Using economic variables to identify adulteration in food imports: application to US seafood imports

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Abstract.
Current inspection systems do not use economic variables in assessing import risks even though adulteration has economic roots. This essay shows that inspection policies may integrate economic data to better target risk. The model considers exporting firms that can buy inputs of two qualities: low and high. The low quality input does not meet quality standards in the importing country such that its use adulterates the output of the exporting firm. The decision by an exporting to adulterate its output depends on the relative price of inputs and the ability of the importing country to detect adulteration. The paper offers an application of the model to US seafood imports from China.

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The inspection of food imports by governmental agencies responds to many objectives. First, inspectors verify compliance with domestic regulation to reduce the risk to the health of consumers. The argument is that production conditions in the foreign country are not observable and that in the event of an incident, the foreign firm responsible of an incident is not subject to the legal system of the importing country. As such, the inspection of food imports helps resolve a moral hazard problem in food import quality. A second motive for import inspection, although not stated publically, is to raise import barriers, thus increasing costs to exporting firms.

Recent incidents involving adulterated food imports have received much media attention. For instance, in 2007, a Canadian firm imported from China wheat gluten tainted with melamine, processed it into pet food, and then exported to the United States, allegedly causing the death of thousands of pets. The same year, baby formula tainted with melamine caused a food safety scare in many countries. Other examples of adulteration that have received media coverage include glycerin contaminated with diethylene glycol, French truffles mixed with Chinese truffles and low quality titanium used in medical implants.[1] What is common with these examples is the economic motive behind adulteration. In particular, the use of low quality and less expensive inputs to substitute for more expensive high quality inputs that meet standards for the integrity of a product.

Food safety incidents from adulterated food imports have motivated recent changes in food policy, in particular in the United States. The Food and Drug Administration (FDA) released in June 2011 a document titled *Pathway to Global Product Safety and Quality,* which outlines the strategy of the FDA in monitoring imports (FDA 2011). The document describes trends in imports and new challenges and possible solutions to more effectively monitor imports. The FDA identifies economic forces through the globalization of markets as a source of increased risk. For instance, globalization increases the complexity of supply chains such that a product (an ingredient) may travel through many countries before the end of its journey. The

[1] The adulteration of food products does not always increase risk to consumers' health. For example, adding cane sugar syrup into honey should not increase the risk of foodborne illness. The substitution of costly inputs by less expensive but unapproved input is called economic adulteration (Fairchild, Nichols and Capps 2003). Although it does not pose a threat to consumers' health, it is illegal.

FDA not only monitors imports but in certain cases production in the exporting country. For food, however, less than one percent of facilities exporting to the United States are inspected. The adoption of the FDA Food Safety Modernization Act (FSMA) in early 2011 gives increased accountability to food suppliers and gives the FDA the power to refuse the entry of products coming from foreign facilities from which the FDA was denied access.

The strategy proposed by FDA (2011) to improve the effectiveness of its border inspection practices is to increase collaboration with trade partners in building food safety nets, better sharing of data on the global market, expand intelligence capabilities and improve resources allocation. The FDA identifies economic forces as a source of increased risk for imports, but paradoxically, the FDA does not identify the use of economics into a strategy to improve the monitoring of food imports. This essay presents a model that provides the linkage between economic data and increased risk from imports. In particular, it shows that increased occurrence of adulteration may originate from changes in economic conditions. The model provides guidance on how economic intelligence may be integrated in import inspection systems.

The model assumes a marketing chain where exporting firms choose between low and high quality inputs. The likelihood of rejection of the product at the importing country's border increases with respect to the relative quantity of the low quality input. The discussion of the model applies to food, but applications of the model to drugs or other products are possible with slight modifications. The model can apply to many other issues such as the domestic inspection policies of food plants, the inspection of medicines and the detection of counterfeits.

The next section situates my work with respect to the literature. I then present background information regarding the inspection of food imports. I then present the model and derive results using comparative statics. The section that follows applies the model to US imports of seafood from China. Finally, I discuss the implications of the model for border inspection policies and then conclude in the last section.

Related literature

The economics behind the production of adulterated food relates to situations where agents take actions to reduce the risk of accidents. An extensive literature investigates accidents and safety, including Brown (1973), Cooter (1991) and Shavell (1984). In contrast to most of the economic literature on safety, my model focuses on intentional adulteration of products when the exporters seek to capture a rent by selling a product that does not meet regulatory standards.[2] In this context, one can think of the inspection of food imports as a game between the exporting firms (or equivalently importing firms or brokers) and the inspection agency. The economic analysis of inspection is thus closely related to the economics of fraud (e.g. Darby and Karni 1973) and crime control (e.g. Becker 1968, Polinsky and Shavell 2000). In all of these economic problems, a group of agents seeks to capture a rent by intentionally committing illegal actions or hiding information.

Alsberg (1931) defined the concept of adulteration at a time when the adulteration of food products was a much more important problem than today in developed countries. For Alsberg (1931), adulteration is "any act that renders an article other than of the nature, substance, and quality demanded by the purchaser or other than of the nature, substance, and quality the purchaser is presumed to have expected."[3] According to this definition, accidental or intentional contamination or any undisclosed modifications of a food product is adulteration. In the United States, it is the Federal Food, Drug, and Cosmetic Act of 1938 that mandated food enforceable food standards. The definition of adulterated food in the Act still applies today and comprises the following elements: (a) poisonous, unsanitary, or deleterious ingredients; (b) absence, substitution, or addition of constituents; (c) if it bears or contains a color additive, which is unsafe. The definition extends further to include putrefaction, unsanitary transportation and supplements. Similar definitions apply for cosmetics and drugs. The essence of these definitions is that a product is adulterated if it is made of unauthorized material or if it contains any pathogen, poison or deleterious substances that may render the product harmful to health.

With the recent access to import refusal data, the empirical literature on food imports inspection has been growing. Those data record shipments that were refused entry at a country's border. Buzby, Unnevehr and Roberts (2008) describe US food import refusal data. The authors find that between 1998 and 2004, 65 percent of refusals were dues to adulteration, 33 percent for misbranding and 2 percent for other violations. The most common type of adulteration was filth.

Recent literature explains import refusals. Baylis, Martens and Nogueria (2009) estimate the factors affecting US food import refusals with a focus on political economy variables. The authors find that riskier products are more often rejected and that lobbying expenditure increase

[2] With slight modifications, the model can apply to the study of incidents as considered in previous literature.
[3] Alsberg (1931) defined several other concepts related to adulteration: substitute, surrogate, imitation, artificial, synthetic and falsification. Some of these concepts have taken different meanings over time.

the number of refusals. Baylis, Nogueira and Pace (2010) and Grant and Anders (2011) estimate the trade diversion and deflection effects of import refusals.[4] Both studies find evidence of trade deflection from import refusals.

