On the Economics of Adulteration in Food Imports:
Application to US Fish and Seafood Imports

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On the economics of adulteration in food imports: application to US fish and seafood imports[*]

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Abstract

This essay shows the role of economics in the adulteration of food imports. The mechanism of impact in the model is the choice of input quality by exporting firms. One implication of the model is that economic variables can be used to predict adulteration in food imports. The essay offers an application to US fish and seafood imports following the closing of fisheries in the Gulf of Mexico because of the Deepwater Horizon platform oil spill. Simulations show an increase in adulteration in fish and seafood imports after the Deepwater Horizon incident. Empirical evidence support simulations' findings.

Cet essai démontre l'existence de motivations économiques derrière l'adultération des importations de produits alimentaires. Le mécanisme d'impact utilisé dans le modèle est le choix de la qualité des intrants par les firmes exportatrices. Une implication du modèle est que des variables économiques peuvent être utilisées pour prédire des changements dans l'adultération des importations. L'essai met en évidence une application du modèle quant aux effets sur les importations américaines de poisson et de fruits de mers causés par la fermeture des pêches dans la Golf du Mexique suite à l'explosion des la plateforme Deepwater Horizon en avril 2010. Des simulations du modèle montrent que la fermeture des pêches dans le Golf du Mexique serait responsable d'une augmentation des cas d'adultérations dans les importations de poisson et de fruits de mer. Une analyse empirique supporte les résultats des simulations.

Key words: Adulteration, Food Safety, Inspection, Trade

JEL classification: Q18, F1, L15

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Adulteration is any act, whether intentional or accidental, that renders an article other than of the quality that a purchaser is presumedly expecting. 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 sickness or death in thousands of pets (FDA 2007). 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 lead in toys, glycerin contaminated with diethylene glycol, French truffles mixed with Chinese truffles and low quality titanium used in medical implants. What is common with these examples is the economic motives 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.[1]

Food safety incidents originating from 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 FDA in monitoring imports (FDA 2011b). The document describes trends in imports and new challenges and possible solutions to more effectively monitor imports. FDA identifies economic forces through the globalization of markets as a source of increased risk. In addition to monitoring imports, FDA monitors 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 FDA the power

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[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.

to refuse the entry of products coming from foreign facilities from which FDA was denied access .

The strategy outlined by FDA (2011b) 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. FDA identifies economic forces as a source of increased risk for imports, but paradoxically, 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 conditions and increased risk of adulteration in food imports. I consider an application of the model to US imports of fish and seafood. Simulations of the model predict the incidence on fish and seafood imports of the closing of fisheries in the Gulf of Mexico after the oil spill cause by the sinking of the Deepwater Horizon platform. Examination of import refusals data validate simulation results.

The discussion of the model applies to food, but applications to drugs or other products are possible with slight modifications. The model can apply to 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 follow by providing background information about the inspection of food imports. I then present the model and show simulations of the model of the effects the Deepwater Horizon incident on US imports of fish and seafood. Finally, I provide empirical evidence of the effects of the Deepwater Horizon spill on fish and seafood imports and then conclude.

Related literature

This paper relates to many strands of the economic literature including crime, product quality, product safety and trade. However, the link to any previous work is not immediate and covering all related literature is outside of the scope of this paper. I offer below a very brief summary of what I consider key elements of relevant economic literature.

Alsberg (1931) defined the concept of adulteration at a time when the adulteration of food products was a much more important problem than today. 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."[2] According to this definition, accidental or intentional contamination or any undisclosed modifications of a food product constitutes adulteration. In the United States, the Federal Food, Drug, and Cosmetic Act of 1938 provides an official definition of adulteration. The definition 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.

An extensive literature investigates accidents and safety, including (e.g. Brown 1973; Cooter 1991; Shavell 1984). In contrast to most of the economic literature on safety, my model focuses on intentional adulteration of products when firms seek to capture a rent by selling a product that does not meet regulatory standards. In this context, one can think of the inspection of food imports as a game between the

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[2]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.

exporting firms 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) and counterfeit (e.g. Grossman and Shapiro 1988b,a). In all of these economic problems, a group of agents seeks to capture a rent by intentionally committing illegal actions or hiding information.

