on the equilibrium quantity of the product marketed as high quality will be determined by the relative magnitude of the demand and supply effects of food fraud. If the demand effect dominates the supply effect of food adulteration (i.e. when the fall in consumer demand for the high-quality product in the presence of food

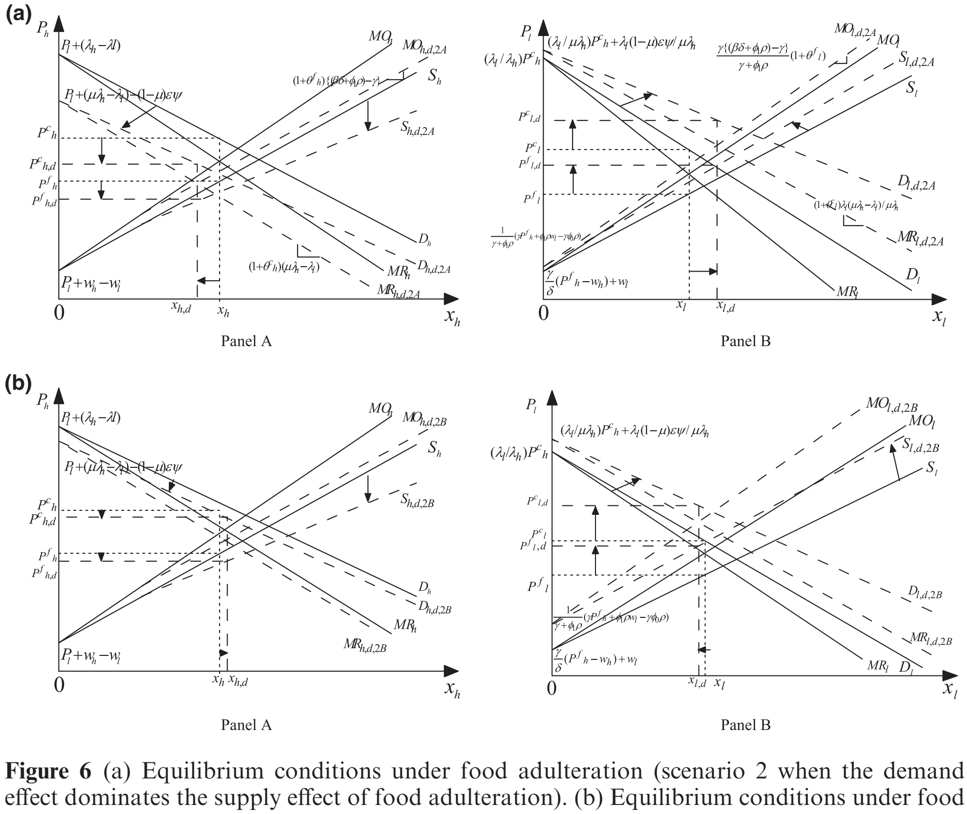

Figure 6 (a) Equilibrium conditions under food adulteration (scenario 2 when the demand effect dominates the supply effect of food adulteration). (b) Equilibrium conditions under food adulteration (scenario 2 when the supply effect dominates the demand effect of food adulteration).

adulteration exceeds the increase in the supply of the product marketed as high quality), the equilibrium quantity of the high-quality product decreases in the presence food adulteration (see Figure 6a panel A). In contrast, the equilibrium quantity of the product marketed as high-quality increases if the supply effect dominates the demand effect of food adulteration (see Figure 6b panel A). Regarding the equilibrium consumer price and price received by producers of the product marketed as high quality, they both decrease in the presence of food adulteration irrespective of the relative magnitude of the demand and supply effects (panel A of Figures 6a,b).

Regarding the market for the low-quality product, food adulteration increases the demand for this product (compare $D_{l,d,2A}$ and $D_{l,d,2B}$ in panel B of Figures 6a,b, respectively). On the other hand, the supply curve of the low-quality product shifts to the left (to $S_{l,d,2A}$ and $S_{l,d,2B}$ in panel B of Figures 6a, b, respectively) since some low-quality producers find it optimal to produce the adulterated product and market it as high quality under scenario 2. As a result, the equilibrium quantity of the low-quality product increases under food adulteration if the demand effect dominates the supply effect and vice versa (see Figures 6a,b panel B). The equilibrium consumer and producer prices of the low-quality product increase irrespective of the relative magnitude of the demand and supply effects of food adulteration.