Background on food import inspections

Virtually all countries inspect imports of food and agricultural commodities. Trade agreements and organizations such as the Codex Alimentarius Commission have contributed to standardize quality standards and inspection methods. Although inspection policy details remain country-specific, developed countries tend to use similar methods of inspection and similar formats for disclosing their inspection policies. The following discussion applies to the United States border inspections, but US policies are similar to those in most developed countries.

The task of inspecting food imports is daunting. In the United States, the FDA monitors the imports of food, drugs, medical devices, veterinary products and biologic products. In 2009, the United States imported 18.5 million shipments that fell under FDA jurisdiction, including almost 11 million shipments of food (FDA 2011). From 2002 to 2009, the number of shipments that the FDA oversees increased at a 13 percent annual rate. The FDA physically inspects less than one percent of all imports.

Working with limited resources, import inspection agencies allocate inspection efforts across many products, from many countries, passing through many ports of entry by different means of transportation. Inspection programs in the United States follow internationally recognized standards and principles. This assures the respect of international trade agreements regarding import inspections, but it also facilitates communication with other countries when a new threat is identified. For example, if the United States finds that the imports of noodles from China do not meet its food safety standards, its findings are publically available to other national inspection agencies which can then increase their oversight of that product.

The FDA targets product for inspection using PREDICT (Predictive Risk-based Evaluation for Dynamic Import Compliance Targeting) and other tools. PREDICT evaluates the risk of imports and identifies products that present lesser risk, therefore helping inspectors to

[4] Trade diversion is trade between two countries that replaces trade with another country because of differences in transaction costs (e.g. preferential tariffs). Trade deflection, a similar concept, is the entry into a low-transaction cost trade partner of imports intended for a purchaser in a high-transaction cost partner. These definitions often describe these concepts with application to tariffs rather than transaction costs.

allocate their effort toward riskier imports. The data mining system analyses information regarding the origin of the product, the type of product, weather information, the name of the exporting firm and labeling information. The FDA completed the nationwide rollout of the system in June 2011.

Food imports must meet the same standards as domestic food. However, an important distinction is how those standards apply. In the United States, imports are deemed in violation if they appear adulterated or misbranded, with no definition of what constitutes appearance (Humphrey 2003). If the FDA finds that an importer is not compliant, it issues an import alert which prevents all future entry into the United States of that product unless the importer demonstrates compliance with US requirements. Importers have the burden of showing that corrective actions were implemented and that their product is compliant. For shipments that are denied entry, the importer can provide evidence that the product complies with US requirements or present a plan regarding the product will be made compliant. The importer may alternatively choose to export the product elsewhere or destroy a shipment that is refused entry.

A model of imports adulteration

The objective of the model is to describe how changes in economic variables can increase the likelihood that a product is adulterated and therefore the role for economics in import risk-assessment models. In general, inspection systems evaluate risk without the use of economics and instead guide inspection efforts based on inspection data, and country and product specific risks. The systems perform better in the long run and provide little help in predicting the emergence of new threats and are often able to detect increased risk only after their development. The role of economics, as my model shows, is in providing additional information about new risks when traditional risk assessment model are most likely to fail. As such, the model focuses on the short run and assumes that the inspection effort for a product is exogenous.

The model considers identical exporting firms that adulterate their output at an intensity that maximizes their profit. Another interpretation of the model is that there is a distribution of exporting firms, with some choosing to adulterate their output while others do not. With that interpretation in mind, one can think of the model with identical firms as capturing the average intensity of adulteration. Thus, if the model shows an increase in the intensity of adulteration, the interpretation in the context with heterogeneous firms is that more firms choose to adulterate their output.

The model

The model uses the same structure as in Muth (1964). Muth's model has been used in agricultural economics to investigate the dispersion of shocks in supply chains. For instance, Gardner (1975) uses a model analogue to Muth (1964) to investigate changes in price margins. Perrin (1980) uses Muth's model to study the pricing of components of soybeans and milk. Alston and James (2002) review the incidence of agricultural subsidies in a supply chain using Muth's model. My use of Muth's model differs significantly from the conventional application of the model.

The model assumes, as in practice, that a border inspection agency does not impose fines to exporting firms that fail inspection. Instead, penalties for failing inspection take the form of losses in revenues. I can model these losses either from a reduction in the price or as a loss in output.[5] Modeling losses in the price space, in general, involves considering an expected price, or equivalently an expected cost, that accounts for the exporters not receiving payment for a shipment that does not pass inspection. This is similar to the modeling assumptions in Brown (1973) and Pouliot and Sumner (2008). The alternative approach in the quantity space is to assume that a certain quantity is lost because it does not meet inspection requirements. This is analogous to Samuelson's iceberg assumption in modeling transaction costs. Border inspections and the rejection of products constitute transaction costs similar to a melting iceberg because an exporting firm that adulterates its product knows that there is a probability that its product will not pass inspection. Such a firm maximizes its profit considering its expected output, which is a share of its total output, thus the melting iceberg assumption. The iceberg assumption is intuitive in the context of this model, and in particular, is convenient in modeling the production function in a way that is consistent with the model of Muth.[6]

An exporting firm can use two inputs that are perfect substitutes, in the sense that output remains constant when substituting one unit of an input with one unit of the other input. However, the two inputs are of different qualities with respect to their content of an adulterant.

[5] Equivalently, a reduction in the price can be modeled as an increase in the cost per unit.
[6] In practice, a one-time rejection entails greater scrutiny for future shipments and thus greater costs to the exporter. In my static model, these costs are implicitly included in the melting iceberg assumption.

The model assumes that the high quality is always free of adulterant. In contrast, the low quality input contains an adulterant that is illegal in the importing country. Thus, the use of the low quality input constitutes adulteration, consistent with the definition of adulteration by Alsberg (1931). Let x^h denote the quantity of a high quality input used by a firm and let x^l be the quantity of the low quality input. What matters in producing a quantity of output is the total quantity of input $x = x^h + x^l$. Thus, total output of the exporting firm is $q\left(x^h + x^l\right)$, where the production function $q\left(x^h + x^l\right)$ exhibits constant return to scale.

There is more than one possible interpretation of input quality in this model. The discussion of the model will assume that quality standards in the exporting country are lower than those in the importing country.[7] Input producers in the exporting country select a quality depending on whether they target firms that produce for domestic market of the export market. The high quality input is produced under the quality standards that meet those of the importing country. Input producers may specialize in the production of high quality inputs and sell to firms specifically targeting the export market. In contrast, input-supplying firms that produce the low quality input target the market within the exporting country, which has lower quality standards than those of the importing country.