With the recent access to import refusal data, the empirical literature on food imports inspection has been growing. Import refusal 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 due to adulteration, 33 percent for misbranding and 2 percent for other violations. The most common type of adulteration was filth.

Recently, economists have developed econometric models to explain import refusals. Baylis, Martens, and Nogueira (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 the number of refusals. Baylis, Nogueira, and Pace (2010) and Grant and Anders (2011) estimate the trade diversion and deflection effects of import refusals.[3] 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

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[3]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.

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methods of inspection. 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, 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 2011b). From 2002 to 2009, the number of shipments that FDA oversees increased at a 13 percent annual rate. In 2010, FDA physically inspected two one percent of all imports (FDA 2011a, p. 383).

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. 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 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. 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 these standards apply to imports. 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 FDA finds that a product is in violation, it issues an import alert for the product and its manufacturer such that all future imports of the product, from that specific manufacturer, are detained without physical examination. To end an import alert and resume trading, importers have the burden of showing that corrective actions were implemented

and that their product is not in violation. For shipments already denied entry, the importer can provide evidence that the product does comply with US requirements. The importer may alternatively choose to export the product elsewhere or destroy a shipment that is refused entry.

A model of import adulteration

The model describes the economics of adulteration in food imports. 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. These systems perform better in the long-run and provide little help in predicting the emergence of new threats and are often able to detect new risks of adulteration only after their occurrence. The role for economics that the model emphasizes is in providing additional information about new risks when traditional risk assessment model are most likely to fail. That is, within the time frame that it typically takes for inspection systems to detect new risks of adulteration. As such, the model applies to the short run and assumes that the inspection effort for a product is exogenous.

The model below is tailored to fit simulations of US imports of fish and seafood in the next section. It is however possible to generalize the model to other products by simple modifications to the production function, the number of inputs and the types of inputs. It is also possible to adapt the model so that it applies to the inspection of domestic food production.

The model

The model builds upon the structure 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

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agricultural subsidies in a supply chain using Muth's model. My use of Muth's model differs significantly from the conventional applications of the model.

The model assumes that food imports follow legal channels and thus ignores smuggling of food. The penalties for failing border inspection take the form of losses in revenues as the inspection agency seizes the product and blocks future entry until demonstration that the product is compliant. I can model these losses either from a reduction in the price or as a loss in output. 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 assumptions in Brown (1973) and Pouliot and Sumner (2008) in models of product safety. 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 exports, 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 assumptions in the model in Muth (1964).[4]

The model assumes that the production of the food product requires one input. Exporting firms, such as manufacturers in the foreign country, can source inputs from two channels. One channel offers inputs of high quality that meet the standards of the importing country. The second channel offers low quality inputs that do not meet

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[4]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.

all the standards specific to the importing country. Differences in standards across destination countries are common and one good example is drug residues in aquaculture. For instance, GAO (2011) reports that FDA has approved maximum residue limits in aquaculture for five drugs; others drugs not being allowed. In contrast, the EU has approved maximum residue limits in aquaculture for 32 drugs. Japan, China and Vietnam have also approved maximum residue limits for more drugs than the United States.[5] The standards for drug residues effectively differentiate input suppliers between those that meet US drug residues limits and those that do not meet those limits. In addition to maximum drug residues, the United States also requires HACCP certification in seafood (Anders and Caswell 2009). The HACCP requirements further increase the differentiation between input suppliers.

The two types of input are perfect substitutes in the sense that output quantity remains constant when substituting one unit of the high quality input with one unit of the low quality input, and vice versa. The model assumes that the high quality input always meet the standards of the import country while the low quality input does not meet all of those standards. Consistent with the definition of adulteration by Alsberg (1931), the use of the low quality input constitutes adulteration. Let me denote x^h the quantity of a high quality input and let me denote by x^l the quantity of the low quality input used by an exporting firm. What matters in producing a quantity of output is the total quantity of input $x^h + x^l$. The total output of the exporting firm is $q(x^h + x^l)$, where the production function $q()$ exhibits constant return to scale.[6] The simulations in the next section apply to US imports of fish and seafood. In that context, the high quality input represents fish and seafood that meet US production standards. The low quality input represents fish and seafood that do not meet US

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[5]GAO (2011) only discusses the number of a maximum residue limits and the not the levels of those limits.