3.3.2 Impact of food adulteration on middlemen

Result 3: In the presence of food adulteration, the profits of the high-quality product suppliers fall while the profits of the low-quality product suppliers increase

As mentioned in Result 1, when the net expected benefit of fraudulent behaviour increases with the efficiency of producers (i.e. scenario 1), food adulteration results in decreased (increased) equilibrium quantity, consumer price and price received by producers of the product marketed as high-quality (the low-quality product). Therefore, under scenario 1, the profits of suppliers of the product marketed as high-quality decrease by $\left(P_h^c - P_h^f\right)x_h - \left(P_{h,d}^c - P_{h,d}^f\right)x_{h,d}$, while the profits of low-quality product suppliers increase by $\left(P_{l,d}^c - P_{l,d}^f\right)x_{l,d} - \left(P_l^c - P_l^f\right)x_l$ (see Appendix S1).

According to Result 2, the equilibrium consumer and producer prices of the product marketed as high-quality (the low-quality product) decrease (increase) under food adulteration scenario 2, while the equilibrium quantities depend on the relative magnitude of the demand and supply effects of food adulteration. Specifically, when the demand effect dominates the supply effect of food adulteration, the equilibrium quantity of the product marketed as high-quality (the low-quality product) decreases (increases) and vice versa. Consequently, when the demand effect dominates the supply effect of food adulteration, the profits of the low-quality product suppliers increase while the profits of the high-quality product suppliers fall. On the other hand, when

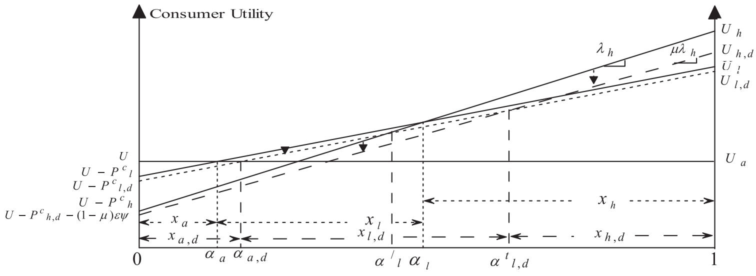

Figure 7 Total effects of food adulteration on consumers.

the supply effect dominates the demand effect, the impact of food adulteration on high-quality and low-quality product suppliers is ambiguous (see Appendix S1).

3.3.3 Impact of food adulteration on consumers

Result 4: The presence of food adulteration reduces the welfare of both high-quality and low-quality product consumers, with the greatest welfare losses incurred by those who continue to consume the high-quality product in the presence of food adulteration.

Figure 7 shows the total effects of food adulteration on consumers. As shown earlier, the uncertainty about the nature of the product marketed as high quality and the probability of getting sick in the presence of food adulteration decrease the utility associated with (and the willingness to pay for) the product marketed as high quality. The change in the slope of $U_{h,d}$ is due to the uncertainty about the nature of the product marketed as high quality while the expected cost of getting sick consuming the adulterated product causes a downward shift of U_h to $U_{h,d}$ (dashed line in Figure 7).[9]

As mentioned previously, the equilibrium price of the low-quality product increases under food adulteration. The increased price of the low-quality product decreases the utility associated with the consumption of the low-quality product. Therefore, the utility function associated with the consumption of the low-quality product shifts downward from U_l to $U_{l,d}$ and limits the number of consumers switching to the low-quality product (dotted line in Figure 7). When the total effects of food adulteration on consumers are considered, the intersection of $U_{h,d}$ and $U_{l,d}$ determines the market share of the high-quality product. When compared with the case of no fraud, the presence of food adulteration reduces the market demand for high-quality product as consumers with differentiating attribute $\alpha \in \left(\alpha_l, \alpha^t_{l,d}\right)$ switch from the consumption of the high-quality product to the consumption of the low-quality product.

Therefore, in the presence of food adulteration, while the uncertainty and potential health hazard decrease the utility associated with the consumption

[9] It is assumed that $(1-\mu)\varepsilon\psi > (P^c_h - P^c_{h,d})$.

of the product marketed as high quality, the increased demand for the low-quality product increases its price which, in turn, decreases the utility associated with its consumption. Thus, food adulteration decreases the welfare of both high-quality and low-quality product consumers (the derivation of the welfare impacts of food fraud can be found in Appendix S2). Consumers realising the greatest welfare loss are those who continue to consume the product marketed as high quality in the presence of food adulteration (i.e. consumers with $\alpha \in \left(\alpha^{t}_{l,d}, 1\right]$).