Total output does not always equal the quantity that is delivered to the importing country. Border inspection services inspect shipments at random, or according to specified rules, and reject shipments that do not meet import requirements. Let me write that the border inspection agency inspects shipments at a rate $r \in (0,1)$. That is, the probability of inspection for one unit of import is r. The model assumes that the inspection rate is exogenous and known to the exporting firms. In practice, a border inspection agency adjusts its inspection rate to information it receives about threats. For instance, the FDA publishes import alerts to respond to increased risk from the import of some products. Risk assessment systems, however, tend use past inspection reports to identify new risks and therefore a new threat may go unnoticed until a random inspection detects a new source of risk. Thus, the model with an exogenous inspection

[7] Another interpretation is that the low quality input is an adulterant. This was the case in the addition of melamine to gluten to falsify tests of protein content. Alternatively, the input can be labor and the amount of human capital may vary across workers. Border inspections do not only verify the salubrity of food imports, but also labeling and documentation. For some products, the list of requirements is quite important and exports handled by qualified workers are more likely to pass inspection.

rate applies to the short-run when risk assessment systems are more likely to fail at identifying new threats.

Deception is an essential feature of adulteration; otherwise, an adulterated product would always be rejected by the border inspection agency. In the model, deception is possible because inputs are perfect substitutes in the production of the good. In addition, the model assumes that organoleptic inspection of the good does not allow for detection of adulteration. Only experts, for example border inspection agents, are sometimes able to detect traces of adulteration. In practice, consumers and inspectors have the ability to detect adulteration. Inspectors, however, are better trained and have access to equipment to detect adulteration. Thus, to simplify the model, I normalize the ability of consumers to detect adulteration to zero, implying that demand for imports is not a function of quality. Inspectors, in contrast, are sometimes able to detect adulteration. These assumptions capture the essential feature that inspectors have more knowledge of adulteration and have access to technology to detect adulteration that is too costly for personal use. For example, inspectors can test for melamine in milk while most consumers do not have the necessary testing kit. Inspectors are also more aware of what constitutes adulteration and thus can more accurately identify adulterated products.

The function $f = f\left(x^h, x^l : e\right) \in \left(0,1\right]$ is the probability that one unit of product cannot be identified as adulterated by inspectors. That is, the function f is the probability that one unit of food is deceptive as it does not appear as adulterated to inspectors. I will, loosely, refer to f as the probability that food is safe. The function f encompasses both the effort of exporting firms into hiding adulteration and the ability of inspectors to detect adulteration. The exporting firms know the quantity of low quality input that enters production and know the probability function f. However, when exporting one unit of food, a firm does not know whether an inspector will detect adulteration for that unit, if inspected.[8]

The probability function f is homogenous of degree zero with respect to the inputs, increases with respect to the quantity of high-quality input, $\partial f / \partial x^h > 0$ and decreases with respect to the quantity of low-quality input, $\partial f / \partial x^l < 0$. To make application of the model more

[8] An interpretation is that the mixing of high and low quality inputs does not always produce the exact same proportion of deceptive products. Another interpretation is that inspectors do not have the same ability to detect adulteration.

simple later in the text, let me assume that the function f depends on the share of the high quality input such that $f = f(s,e)$, where $s \equiv x^h / (x^h + x^l)$ is the share of the high quality input.

The parameter e in the function f captures the relative quality of the low quality input with respect to the high quality. As e decreases, the difference in quality between the low and the high quality input grows as the quality of the low quality input diminishes. For $e = e_{\max}$, the low and high quality are the same, meaning that the low quality input never contains an adulterant.

What matters to the exporting risk-neutral firm in maximizing its expected profit is the expected quantity of output that passes inspection. I assume that the inspection agency never rejects an adulterated product that does not appear as adulterated and never accepts a product, if inspected, that appears adulterated. That is, if the adulterated output is deceptive, then it always passes border inspection. If, however, deception fails and the output is inspected, then border inspectors always reject the shipment. I normalize the return to the exporting firm to zero when a shipment is rejected.[9] I write the expected output that passes inspection as

(1) $$Q = fq + (1-f)(1-r)q.$$

The expression for the total output assumes that the exporting firm knows the rate of inspection. In practice, exporters have good knowledge of how inspections are conducted from previous experience and know inspection requirements because they are publically available. [10]

Even though x^h and x^l are perfect substitutes in the production function q, they may not be perfect substitutes in the expected output because of the probability function f. The expected output is homogenous of degree one with respect to the inputs because the probability function is homogeneous of degree zero and the production function is homogeneous of degree one. Thus, following Allen (1938), I can write the elasticity of substitution between x^h and x^l as

$$\sigma = \frac{Q_h Q_l}{Q_{hl} Q},$$

where the subscripts identify partial derivatives.

[9] In practice, the return may not be exactly zero as a rejected shipment may be diverted to a different location where it may pass inspection. See Baylis, Nogueira and Pace (2010) and Grant and Anders (2011) for discussion and evidence of trade deflection.
[10] For instance, the Canadian Food Inspection Agency readily makes available its inspection requirements using the AIRS system (CFIA 2011).

To better understand the expression for the expected output, consider the following example. Assume that

(2) $$f=\left(\frac{x^h+ex^l}{x^h+x^l}\right)^{\gamma}=\left(s+e\left(1-s\right)\right)^{\gamma}$$

with $\gamma\in[0,1]$ and let the production function be $q=x^h+x^l$. Note that if $e=e_{\max}=1$, then both inputs are high quality and the output is never adulterated. With these functional forms, the expected output simplifies to

(3) $$Q=\left(1-r\left(1-\left(s+e\left(1-s\right)\right)^{\gamma}\right)\right)\left(x^h+x^l\right).$$

Figure 1 shows the shape of two isoquants. Consistent with the assumptions for the function f, the probability function equals one when an exporting firm uses only the high quality input. Thus, the intercept on the vertical axis of figure 1, where $x^l=0$, represents the level of the isoquant for the expected output that passes the border with $\overline{Q}=x^h$. Trading off high quality inputs for low quality inputs, the firm must increase its total production for the expected output to remain constant. Figure 1 assumes a value of 0.5 for γ, which implies convex isoquants. With a value $\gamma=1$ (not shown), low and high quality inputs are perfect substitutes and isoquants are linear despite the difference in input qualities.

Depending on the price ratio of the two inputs, a firm may buy only the high quality input or buy a combination of low and high quality inputs. Figure 1 shows two isoquants for the same level of production $\overline{Q}$. The black line assumes a low rate of inspection and the gray line assumes a higher rate of inspection. The tangency between the iso-cost line and the iso-quant determines the quantity of the low and the high quality input. Thus, when the border inspection service examines a large share of imports, the exporting firms must use a large share of the high quality input to export the same expected output.

The demand is the residual demand by the importing country. I denote the demand function by $Q=D\left(P:a\right)$, where P is the import price and a is a shock that affects the residual demand. As mentioned above, I assume that consumers in the domestic country do not observe adulteration of the imported product even for adulterated products that are not deceptive for inspectors. The implication for my model is that the demand does not include a shifter for product quality.[11]

Supplies of the two inputs are competitive. I denote by $x^h = g^h\left(w^h, b^h\right)$ the supply of the high quality input and denote by $x^l = g^l\left(w^l, b^l\right)$ the supply of the low quality input. The variable w^j is the price of input of quality $j = \{h, l\}$ and the parameter b^j shifts the supply of input of quality j down. The high quality input is likely specialized toward the export market, implying an inelastic supply. In contrast, the low quality input is used in the exporting country domestic market and is therefore purchased by firms that do not export. Consequently, the residual supply of the low quality input is more elastic.