[6]It is straightforward to generalize the model and allow inputs to enter the production as imperfect substitutes. The limiting assumption for the derivation of the model is that the production function exhibits constant return to scale.

production standards. Although in appearance the types of inputs may be physically identical, they may differ significantly with respect to their safety.

Deception is an essential feature of adulteration as, otherwise, an adulterated product would always be rejected by the border inspection agency. In the model, deception is possible because inputs of different qualities are substitutes and their relative quantities do not affect the physical appearance of the product. 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, both consumers and inspectors have imperfect abilities 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 detection technologies that are too costly for for the average consumer. For example, inspectors can run lab test for drug residues in seafood or test for melamine in dairy products while these tests are too expensive for most consumers.

The function $f = f(x^h, x^l) \in (0, 1]$ is the probability that one unit of product cannot be identified as adulterated by inspectors at the border. That is, the function f is the probability that one unit of food is deceptive as it appears to inspectors to meet standards in the importing country. 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 probability function f, but, however,

firms do not know whether an inspector will be able to detect adulteration for one specific unit of product, if inspected.[7]

The probability function f is homogenous of degree zero with respect to the ingredient quantities, increases with respect to the quantity of the high quality input, $\partial f/\partial x^h > 0$, and decreases with respect to the quantity of the low quality input, $\partial f/\partial x^u > 0$. To simplify the application of the model later in the text, let me assume that the function f depends on the quantity share of the high quality input such that $f = f(s)$, where $s = x^h/(x^h + x^l)$ is the share of the high quality input.[8]

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. I assume here that inspections do not vary in intensity. In practice, FDA conducts only a limited number of laboratory testings and most inspections consist of reviewing paperwork and organoleptic inspection.[9] The model assumes that the inspection rate is exogenous. This contrasts with, in practice, border inspections agency adjusting their inspection efforts to information about threats. Risk assessment systems, however, tend to use past inspection reports to identify new risks and therefore new threats may go unnoticed until a random inspection detects a new source of risk. Thus, the model with an exogenous inspection rate, applies to the short-run when risk assessment systems are more likely to fail at identifying new threats.

What matters to risk-neutral exporting firms in maximizing their profits is their expected quantity of output that enter the importing country.[10] I assume that

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[7]A possible addition to f is the relative quality of the inputs. For example, one can write $f = f(x^h, x^l : e)$ where the parameter e captures the ability of a border inspection agency to detect adulteration. The parameter e may increase because of the introduction of new inspection technologies.

[8]The assumption that f is a function of s is similar to the saying that "the dose makes the poison."

[9]The inspection rate depends on FDA resources and the number of shipments. FDA determines the number of laboratory testings based on risk and its financial resources. In fiscal year 2009, FDA tested about 0.1 percent of seafood imports for drug residues (GAO 2011).

[10]Assuming risk-neutral firms allows to derive the model using the same assumptions as in Muth (1964). Allowing for risk aversion would not change qualitatively the results but would reduce the rate of adulteration.

the inspection agency never rejects an adulterated product that does not appear as adulterated and never accepts a product, if inspected, that appears adulterated. I normalize the return to the exporting firm to zero when a shipment is rejected.[11] Thus, I can write the expected output that passes inspection as

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

The expression for the total output assumes that exporting firms know 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 publicly available.[12]

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.

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

$$(1) \quad f = \left(\frac{x^h}{x^h + x^l} \right)^\gamma = s^\gamma,$$

with $\gamma \in (0,1]$ to assure quasi-concavity of the production function. The parameter γ captures the fact that the ability of inspectors to detect adulteration may be a nonlinear function. Assume that the production function is $q = x^h + x^l$. With the

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[11]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 or destroyed and the cost of the importing firm.