3.3.4 Impact of food adulteration on producers

Scenario 1. Result 5: When the net expected benefit of fraudulent behaviour increases with the efficiency of producers (i.e. scenario 1), (a) the most efficient producers produce the adulterated product and (b) producers who adulterate food gain the most while producers who continue to produce the high-quality product and do not commit fraud realise the greatest welfare loss.

As mentioned previously, producers' production decision is determined by comparing the net returns associated with the production of the high-quality, the adulterated and the low-quality products. In the presence of food adulteration, the reduction in the equilibrium price of the product marketed as high quality causes a downward parallel shift of the net returns curve associated with the production of the high-quality product (dashed line in Figure 8).

The intersection of the net returns curve associated with the production of the high-quality product and the net returns curve associated with the production of adulterated product determines the differentiating attribute of the producer who is indifferent between producing a unit of the adulterated and the high-quality products, $A^{ch}_{h,d}$. Producers to the left of $A^{ch}_{h,d}$ in Figure 8 find it optimal to switch from the production of the high quality to the production of the adulterated product since the net returns associated with

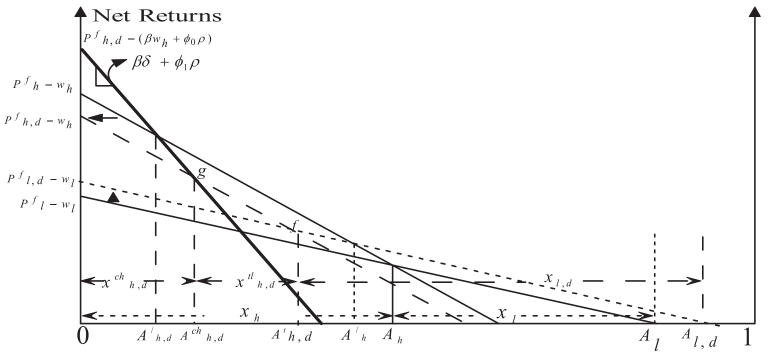

Figure 8 Total effects of food adulteration on producers (scenario 1).

the production of adulterated product exceed those of the alternatives. Consequently, under scenario 1, it is the most efficient producers that adulterate their products and market them as high quality.

Since, in the presence of food adulteration, the equilibrium price of the low-quality product increases, the net returns curve associated with the production of the low-quality product shifts upward (see dotted line in Figure 8). Similarly, the intersection of the net returns curve associated with the production of the low-quality product and the net returns curve associated with the production of the high-quality product determines the differentiating attribute of the producer who is indifferent between producing a unit of the high-quality and the low-quality products, $A^t_{h,d}$. Producers with $A \in \left(A^{ch}_{h,d}, A^t_{h,d}\right)$ continue producing the high-quality product as the net returns associated with the production of the high-quality product are greater than the net returns associated with the production of the adulterated product. Producers with $A \in \left(A^t_{h,d}, A_h\right]$ find it optimal to switch from the production of the high quality to the production of the low-quality product, while producers with $A \in (A_h, A_l)$ continue to produce the low-quality product in the presence of food adulteration. Therefore, when the net expected benefit of fraudulent behaviour increases with the efficiency of producers, it is the most efficient high-quality producers who engage in fraudulent behaviour.

Comparing the welfare effects in the presence and absence of food adulteration reveals that producers benefiting the most from food adulteration are those producing the adulterated product (i.e. producers with $A \in [0, A^{ch}_{h,d})$), followed by producers who continue to produce the low-quality product (i.e. producers with $A \in (A_h, A_l)$). Previous producers of the alternative product who find it optimal to switch to the production of the low-quality product (i.e. producers with $A \in (A_l, A_{l,d})$) also gain. In contrast, producers who continue to produce the high-quality product in the presence of food adulteration (i.e. producers with $A \in (A^{ch}_{h,d}, A^t_{h,d})$) lose, and so do some of the high-quality product producers who switch to the production of the low-quality product (i.e. producers with $A \in (A^t_{h,d}, A^{/}_h)$).[10]

Scenario 2. Result 6: When the net expected benefits of fraudulent behaviour decrease with the efficiency of producers and the supply effect dominates the demand effect (i.e. scenario 2A), (a) (some) high-quality and low-quality producers (i.e. producers with intermediate level of efficiency) find it optimal to produce the adulterated product and market it as high quality, and (b)

[10] In the presence of food adulteration, (some) high-quality producers (i.e. producers with $A \in \left(A^t_{h,d}, A^{/}_h\right)$) switch from the production of high-quality product to the production of low-quality product as the net returns associated with the production of low-quality are greater.