The model summarizes to the six following equations:

(4) $$Q = D\left(P : a\right),$$ import demand;

(5) $$Q = fq + \left(1 - f\right)\left(1 - r\right)q,$$ expected exports;

(6) $$w^h = PQ_h,$$ demand for high quality input;

(7) $$w^l = PQ_l,$$ demand for low quality input;

(8) $$x^h = g^h\left(w^h, b^h\right),$$ supply of high quality input;

(9) $$x^l = g^l\left(w^l, b^l\right),$$ supply of low quality input.

Expressions (4), (5), (8) and (9) are described in the text above. Expressions (6) and (7) are the input demands derived from profit maximization by the exporting firms.

Comparative statics

I derive below comparative statics results that show how shocks on the system affect adulteration. I do not give all the details of the derivations. For more explanation of the derivation of similar models, I refer readers to Muth (1964), Alston, Norton and Pardey (1995) or Alston and James (2002).

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[11] The assumption that consumers do not observe adulteration is strong for products such as clothing where adulteration is often detectable with the naked eye. However, for products such as food and drugs, detecting adulteration often requires sophisticated instruments. For example, melamine in dairy products imported from China could not be detected by organoleptic inspection. An alternative but equivalent assumption, which is similar to the Armington assumption, is that the residual demand incorporates consumers' expectations of the adulteration of imported products.

Taking the total differential of (4)-(9), and expressing the results in terms of elasticities and percentage changes (e.g. $EX = dX/X$), the expressions for the model become:

(10) $$EQ = \eta\left(EP - \alpha\right),$$ import demand;

(11) $$EQ = \tau Ex^h + \left(1-\tau\right)Ex^l + \rho Er + \pi Ee,$$ expected imports;

(12) $$Ew^h = EP - \frac{\left(1-\tau\right)}{\sigma}Ex^h + \frac{\left(1-\tau\right)}{\sigma}Ex^l + \theta^h Er + \phi^h Ee,$$ demand for high quality input;

(13) $$Ew^l = EP + \frac{\tau}{\sigma}Ex^h - \frac{\tau}{\sigma}Ex^l + \theta^l Er + \phi^l Ee,$$ demand for low quality input;

(14) $$Ex^h = \varepsilon^h\left(Ew^h + \beta^h\right),$$ supply of high quality input;

(15) $$Ex^l = \varepsilon^l\left(Ew^l + \beta^l\right),$$ supply of low quality input.

Table 1 summarizes the definitions the signs of the parameters in (10)-(15). The parameter α is a demand shifter measured in the output price space. If $a > 0$, then the demand shifts up. The parameters β^j for $j = \{h, l\}$ are supply shifters in the input price space for the supplies of the inputs. For $\beta^j > 0$, the supply of input j shifts down, meaning a growth of the supply. Note that because the inputs are vertically differentiated, the high quality input is strictly preferred to the low quality at equal input prices. Accordingly, it must be that $w^h > w^l$ for $x^l > 0$. Thus, from (6) and (7) it follows that $Q_h > Q_l$ such that $\theta^h < \theta^l < 0$. The sign of θ^h is undetermined and depends on the share of high quality and low quality inputs.

Solving the system of equations in (10)-(15) yields solutions for EQ, EP, Ex^h, Ex^l, Ew^h and Ew^l in function of exogenous shifters α, β^h, β^l, Er and Ee. Rather than reporting all solutions, often cumbersome, I will instead focus on the expressions for percentage changes in the total import quantities, the changes in the safety of imports and the expected number of import refusals. I define and derive below expressions for these two measures.

Recall that f, the probability that one unit of output appears safe to an inspector, is a function of the share of the high quality input and a parameter e that captures the difference in quality between the low and the high quality inputs. Taking the differential of f, we can then write that the percentage change in the probability that one unit of output appears safe to inspectors is

(16) $$Ef = \varphi^s (1-s)\left(Ex^h - Ex^l\right) + \varphi^e Ee\,.$$

That is, consistent with the assumptions on the production function, one unit of output is more likely to pass inspection if a shock causes an increase in the use of the high quality input compared to the low quality input, i.e. $Ex^h - Ex^l > 0$. Otherwise, if $Ex^h - Ex^l < 0$, then one unit of output is less likely to pass inspection. Improvement in the quality of the low quality input, i.e. $Ee > 0$, increases the odds that one unit of food passes inspection.

The percentage change in the safety of imports is instructive of the quality of imports but is, however, not directly observable. What the FDA reports is the number of import refusals which depends on the compliance of food imports with US standards, on the intensity of inspection and on the quantity of imports. Let me define the expected number of import refusals as

(17) $$IR = (1-f)rq\,.$$

Taking the differential of (17) to find the percentage change in import refusals yields

(18) $$EIR = -\frac{f}{1-f}Ef + Er + sEx^h + (1-s)Ex^l\,.$$

Thus, the percentage change in the expected number of import refusals depends on the percentage change in safety, on the percentage change in inspection effort and on the percentage changes in input quantities.

The signs of expressions (16) and (18) are largely influenced by the changes in input quantities. Thus, in the interest of space, I will not report in what follows expressions for Ef and EIR. Instead, I refer readers to table 2 which reports the expressions for the percentage changes in input quantities and the signs of the changes in Ef and EIR.

Increase in inspection effort

Recall that the inspection effort is exogenous as the model does not consider the objective function of the inspection agency. Here, I explore the effects of increased inspection effort that arise from an exogenous shock. For example, the number of import inspections may increase because a government allocates more financial resources to the inspection agency.

The percentage change in the expected output from an increase in inspection effort is

(19) $$EQ = \frac{\eta\left(\rho\left(\sigma + \varepsilon^l \tau + \varepsilon^h (1-\tau)\right) + \varepsilon^l \theta^l (1-\tau)\left(\sigma + \varepsilon^h\right) + \varepsilon^h \theta^h \tau\left(\sigma + \varepsilon^l\right)\right) Er}{D},$$

where $D = -\sigma\left(\varepsilon^l (1-\tau) + \varepsilon^h \tau - \eta\right) + \eta\left(\varepsilon^l \tau + \varepsilon^h (1-\tau)\right) - \varepsilon^l \varepsilon^h < 0$. If the parameter θ^h is negative, the expected output always declines from an increase in the rate of inspection.[12] However, if the parameter θ^h is positive then the sign of (19) is undetermined. The parameter θ^h is the elasticity of the marginal product of the high quality input with respect to inspection intensity. At the margin, an increase in the quantity of high quality input may more than offset the effect of the increase in the inspection rate on the expected output. The importance of the parameter θ^h in (19) depends on the share of high quality input and the elasticity of supply of the high quality input. As mentioned previously, the elasticity of supply for the high quality input should be small compared to the elasticity of the low quality input. For illustration, let me assume that the elasticity of supply for the high quality input is zero such that (19) becomes

(20) $$EQ = \frac{\eta\left(\rho\left(\sigma + \varepsilon^l \tau\right) + \varepsilon^l \theta^l (1-\tau)\sigma\right) Er}{D} < 0.$$

Therefore, if the supply of the high quality input is perfectly inelastic, then the expected output declines. This is the most likely result given the relative size of elasticities of supply for the high and the low quality inputs.