[12]For instance, the Canadian Food Inspection Agency readily makes available its inspection requirements using the AIRS system (CFIA 2011).

functional forms for f and q, the expected export simplifies to

(2) $\quad Q = (1 - r(1 - s^\gamma))(x^h + x^l).$

Expression (2) illustrates that Q is the expected export as $(1 - r(1 - s^\gamma))$ is the probability that one unit of output crosses the border and $x^h + x^l$ is the total production.

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 $\bar{Q} = x^h$. 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 $\gamma < 1$, which implies convex isoquants.[13]
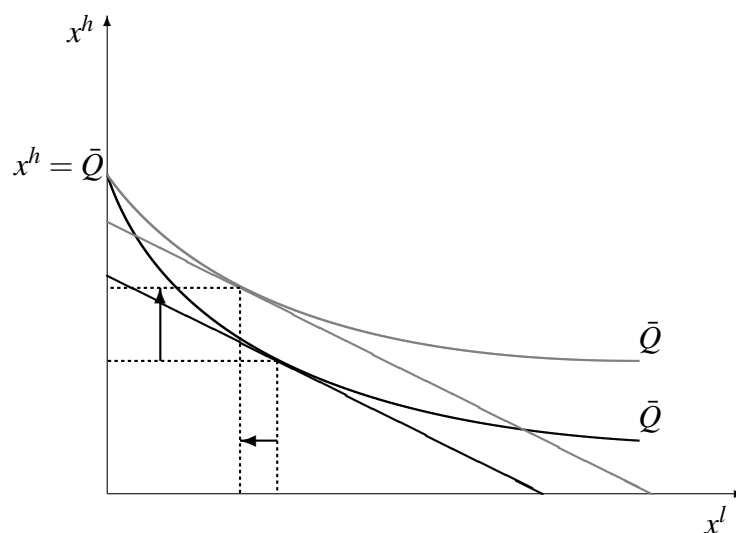
Note: The two lines are isoquants for the same expected output $\bar{Q}$. The gray line embodies a higher inspection rate than the isoquant in black.

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

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 $\bar{Q}$. The black line assumes a low rate

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[13]With $\gamma = 1$ (not shown), low and high quality inputs are perfect substitutes in Q such that isoquants are linear despite of the difference in input qualities.

of inspection and the gray line assumes a higher rate of inspection. The tangency between the isocost line and the isoquant determines the quantity of the low and the high quality input. Thus, when the border inspection service examines imports at a greater rate, the exporting firms must use a larger share of the high quality input to export the same quantity.

The demand for imports is the total demand net of domestic production in the importing country. I denote the demand function by $Q = D(P : a)$, 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.[14]

Supplies of the two inputs are competitive. I denote by $x^h = g^h(w^h, b^h)$ the supply of the high quality input and denote by $x^l = g^l(w^l, b^l)$ 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. The input supplies are the supply curves that firms exporting to a specific locations face. For instance, in the case of US fish and seafood imports in the next section, the supply curves are those perceived by firms that export fish and seafood to the United States.

The shape of the high quality input supply curve depends on the relative sizes of the import and export markets and how restrictive are the standards in the importing country. If the quality standards in the importing country are stricter than in any other destinations, then the high quality input supply is inelastic. The more

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[14]The assumption that consumers do not observe adulteration is strong for products such as clothing where adulteration is 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.

the standards in the importing country are similar to those of other destinations, the more elastic is the supply of the high quality input. The low quality input represents all inputs that do not meet the standards in the importing country. As a larger quantity share of the low quality input increases the probability of refusal by the importing country, the quantity share of the low quality input should be small. In addition, the importing country is most likely to represent a small share of the total market for the product of interest. This suggests an elastic supply for the low quality input.

The model summarizes to the six following equations

(3) $Q = D(P : a)$ import demand;

(4) $Q = fq + (1-f)(1-r)q$ expected export;

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

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

(7) $x^h = g^h(w^h, b^h)$ supply of high quality input;

(8) $x^l = g^l(w^l, b^l)$ supply of low quality input.