(some) high-quality producers and all low-quality producers who switch to the production of the adulterated product benefit, while all producers who continue to produce the high-quality product in the presence of food adulteration realise welfare losses.

Figure 9a depicts the market and welfare effects under scenario 2 when the supply effect dominates the demand effect of food adulteration (i.e. when the increase in the supply of the product marketed as high quality in the presence of food adulteration exceeds the fall in the consumer demand for this product). Like scenario 1, the presence of food adulteration results in an inward (outward) parallel shift of the net returns curve associated with the production of the high (low)-quality product. The intersection of the net returns curve associated with the production of the high-quality product and the net returns curve associated with the production of the adulterated product (i.e. dashed and bold lines in Figure 9a, respectively) determines the equilibrium quantity of the high-quality product in the market, $x^{tl}_{h,d}$. Similarly, the intersection of the net returns curve associated with the production of the low-quality product (i.e. dotted line in Figure 9a) and the net returns curve associated with the production of adulterated product

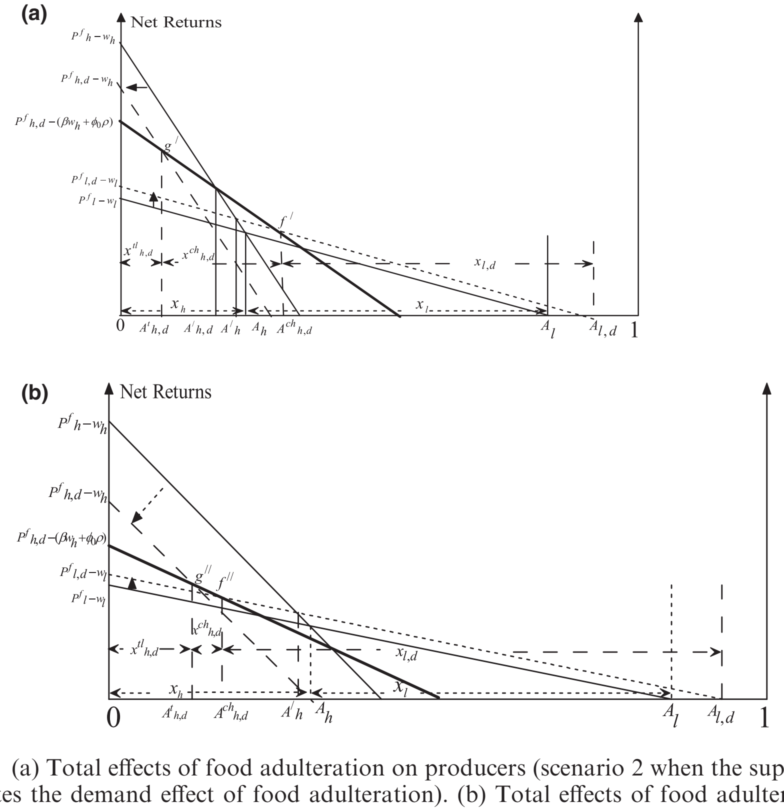

Figure 9 (a) Total effects of food adulteration on producers (scenario 2 when the supply effect dominates the demand effect of food adulteration). (b) Total effects of food adulteration on producers (scenario 2 when the demand effect dominates the supply effect of food adulteration).

determines the equilibrium quantity of the product marketed as high-quality $x_{h,d}\left(= x^{tl}_{h,d} + x^{ch}_{h,d}\right)$.