Table 2 shows that the signs of the changes in both input quantities are undetermined. However, because $\varepsilon^l > \varepsilon^h$ and $\theta^h > \theta^l$, the percentage changes in input quantities are such that $Ex^h > Ex^l$. Thus, this means from (16) that $Ef > 0$, implying that an increase in the intensity of border inspection reduces the adulteration of imports because exporters have more incentives to export non-adulterated food. Although the intensity of adulteration declines, the sign of the change in the number of import refusals, EIR, is undetermined as the increase in the inspection rate make it more likely to detect violations.

In summary, the effect of increased inspection is to decrease the value of the low quality input to exporting firms because their output is more likely to be rejected at the border. Indeed, to the exporting firms, the marginal value of the high quality input increases compared to the marginal value of the low quality input. Thus, exporting firms will increase the quantity of high

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[12] Recall that comparative statics assume an interior solution where $x^h > 0$ and $x^l > 0$.

quality input relative to the quantity of low quality input. The effects are that the change in the expected output is most likely negative and that foreign firms reduce the intensity of adulteration.

Increase in import demand

Import demand may shift up for several reasons. For instance, a negative production shock in the domestic country will cause a shift to the right of the demand for imports. In my displacement model, a shift to the right in the import demand is modeled as a positive value for the parameter α.

From (10)-(15), the effect of an increase in the demand for imports on expected import quantities is

$$EQ = \frac{\eta\left(\sigma\left(\varepsilon^{l}\left(1-\tau\right)+\varepsilon^{h}\tau\right)+\varepsilon^{l}\varepsilon^{h}\right)\alpha}{D} > 0. \tag{21}$$

As one would expect, the positive shift in the demand increases the price paid to exporters who then increase their exports.

Table 2 shows that change in the quantity of high quality inputs and the change in the quantity of the low quality input are both positive. Whether the import product is more adulterated depends on the relative sizes of the input quantity changes, which depend on the elasticities of supply for the two inputs. As discussed previously, the supply of the low quality input should be more elastic than the supply of the high quality input intended for exports. Thus, an increase in the import demand will cause a relatively larger increase in the quantity of the low quality input than the high quality input, causing an increase in the rate of adulteration such that $Ef < 0$. From (18), the effect of increased demand on the expected number of import refusals is undetermined as changes in import quantities and food safety have opposite signs.

Decline in input prices

Changes in input prices affect export quantities and the intensity of adulteration in predictable ways as the model shows below. Exporting firms reduce their use of the input for which the price increases, therefore causing the intensity of adulteration to change in a predictable manner.

Let me first explore the effect of a positive shock that shifts downs the supply of the high quality input. Recall that a positive shock on the supply of the high quality input is modeled as a positive value for the parameter β^h. The percentage change on the expected quantity of imports is

(22) $$EQ = \frac{\varepsilon^h \eta(\varepsilon^l + \sigma)\tau\beta^h}{D} > 0 .$$

That is, as the supply of the high quality input increases, the total quantity that crosses the importing country's border increases. Table 2 shows that a shift down of the supply of the high quality input increases the quantity of the high quality input. In contrast, the effect on the quantity of low quality input is undetermined and depends on the elasticity of substitution between the high and the low quality input. However, the difference in the percentage changes of input quantities is positive, $Ex^h - Ex^l > 0$, such that the adulteration of imports decreases, $Ef > 0$. Thus, given an increase in exports and increase in safety, the sign of the effect of a decline in the price of the high quality input has an undetermined effect on import refusals.

One implication of these results is that a scare in the importing country is more likely if the price of high quality input increases. This might have been the case with melamine contamination for multiple imports from China. As the price of gluten increased, Chinese firms sought a cheap but illegal substitute in melamine.

For an increase in the price of the low quality input, the expressions for the percentage changes are similar but the effect on the quantities of inputs and adulteration differ. Let me consider a shift down in the supply of the low quality input, $\beta^l > 0$. The percentage change in the expected imports is

(23) $$EQ = \frac{\varepsilon^l \eta(\varepsilon^h + \sigma)(1-\tau)\beta^l}{D} > 0 .$$

That is, like a shift down in the supply of the high quality, a shift down in the supply of the low quality input increases the expected quantity that passes border inspection. An increase in the price of the low quality input increases the quantity of low quality input but has an undetermined effect on the high quality input, for which the sign depends on the elasticity of substitution. The difference in the percentage changes of input quantities is negative, $Ex^h - Ex^l < 0$, such that adulteration increases, $Ef < 0$. As imports increase and food safety declines, the change in import refusals is positive, $EIR > 0$.

Increase in the quality of the low quality input

My description of the model, which is one possible interpretation, is that the low quality input is destined to domestic consumption in the exporting country and the high quality input for the production of food exports. This is consistent with the production of many food products in developing country. Food safety in developing country is, in many cases, perceived as having significant incidence on quality of life and several governments in developing countries have taken steps to improve food safety. One example is China which has taken several steps to improve food safety after the melamine incident. The Chinese government went as far as shutting down plants with a history of food safety incidents.

Consider that the government in the exporting country enforces new food safety standards that effectively raise the quality of the low quality input. In the model, the parameter e captures the relative quality of the low quality input with respect to the high quality input, which does not contain any adulterant. As e increases, the quality of the low quality input increases, making the two types of inputs more similar. Thus, I model an increase the quality of the low quality input from government regulations as an increase in the parameter e.

The percentage change in the expected quantity of imports from an increase in the quality of the low quality input is

$$(24) \quad EQ = \eta \frac{\pi\left(\sigma + \varepsilon^{l}\tau\right) + \varepsilon^{h}\pi\left(1-\tau\right) + \sigma\left(\varepsilon^{h}\tau\phi^{h} + \varepsilon^{l}\phi^{l}\left(1-\tau\right)\right) + \varepsilon^{h}\varepsilon^{l}\left(\phi^{h}\tau + \phi^{l}\left(1-\tau\right)\right)}{D} Ee.$$

The sign of change in the expected quantity of imports is undetermined as low quality inputs may enter in a greater proportion, therefore lowering production cost, but at the same time increasing the probability of detection at the border despite improvement in quality. Table 2 shows that the changes in quantities for both input qualities are undetermined.

Although the low quality input becomes safer, imports may be less safe because the proportional change in input quantities may largely favor the low quality input. Comparing the changes in input quantities shows that an increase in the quality of the low quality input has an undetermined effect on the safety of imports. This means that more stringent regulation in the exporting country does not necessarily improve the safety of food imports. By extension, as the sign of the change in food safety is undetermined, the sign of the change in import refusals is also undetermined.