Expressions (3), (4), (7) and (8) are described in the text above. Expressions (5)-(6) 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 of imports. I do not give details about the derivations and for more explanations, I refer readers to Muth (1964), Alston, Norton, and Pardey (1995) or Alston and James (2002).

Taking the total differential of (3)-(8), and expressing the results in terms of elasticities and percentage changes (e.g. $EX = dX/X$), the expressions for the model become:

(3') $EQ = \eta EP + \alpha$;

(4') $EQ = \tau Ex^h + (1-\tau)Ex^l + \rho Er;$

(5') $Ew^h = EP - \dfrac{(1-\tau)}{\sigma}Ex^h + \dfrac{(1-\tau)}{\sigma}Ex^l + \theta^h Er;$

(6') $Ew^l = EP + \dfrac{\tau}{\sigma}Ex^h - \dfrac{\tau}{\sigma}Ex^l + \theta^l Er;$

(7') $Ex^h = \varepsilon^h Ew^h + \beta^h;$

(8') $Ex^l = \varepsilon^l Ew^l + \beta^l.$

Table 1 summarizes the definitions the signs of the parameters in (3')-(8'). The parameter α is a demand shifter measured in the output space. If $\alpha > 0$, the demand for imports shifts to the right. The parameters β^j for $j = \{h, l\}$ are supply shifters in the quantity space. For $\beta^j > 0$, the supply of input j shifts right. Note that because the inputs are vertically differentiated, at equal input prices, the high quality input is strictly preferred to the low quality input. Accordingly, it must be that $w^h > w^l$ for $x^l > 0$. Thus, from (5) and (6) it follows that $Q_h > Q_l > 0$ and thus implying from the expressions in table 1 that $\theta^l < 0$. The sign of θ^h is undetermined and depends on the quantity share of the high quality input.

Solving the system of equations in (3')-(8') yields solutions for EQ, EP, Ex^h, Ex^l, Ew^h and Ew^l in function of exogenous shifters, elasticities and expenditure shares. I show in appendix solutions of comparative statics.

FDA reports monthly import refusals as the number of shipments that are refused entry. I can derive from the model the expected quantity of refused imports, a measure that can be interpreted as an analogue to the number of import refusals. However, before deriving the expression for the expected quantity of refused imports, let me derive an expression for the change in the probability that an inspector find one unit of imported food as adulterated.

Recall that f, the probability that one unit of output appears not adulterated to an inspector, is a function of the quantity share of the high quality input. Taking the differential of f, I can write that the percentage change in the probability that

Table 1. Definitions of parameters

Parameter	Expression	Definition
η	$\frac{dQ}{dP}\frac{P}{Q} \leq 0$	Price elasticity of import demand.
ε^j	$\frac{dx^j}{dw^j}\frac{w^j}{x^j} \geq 0$	Price elasticity of supply for input j.
s	$\frac{x^h}{x^h+x^l}$	Quantity share of the high quality input.
τ	$\frac{w^h x^h}{w^h x^h + w^l x^l}$	Expenditure share for the high quality input.
σ	$\frac{Q_h Q_l}{Q_{hl} Q}$	Elasticity of substitution between input qualities h and l.
ρ	$\frac{dQ}{dr}\frac{r}{Q} = \frac{-r(1-f)}{1-r(1-f)} < 0$	Expected export elasticity with respect to inspection rate.
θ^j	$\frac{dQ_j}{dr}\frac{r}{Q_j} = \frac{r(f_j q-(1-f)q_j)}{Q_j}$	Elasticity of marginal product with respect to inspection rate.
α	$\frac{dQ}{da}\frac{a}{Q}\frac{da}{a}$	Output demand shifter. If positive, the demand shifts to the right.
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, the supply shifts right.
φ	$\frac{df}{ds}\frac{s}{f} > 0$	Elasticity of deception with respect to the quantity share of the approved ingredient.

one unit of output appears not adulterated to inspectors is

$$Ef = \phi(1-s)(Ex^h - Ex^l).$$

That is, 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.