More efficient producers with differentiating attribute $A \in \left[0, A^{t}_{h,d}\right)$ continue to produce the high-quality product in the presence of food adulteration, while producers with differentiating attribute $A \in (A^{t}_{h,d}, A_h)$ switch from the production of the high-quality product to the production of the adulterated product. Unlike scenario 1, producers with differentiating attribute $A \in \left(A_h, A^{ch}_{h,d}\right)$ find it optimal to switch from the production of the low-quality product to the production of the adulterated product, while producers with differentiating attribute $A \in (A^{ch}_{h,d}, A_l)$ continue to produce the low-quality product. Therefore, when the net expected benefit of fraudulent behaviour decreases with the efficiency of producers and the supply effect dominates the demand effect, producers with intermediate level of efficiency (who produce either the high-quality product or the low-quality product in the absence of food adulteration) adulterate their product and market it as the high-quality product. However, unlike scenario 1, the most efficient high-quality producers do not find it optimal to engage in fraudulent behaviour.

Comparing the producer surpluses in the presence and absence of food adulteration reveals that producers who continue to produce the high-quality product in the presence of food adulteration (i.e. producers with $A \in \left[0, A^{t}_{h,d}\right)$) lose and so do some of the high-quality product producers who switch to the production of the adulterated product (i.e. producers with $A \in \left(A^{t}_{h,d}, A^{/}_{h,d}\right)$. On the other hand, producers with differentiating attribute $A \in \left(A^{/}_{h,d}, A^{ch}_{h,d}\right)$ who find it optimal to adulterate their product are benefiting the most under food adulteration followed by producers who continue to produce the low-quality product (i.e. producers with $A \in \left(A^{ch}_{h,d}, A_l\right)$) and producers who find it optimal to switch from the alternative product to the low-quality product in the presence of food adulteration (i.e. producers with $A \in \left(A_l, A_{l,d}\right)$).

<u>Result 7</u>: When the net expected benefit of fraudulent behaviour decreases with the efficiency of producers and the demand effect dominates the supply effect (i.e. scenario 2B), (a) (some) high-quality producers find it optimal to adulterate their product and market it as high quality and (b) producers who continue to produce the low-quality product gain while all producers who continue to produce the high-quality product or switch to the production of adulterated product realise welfare losses.

Figure 9b presents the total effects of food adulteration when its demand effect dominates its supply effect under scenario 2 (i.e. when the fall in consumer demand for the high-quality product in the presence of food adulteration exceeds the increase in the supply of the product marketed as high quality). The most efficient high-quality producers (i.e. producers with differentiating attribute $A \in \left[0, A^t_{h,d}\right))$ continue to produce the high-quality product. On the other hand, (some) producers with intermediate level of efficiency (i.e. producers with differentiating attribute $A \in \left(A^t_{h,d}, A^{ch}_{h,d}\right))$ find it optimal to switch from the production of the high-quality product to the production of the adulterated product. Producers with differentiating attribute $A \in \left(A^{ch}_{h,d}, A_h\right)$ who produce the high-quality product in the absence of food adulteration switch to the production of the low-quality product, increasing the total production of the low-quality product by $A_h - A^{ch}_{h,d}$. Therefore, when the net expected benefit of fraudulent behaviour decreases with the efficiency of producers and the demand effect dominates the supply effect of food adulteration, (some) producers with intermediate level of efficiency produce the adulterated product. However, most efficient high-quality producers and low-quality producers have no incentive to engage in fraudulent behaviour.

Producers who continue to produce the low-quality product in the presence of food adulteration (i.e. producers with $A \in (A_h, A_l))$ and alternative product producers who switch to the production of the low-quality product (i.e. producers with $A \in \left(A_l, A_{l,d}\right))$ gain the most. Some high-quality product producers who find it optimal to switch to the production of the low-quality product (i.e. producers with $A \in (A^{/}_h, A_h))$ also gain in the presence of food adulteration. On the other hand, producers losing the most from food adulteration are those who continue to produce the high-quality product (i.e. producers with $A \in \left[0, A^t_{h,d}\right))$, followed by producers who switch to the production of the adulterated product (i.e. producers with $A \in \left(A^t_{h,d}, A^{ch}_{h,d}\right))$ and (many) high-quality producers who switch to the production of the low-quality product (i.e. producers with $A \in (A^{ch}_{h,d}, A^{/}_h))$.