The discussion above assumes that the supply of the low quality input does not shift after the implementation of stricter regulation in the exporting country. In practice, more stringent food safety regulations should shift the supply of low quality input to the left. In my model, this means that a positive value for Ee should be paired with a negative value for β^l. Including the shift in the supply of the low quality input weakens the conditions for the increase in the quality of the low quality input to yield an increase in the safety of food imports as the increase in the price reduces the use of the low quality input.

These results suggest that a border inspection agency must be cautious of the effects of more stringent food safety regulations in an exporting country. In particular, if the regulation has a small effect on the cost of production, then the new regulation is more likely to have a perverse effect on the quality of food imports. Conversely, if the regulation is costly to foreign firms, then it signals that food exporting firms are less likely to use the low quality input and therefore the quality of food imports is more likely to rise. Note, however, that this statement is true only if the new regulation does not give rise to significant illegal production of lower quality food.

Application to US seafood imports from China

To show applications of the model, let me consider the case of US seafood imports. A model of the economics of food adulteration may prove particularly important for the inspection of seafood imports. Imports represent more than 80% of seafood consumption in the United States. Most seafood originates from developing countries (Anders and Caswell 2009, Grant and Anders 2011), and fishery and seafood imports represents about 20 percent of violations of imports laws enforced by FDA (Buzby, Unnevehr and Roberts 2008). Thus, seafood imports offer an interesting case where economics may play a significant role in guiding import inspections.

Canada is the largest exporter of fish and seafood to the United States, followed in decreasing order by China, Thailand and Chile (Brooks, Regmi and Jerado 2009). Production practices in Canada are similar to those in the United States and therefore there should be little discrepancy between the quality of seafood in Canada and the United States. For the three other countries, however, the quality of seafood for exports and for domestic consumption may significantly differ. Let me show applications for the model considering recent events that have affected China's seafood exports.

Numerical solutions for the model require data for several parameters. Unfortunately, empirical estimates for many of these parameters do not exist. I therefore will rely on guestimates of parameters that are consistent with imports of seafood from China. For some parameters it is difficult to gauge reasonable values. However, using functional forms for the food safety function and the production functions such as those in (2) and (3), I can find values for those parameters based on observable data and guestimates for other model parameters. The numerical solutions will apply for all seafood in aggregate rather than specific seafood products. Table 3 summarizes parameter values.

I will not conduct a sensitivity analysis as the objective of this application of the model is for illustration purposes. A study that specifically aims at estimating the change in risk from the import of seafood from China should, of course, take a careful approach and examine results' sensitivity.

I set the elasticity of demand at minus 5. The model considers the residual demand for imports of seafood from China. US total demand for seafood should be inelastic. However, as Chinese imports compete with US domestic production and imports from other countries, the US demand for Chinese seafood is more elastic than the total demand for seafood. Nonetheless, imports from China represent one of the most important sources of seafood. A value of minus 5 represents a compromise that accounts for the inelastic demand for all seafood, for the competition from other sources and the importance of China supplies in US consumption.

The supply elasticities of Chinese inputs account for production specialization for the two markets. The supply elasticity for low quality seafood, directed toward consumption in China, is set at 20. Supply for high quality seafood, which is the seafood that is exported, is set at 0.5. These values capture the relative sizes of the two markets and the specialization of seafood producers toward the export market. I set the value of s to 0.90, implying that low quality seafood constitutes 10 percent of the seafood that is exported to the United States from China. The value of τ, the exporters expenditure share for the high quality input, is set at 0.98.[13] It is possible to calculate the value of the elasticity of substitution between high and low quality inputs based on the functional form assumptions but it requires observing the quantity of low

[13] Together, the values for s and τ imply that the price of high quality seafood in China is about 5.44 times higher than the price of low quality seafood.

quantity input and the total production Q. As these data are not available, I set the value for the parameter σ to 25.

I calculate the values for the other parameters using expressions (2) and (3) as well as guesstimates for the values for the parameter in f and the rate of inspection r. In the expression for f in (2), I set that the parameter γ equals 0.9. I assume a 5% inspection rate and that food imports from China meet US food safety standards 95% of the time. Based on these values and the assumption that $s = 0.9$, I calculate that the parameter e in expression (2) equals 0.446. I calculate values for the other parameters of the model using definitions in table 1 and values of the other parameters.

Deepwater Horizon – shift up in US demand

In April 2010, an explosion occurred on Deepwater Horizon, an oil rig in the Gulf of Mexico off the coast of Louisiana. The explosion killed eleven workers and caused what may qualify as the largest oil spill in the history of marine oil extraction. The oil disaster caused significant damage to marine wildlife. In an effort to keep seafood safe, the National Oceanic and Atmospheric Administration (NOAA) closed down fisheries in several areas of the Gulf.[14] It was not until April 19, 2011 that fisheries fully reopened in the Gulf of Mexico (NOAA 2012).

The ban on fisheries in the Gulf of Mexico received much media attention as it affected the income of many fishermen. Even though fisheries are an important economic activity along the coast of the Gulf of Mexico, it is small relative to US total consumption of seafood. Supplies from the Gulf of Mexico account for 2 percent of US consumption of seafood (Zhao 2010). Thus, even a complete ban of fisheries in the Gulf of Mexico has a small effect on the domestic production of seafood.

Let me explore the effect of the oil spill on the import of seafood from China. I assume that the effect of the ban in fisheries in the Gulf of Mexico is a 2 percent increase in the demand for China seafood. This represents an upper bound as the ban did not cover all fisheries in the Gulf. However, consumers may have lost confidence in US seafood therefore increasing demand for foreign seafood. Thus, a vertical shift in the demand for Chinese seafood that is proportional

[14] In an oil spill, NOAA has five primary roles: conduct science, keep seafood safe, protect wildlife, assess damage, and restore habitat (NOAA 2012).

to a full ban on production in the Gulf of Mexico is a reasonable assumption for my numerical exercise.

Table 3 shows the effect of the ban on China imports. For most variables, the oil spill causes less than a 2 percent change. However, the model shows the oil spill caused almost a 20 percent increase in the use of the low quality input in the seafood that is exported from China to the United States. The increase in the use of the low quality input causes a decrease by 0.9 percent in the safety of food imports. Import refusals increase by about 20 percent as seafood imports are less safe and imports increase. This shows that even a small change in safety can trigger a large change in the number of import refusals.

Antibiotic crisis

The European Union reported high levels of antibiotics in shrimp from East Asia in the summer of 2001. The detection of antibiotics resulted in the ban by the European Union of shrimp from Vietnam and China and the testing of all shipments of shrimp from Thailand. European concerns over antibiotics in East Asian shrimp caused a surge in shrimp exports to the United States (Debaere 2010). In response to the increase in exports of shrimp from Asia, the United States later imposed anti-dumping on shrimp from six countries.