The percentage change in the appearance of adulteration is instructive of the quality of imports but is, however, not directly observable. What 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. The

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expected number of import refusals is

(9) $IR = (1-f)rq$

Taking the differential of (9) to find the percentage change in import refusals yields

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

Thus, the percentage change in the expected number of import refusals depends on the percentage change in the probability that one unit of food does not appear as adulterated, on the percentage change in inspection effort and on the percentage changes in input quantities.

Simulations of the effects of the Deepwater Horizon incident

As an application of the model, let me consider import of fish and seafood by the United States. Economic conditions may prove particularly important for the adulteration and inspection of fish and seafood imports. Imports represent more than 80% of fish and seafood consumption in the United States. 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). Most imports of fish and seafood originate from developing countries (Anders and Caswell 2009; Grant and Anders 2011), and fish and seafood imports represent about 20 percent of violations of imports laws enforced by FDA (Buzby, Unnevehr, and Roberts 2008).

I show using simulations how the Deepwater horizon incident affects imports as if the analysis was attempted shortly after the incident. The objective is to show an example of how the model can be used in practice to determine whether an events has the potential to significantly increase adulteration in the imports of a food product.

The Deepwater Horizon incident

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 and in an effort to keep seafood safe, the National Oceanic and Atmospheric Administration (NOAA) closed down fisheries on May 5 in several areas of the Gulf.[15] NOAA adjusted several times the areas closed to fisheries depending on the movement of the oil plume. 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).

Calibration

I use simulations of the theoretical model to measure the potential impact of the Deepwater Horizon incident on US import refusals of fish and seafood. The simulation method follows from Davis and Espinoza (1998) and Zhao et al. (2003). The basic idea is that there is uncertainty regarding the values of parameters in the model. The approach is to run sensitivity analysis by assuming a distribution on the model parameters. Then, by taking draws of the parameters, it is possible through simulations to cover the whole set of combinations of parameter values and derive distributions around outcomes of the model.

I draw independent values for the parameters of the model from affine transformations of beta distributions, $\beta(c,d) \in (0,1)$, where c and d are scale parameters. I set the value of c to five which assures in the calibration, given the mean, min and max of the parameters, that $d > 1$ such that the distribution of all parameter is bell shaped. I find the value for d using the mean of the parameter of interest. Table 2 summarizes the distribution of parameters that enter the simulation model.

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

Table 2. Parameter values for simulations

Parameter	Mean	Min	Max
α	0.02		
η	-0.70	-1.20	-0.10
ε^h	50	0	100
ε^l	∞		
γ	0.50	0.01	0.99
r	0.02	0.001	0.05
s	0.985	0.900	0.999
σ	768	44	16,280
τ	0.988	0.929	0.999

Note: The value of the shifter α is assumed fixed for all runs of the model. There is no range for the value of ε^l as it is set to a very large value in all iterations of the model. Values for other parameters of the model are not required for these simulations.

Estimates of the elasticity of demand for fish and seafood are scarce. There are however several estimates of the elasticity of demand for fish but it is often unclear whether the fish category is inclusive of seafood. Using micro-data, Lambert et al. (2006) find values for the elasticity of demand for fish of -0.47 in Central Canada, -0.74 in Atlantic Canada and -0.77 Western Canada. Although that study applies to demand for fish in Canada, its results should translate well to its US neighbor. ERS (2012) lists estimates of the elasticity of demand for fish from several sources. The average value of the price elasticity for fish in the United States from those studies is -0.29, with a minimum of -0.48 and a maximum of 0.01. In a meta-analysis, Gallet (2010) report a median price elasticity of the demand for fish of -0.8. Andreyeva, Long, and Brownell (2010) find from a review of 18 studies a mean price elasticity of demand for fish in the United States of -0.5, with a minimum of -1.14 and a maximum of -0.05.