4. Food fraud: mislabelling

This section analyses the market and welfare effects of food fraud in the form of mislabelling.[11] While, as noted earlier, the consumption of an adulterated product can make the consumer of this product sick, the consumption of mislabelled products (i.e. low-quality products mislabelled as high-quality ones like virgin olive oil labelled as extra virgin or conventional milk labelled as organic) generally involves no such risk. The analysis of cases where

[11] Since mislabelling involves, in essence, a misrepresentation of the true nature of the product being sold, its analysis also applies to cases of false or exaggerated claims about the true nature/actual quality of the product being sold (i.e. whether a particular product has the high quality attributes it claims).

mislabelling may cause health issues (such as an allergic reaction due to mislabelled ingredients) would be similar to that of food adulteration. With mislabelling not involving a health risk, the consumer utility associated with the consumption of the product marketed as high quality in the presence of mislabelling can be derived by substituting zero for the term $(1-\mu)\,\epsilon\psi$ (i.e. the expected cost of getting sick) in equation (16). Moreover, since producers mislabel the low-quality product as the high-quality one, the producer net returns function in the presence of mislabelling can be derived by substituting $w_l + \gamma A$ for $\beta(w_h + \delta A)$ in equation (21).

While the reduced costs associated with the consumption of the product marketed as high quality under mislabelling (relative to those under food adulteration) change the quantitative nature of our results, the qualitative nature of our findings on the market and welfare effects of mislabelling are similar to those of food adulteration. In particular, since mislabelling does not result in a health hazard, the reduction (increase) in the consumer valuation of the product marketed as high (low) quality is smaller under mislabelling and so is the reduction (increase) in the consumer and producer prices. Consequently, the consumer welfare loss under mislabelling is lower than under food adulteration and the market share of the low-quality product (the product marketed as high quality) under mislabelling is lower (higher) than that under food adulteration.

While the equilibrium quantity of the product marketed as high quality is greater in the presence of mislabelling, the extent of fraudulent behaviour is also increased. Due to higher price premia enjoyed by the product marketed as high quality under mislabelling, producers are more likely to mislabel than adulterate their products. The welfare loss (gain) of high-quality producers (dishonest and low-quality producers) under mislabelling is lower than under food adulteration. Moreover, the profits of suppliers of the product marketed as high quality (low-quality) under mislabelling are greater (less) than that under food adulteration (a complete analysis of the market and welfare effects of mislabelling is available in Appendix S4).

5. Alternative considerations

5.1 Food fraud by middlemen

While the previous analysis focused on the case of food fraud by agricultural producers, the results are more general and also apply to cases where it is heterogeneous middlemen, rather than producers, that adulterate and mislabel their products. The reasoning is as follows. As it is the presence of food fraud (rather than its sources) that affects the consumer valuation and demand for the different products, the consumer utility and demand effects of food fraud by middlemen are similar to those of food fraud by producers analysed earlier. Also similar are the (cost reduction) benefits and expected costs to those middlemen who choose to adulterate or mislabel their products, and, thus, the supply effects of food fraud. Note that, when (like producers) middlemen differ in their costs of production, their detection probability would capture the notion that more efficient firms can be expected to be better able to cover up their fraudulent activities.

With similar demand and supply effects of food fraud, the key results of the analysis of food fraud by heterogeneous middlemen would be qualitatively similar to those derived earlier. The key difference, of course, would be on the group that benefits directly from food fraud, which, depending on whether the net expected benefits of fraudulent behaviour increase or decrease with the efficiency of middlemen, would be the more or less efficient middlemen involved in food fraud (rather than the more or less efficient agricultural producers).

5.2 Impact of liability costs

Food fraud incidents can result in liability costs incurred by either producers or middlemen. In our model, liability costs are captured in the expected cost of fraudulent behaviour faced by those who adulterate or mislabel their products. For instance, when liability costs for food fraud incidents are borne by the party responsible for this activity, the penalty for detected food fraud ρ increases. In contrast, when liability costs are borne by middlemen but fraud is committed by producers, the probability that producers will be detected by third parties if they engage in fraudulent behaviour, ϕ_0, will increase as middlemen have an incentive to bolster their monitoring efforts. Thus, depending on the group that is involved in fraudulent activities and the group responsible for liability costs (producers or middlemen), these costs increase either the penalty or the probability of food fraud detection. Either way, liability costs increase the expected cost of fraudulent behaviour, reducing, this way, the net expected benefit of fraudulent behaviour (i.e. $\{(w_h - \beta w_h) + (\delta - \beta\delta)A\} - \{(\phi_0 + \phi_1 A)\rho\}$) and the total number of producers engaging in fraudulent behaviour under both scenarios 1 and 2.