After the ban of Chinese shrimps by the European Union, the destination for nearly all China exports of shrimp was the United States. Debaere (2010) shows that the detection of antibiotics by the European Union caused an increase in the share of Chinese shrimp exports to the United States by almost 90 percent.

In my model, the ban by the European Union effectively increases the supply of high quality shrimps for the United States. The ban moves the residual supply of high quality seafood as European countries were also importers of high quality shrimp. Let me assume that the European ban on shrimp causes a 50 percent increase in the supply of high quality shrimp to the United States as shrimp constitutes a large share of China exports to the United States. I will assume that the ban has no effect on the supply of low quality seafood, as only a small quantity of low quality seafood was exported to Europe. I will also assume no change in the quality of China seafood exports to the United States because the United States tolerated the antibiotics banned by the European Union (Debaere 2010).

Table 3 shows that the new export of seafood from China increased by more than 20 percent. As high quality seafood going to Europe is diverted, US imports of seafood contain more of the high quality input and less of the low quality input. The safety of seafood imports from China increases by almost 3 percent. Even though the total quantity of seafood imports from China increases, the expected number of import refusals decreases as the quality of seafood increases.

New food safety standards in China

China has been dealing in recent years with many large-scale food safety incidents. For instance, some claims that melamine in dairy products and in infant formula caused illnesses for as many as 300,000 babies (Branigan 2008). In response to recurring food safety incident, the Chinese government has been tightening its control over food production. For instance, after the melamine scandal, the Chinese government increased oversight of its dairy industry (Kent 2010).

It is difficult to measure food safety but guesstimates of effectiveness are used in cost-benefit analyses. For instance, Antle (2000) uses in his calculation of cost and benefits of HACCP in US red meat an effectiveness rate of 20 percent. In a hypothetical scenario where China enforces tighter control on the production of seafood, let me assume that the quality of the low quality input increases by 20 percent. The high quality input is unaffected as it already meets the new requirements. In the first case, I will consider that improvement in seafood safety comes at no cost to Chinese producers. Then I will consider a case where the new regulation shifts up the supply of low quality input by 2 percent.

As table 3 shows, increasing the safety of the low quality input alone has a small positive impact on import quantities. Exporters use less of the high quality input and more and of the low quality input. However, as these two inputs become more similar in quality, the safety of imports increases by 0.64 percent. The expected number of import refusals declines by nearly 12 percent.

If the new food safety standard causes the supply of the low quality input to shift up by 2 percent, then the results are quite different. The last line of table 3 shows the outcomes of that scenario. Import quantity declines despite that the shift in supply is small. Exporters use less of the low quality input even though it is safer, thus causing an increase in the safety of seafood imports from China. Import refusals decline by one third as the new regulations affect the quantity and the quality of the low quality input that enters into exports.

Conclusion

The inspection of food imports has long been an issue because of fear that food imports are not as safe as domestically produced food. Recently, concerns over the adulteration of food imports have risen following the case of pet food tainted by ingredients from China and the imports of melamine tainted baby formula from China. Inspection agencies, which cannot assure the safety of all food imports, often take the blame for the entry of adulterated product.

Border inspection agencies like the FDA allocate their inspection effort on the basis of the information they receive regarding risks. That information comes from a variety of sources including findings from previous inspections and information from similar agencies in foreign countries. New threats are difficult to identify and there might be delays between the first imports of an adulterated product and the moment that an import inspection agency learns about increased risk of adulteration. An inspection agency may respond quite effectively in the long run as it observes adulteration, but in the short run it may be quite ineffective at identifying new threats. This may lead to a significant amount of adulterated products entering the importing country, like the case of melamine tainted dairy products from China in 2007.

As economic conditions motivate the adulteration of a food product, economic variables may therefore play a role in forecasting risks of adulteration. I model the adulteration of food by exporting firms that select between two inputs of different qualities. The two inputs are perfect substitutes in production but the low quality input is an adulterant such that its use is not permissible in the importing country. Exporting firms substitute the high quality input by the low quality input to save on input costs. The probability of detection of adulteration of the output by import inspectors increases with respect to the quantity share of the low quality input.

Comparative statics shows that adulteration occurs in predictable ways with respect to shifts in demand for imports and shifts in input supplies in the exporting country. This highlights the role for economic variables in risk assessment by inspection agencies, in particular with respect to forecasting the risks adulteration. Economic variables can be used as leading indicators that new threats will soon appear. For instance, by monitoring prices, an inspection agency can then identify threats even before they materialize in imports because of lags between production and change in prices. The gain for an inspection agency is in the short-run when information about new threats is most valuable. In the long run, an inspection agency can learn about adulteration by observing high rates of rejection or obtaining information from other inspection agencies.

I show application of the model using US imports of seafood from China. The numerical solutions show that a small change in an economic variable can cause a significant change in the quality of imports. The model also provides a framework to build future empirical analyses of import refusals data. However, empirical investigation of food import quality is still limited by the availability of inspection data. The main econometric challenge is to find suitable instruments for import inspection effort over time.

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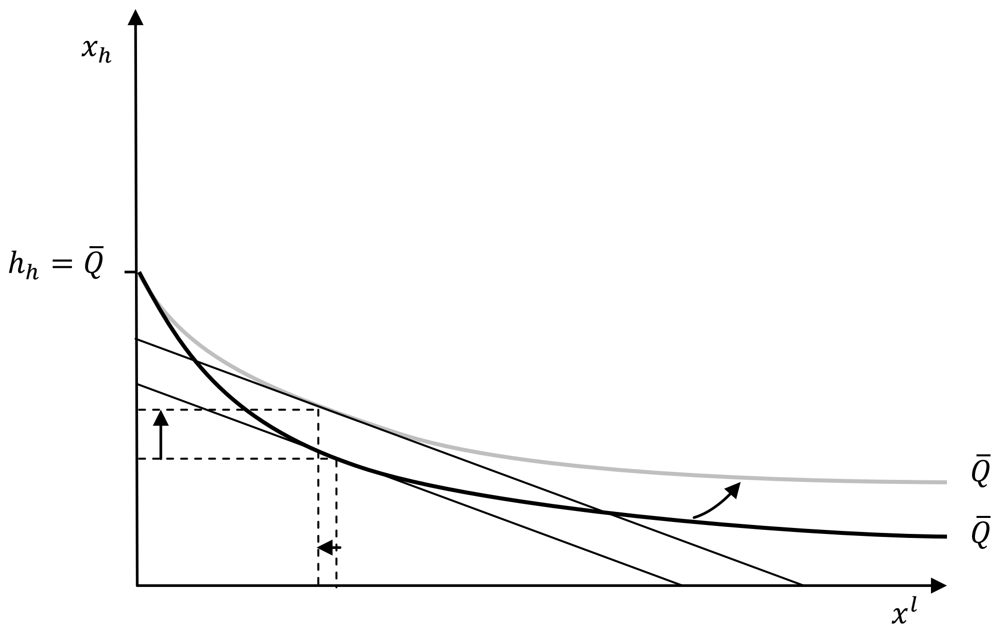
Figure

Figure 1: The effect of an increase in inspection rate on the isoquant for the expected output



Note: The two lines are isoquants for the same expected output $\bar{Q}$. The gray line embodies a higher inspection rate than the isoquant in black.