6. Conclusions

While food fraud is not a novel phenomenon, its intensity and frequency have been on the rise with the increased emphasis on quality and use of labelling in the agri-food marketing system (Johnson 2014). Food fraud in the form of food adulteration and mislabelling is viewed as a threat to the integrity of the increasingly industrialised agri-food system and is a major concern for consumers, the food industry, and governments around the world.

Despite the prevalence of food fraud and its, sometimes, devastating consequences for consumer well-being and the sectors involved, a systematic economic analysis of food fraud is absent. This study used a theoretical framework of heterogeneous consumers and producers to examine the market and welfare effects of food fraud in the form of food adulteration and mislabelling. The explicit consideration of consumer and producer heterogeneity, asymmetries in the probability of fraud detection, and endogenous production decisions allows the disaggregation of the welfare effects of food fraud (i.e. the determination of the effects of food fraud on different consumers and producers of the products of interest) and reveals the diverse incentives faced by different producer groups engaged in, and affected by fraudulent behaviour. Different scenarios on the relationship between the benefits of fraudulent behaviour and the efficiency of producers were considered within this framework.

The results show that the price of high (low)-quality product decreases (increases) in the presence of food fraud, while the effects of food fraud on equilibrium quantities are case-specific and dependent on the relative magnitude of the demand and supply effects of food adulteration and mislabelling. Moreover, the magnitude of the price effects of food fraud depends on the type of food fraud with the equilibrium price of the high (low)-quality food falling (increasing) more under food adulteration than under mislabelling. In most cases, the profits of the high-quality product suppliers fall while the profits of the low-quality product suppliers increase in the presence of food fraud.

The involvement of low-quality producers in fraudulent behaviour is case-specific. In particular, low-quality producers will find it optimal to adulterate and/or mislabel their products when the net expected benefit of fraudulent behaviour decreases with the efficiency of producers and the supply effect dominates the demand effect of food fraud. A key insight of this study is that producers of high-quality products can also find it optimal to commit fraud. In fact, our analysis shows that, at least some, producers of high quality will always have incentives to commit fraud. The subgroup of high-quality producers that commits fraud was shown to depend on the social attitudes towards food fraud, the enforcement policy parameters, and the relative magnitude of the demand and supply effects of food fraud.

Explicitly accounting for consumer and producer heterogeneity is critical in understanding the highly asymmetric welfare effects of food fraud across consumers (with different preferences) and producers (with different levels of efficiency). Our results indicate that, in most cases, (many) high-quality producers and all low-quality producers who adulterate or mislabel their product gain the most, followed by low-quality producers who continue to produce the low-quality product but do not commit food fraud. While honest low-quality producers gain, honest high-quality producers always lose in the presence of food fraud. Intriguingly, even though the presence of food fraud has different impacts on honest producers of low and high-quality products, it is shown to reduce the welfare of *both* high and low-quality product consumers.

A comparison of the consumer welfare losses under food adulteration and mislabelling indicates that the total consumer welfare loss is higher under food adulteration. While the equilibrium quantity of the high-quality product is higher in the presence of mislabelling, the increased price premia enjoyed by the product marketed as high quality under mislabelling make producers more likely to mislabel than adulterate their products.

Having identified the market and welfare effects of food fraud on all interest groups involved and the groups which are more likely to engage in fraudulent behaviour, our analysis can serve as the basis for the determination of the optimal policy response to food fraud, like the optimal level of monitoring and enforcement under different government objectives and weights on the interest groups involved. It can also provide the basis for estimating the effects of food fraud information on consumers' valuation of the affected products and for quantifying the market and welfare impacts of food fraud incidents on the interest groups involved. Since important market and welfare effects of food fraud were shown to be case/scenario specific, determining the values of the key parameters is critical for identifying the relevant scenario at play and, through this, the market and welfare impacts of fraudulent activity. Interesting extensions of this research also include the disaggregation of middlemen and the consideration of various successive and bilateral monopoly/oligopoly relationships between food manufacturers and retailers, as well as their impact on the causes and consequences of food adulteration and mislabelling.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Equilibrium conditions.
Appendix S2. Welfare effects.
Appendix S3. Food adulteration.
Appendix S4. Mislabelling.