Table

Table 1: Definitions of parameters

Parameter	Expression	Definition
η	$\frac{dQ}{dP}\frac{P}{Q} \le 0$	Price elasticity of output demand.
ε^{j}	$\frac{dx^{j}}{dw^{j}}\frac{w^{j}}{x^{j}} \ge 0$	Price elasticity of supply for input j.
s	$\frac{x^{h}}{x^{h}+x^{l}}$	Share of the high quality input in the total quantity of input.
τ	$\frac{w^{h}x^{h}}{w^{h}x^{h}+w^{l}x^{l}} \ge 0$	Expenditure share of the high quality input.
σ	$\frac{Q_{h}Q_{l}}{Q_{hl}Q} > 0$	Elasticity of substitution between inputs of quality h and l.
ρ	$\frac{dQ}{dr}\frac{r}{Q} = \frac{-r(1-f)}{1-r(1-f)} < 0$	Expected output elasticity with respect to inspection intensity.
θ^{h}	$\frac{dQ_{h}}{dr}\frac{r}{Q_{h}} = \frac{r\left(f_{h}q-(1-f)q_{x}\right)}{Q_{h}} \gtrless 0$	Marginal product elasticity of the high quality input with respect to inspection intensity.
θ^{l}	$\frac{dQ_{l}}{dr}\frac{r}{Q_{l}} = \frac{r\left(f_{l}q-(1-f)q_{x}\right)}{Q_{l}} < 0$	Marginal product elasticity of the low quality input with respect to inspection intensity.
φ^{s}	$\frac{df}{ds}\frac{s}{f} > 0$	Elasticity of deception with respect to the share of the high quality input.
φ^{e}	$\frac{df}{de}\frac{e}{f} > 0$	Elasticity of safety with respect to relative quality parameter.
π	$\frac{dQ}{de}\frac{e}{Q} = \frac{re}{\left(1-r(1-f)\right)}\frac{\partial f}{\partial e} > 0$	Expected output elasticity with respect to the relative quality of the high and the low quality inputs.
ϕ^{h}	$\frac{dQ_{h}}{de}\frac{e}{Q_{h}} = \left(q_{x}f_{e}+qrf_{he}\right)\frac{e}{Q_{h}} < 0$	Elasticity of marginal product of the high quality input with respect to the relative quality of inputs.
ϕ^{l}	$\frac{dQ_{l}}{de}\frac{e}{Q_{l}} = \left(q_{x}f_{e}+qrf_{le}\right)\frac{e}{Q_{l}} > 0$	Elasticity of marginal product of the high quality input with respect to the relative quality of inputs.
α	$\frac{dQ}{dP}\frac{dP}{da}\frac{da}{a}$	Output demand shifter. If positive then the demand shifts up.
β^{j}	$\frac{dx^{j}}{dw^{j}}\frac{dw^{j}}{db^{j}}\frac{db^{j}}{b^{j}}$	Shifter for the supply of input j. If positive then the supply shifts down.

Table 2: Expressions and signs of percentage changes

Shock	**Expressions**		**Signs**	
	Ex^h	Ex^l	Ef	EIR
Er	$\frac{\varepsilon^h\left(\rho\left(\sigma+\varepsilon^l\right)+\theta^h\left(\eta\left(\sigma+\varepsilon^l\tau\right)-\varepsilon^l\sigma(1-\tau)\right)+\theta^l\varepsilon^l(1-\tau)(\sigma+\eta)\right)}{D}$	$\frac{\varepsilon^l\left(\rho\left(\sigma+\varepsilon^h\right)+\theta^l\left(\eta\sigma-\varepsilon^h+(1-\tau)\right)+\tau\varepsilon^h\theta^h(\sigma+\eta)\right)}{D}$	+	?
α	$\frac{\varepsilon^h\eta(\varepsilon^l+\sigma)}{D}>0$	$\frac{\varepsilon^l\eta(\varepsilon^h+\sigma)}{D}>0$	-	?
β^h	$\frac{\varepsilon^h\left(\eta\sigma+\varepsilon^h\left(\eta\tau-\sigma(1-\tau)\right)\right)}{D}>0$	$\frac{\varepsilon^h\varepsilon^l(\eta+\sigma)\tau}{D}$	+	?
β^l	$\frac{\varepsilon^h\varepsilon^l(\eta+\sigma)(1-\tau)}{D}$	$\frac{\varepsilon^l\left(\eta\sigma+\varepsilon^h\left(\eta(1-\tau)-\sigma\tau\right)\right)}{D}>0$	-	+
Ee	$\varepsilon^h\frac{\sigma\left(\pi+\eta\phi^h\right)+\varepsilon^l\left(\pi-\sigma(1-\tau)\left(\phi^h-\phi^l\right)+\eta\left(\tau\phi^h+\phi^l(1-\tau)\right)\right)}{D}$	$\varepsilon^l\frac{\sigma\left(\pi+\eta\phi^l\right)+\varepsilon^h\left(\pi+\sigma\tau\left(\phi^h-\phi^l\right)+\eta\left(\tau\phi^h+\phi^l(1-\tau)\right)\right)}{D}$	?	?

where $D=-\sigma\left(\varepsilon^l(1-\tau)+\varepsilon^h\tau-\eta\right)+\eta\left(\varepsilon^l\tau+\varepsilon^h(1-\tau)\right)-\varepsilon^l\varepsilon^h<0$. + indicates a positive change, - indicates a negative change and ? indicates that the sign is undetermined.

Table 3: Parameter values for US imports of seafood from China

Parameter	Values
Assumed values	
η	-5
ε^h	0.50
ε^l	20
s	0.90
τ	0.98
σ	25
f	0.95
r	0.05
γ	0.90
Calculated values	
e	0.4460
ρ	-0.0025
θ^h	$7.2 \text{x} 10^{-6}$
θ^l	-0.0257
φ^s	0.4750
φ^e	0.0425
π	0.0020
ϕ^h	$-1.2 \text{x} 10^{-5}$
ϕ^l	0.0208

Table 4: Results of numerical solutions – in percent

EQ	*EP*	Ew^h	Ew^l	Ex^h	Ex^l	*Ef*	*EIR*
Deepwater Horizon: 2% increase in excess demand							
1.26	1.75	1.76	1.00	0.88	19.98	-0.91	20.03
Antibiotic crisis: increase in China supply of high quality input							
21.59	-4.32	-4.37	-1.92	22.82	-38.39	2.91	-38.54
Increases safety standard in China – no shift in supply							
0.12	-0.02	-0.02	0.22	-0.01	4.40	0.64	-11.74
Increases safety standard in China – shift down in supply							
-0.88	0.18	0.14	2.53	0.07	-49.38	3.20	-65.66