For the simulations, I fix the value of the price elasticity of import demand based on estimates in Lambert et al. (2006), Gallet (2010), Andreyeva, Long, and Brownell (2010) and ERS (2012). The US domestic supply of fish and seafood accounts for only about 20 percent of total consumption. Thus, the elasticity of demand

for fish and seafood imports should be slightly more elastic than the total demand. Consistent with this observation and findings in the literature, I will set the mean elasticity of demand to -0.70, with a range of -0.10 and -1.20.

Estimates of elasticities of supply for high and low quality inputs do not exist. Still, with knowledge of the fish and seafood markets it is possible to narrow the values for the supply elasticities to reasonable ranges. The United States is one the destinations fish and seafood and represent a small share of the total seafood production of any country, suggesting elastic supplies. The low quality input are all fish and seafood that does not meet US standards. As the United States has stricter standards than most countries that export to the United States, e.g. with respect to drug residues and HACCP certification (GAO 2011; Anders and Caswell 2009), the supply of the low quality input should then be very elastic, even over a short period of time. For the simulations, I assume that the supply of the low quality input is perfectly elastic. The elasticity of supply for the high quality input should be less than perfectly elastic. In exporting countries, in particular in developing countries, processors can source only from a limited number of farms that follow US standards.[16] As such, the capacity to expand exports to the United States is limited, especially in the short run. In contrast, for developed countries such as Canada, expanding exports to the United States is less difficult as domestics standards are similar to those in the United States. However, US imports of fish and seafood from developed countries are a small share of total US imports of fish and seafood. Against this back drop, I assume that the elasticity of supply for the high quality input covers a wide range between 0 and 100, with a mean value of 50.[17]

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[16]In the case of fish and seafood, US standards are more constraining than standards from most other developed importing countries. If US standards were below or equal to those of other seafood importing countries, then it would be reasonable to use a perfectly elastic supply of the high quality input.

[17]In the simulations, the elasticity of supply effectively determines the length of run of the model. The length of run must be short enough such that inspection intensity does not adjust.

I can find values for the parameters τ and σ with the help of functional forms for f and q. For the function f, let me use the functional form in (1). For the value for the parameters γ, I assume a beta distribution that covers the range between 0 and 1, with a mean value of 0.5. The high and the low quality inputs enter production function as perfect substitutes such that the expression for Q is given by (2).

Finding values for τ and σ using functional forms requires values for r and s. GAO (2011) reports that FDA tested for drug residues about 0.1 percent of all seafood imports. Border inspections however vary in intensity and most inspections are organoleptic. To capture the range in inspection rate and inspection intensity, I set the average value for r to 0.02, which is the average rate of physical inspection for all food imports (FDA 2011a, p.383) for 2010, with a range between 0.001 and 0.05. The parameter s is not observable. However, I conjecture that the share of the high quality input in seafood imports should be near 1, as most seafood imports pass inspection. For the simulations, I set and average value for s to 0.985, with a range of 0.90 and 0.999.

From the definitions for s and τ in table 1, I can write that

(10) $\quad \tau = \dfrac{sw^h}{sw^h + (1-s)w^l}.$

The prices w^h and w^l are not observable. However, the high quality input should command a premium as US standards are restrictive. Let me assume that suppliers of the high quality input receive a 30 percent premium. Thus, simplifying the expression in (10) and given the range of values for s, the parameter τ varies between 0.92 and 0.999 with a mean value of 0.988.

From the functional forms for f and q, the expression for the elasticity of substitution is

$$\sigma = \frac{(1-r(1-s^\gamma(1-\gamma)))(s(1-r)) + rs^{1+\gamma}(1-\gamma(1-rs^\gamma))}{\gamma(1-\gamma)s^\gamma(1-s)(1-r(1-s^\gamma))}.$$

Given the range of values for s and r, the elasticity of substitution ranges from 44 to 16,280 with a mean of 768.

As the the supply of fish and seafood from the Gulf of Mexico represents 2 percent of US consumption of seafood, I perform the simulations assuming that US demand fish and seafood imports shifts to the right by 2 percent (i.e. $\alpha = 0.02$).

Simulation results

Table 3 shows simulation results for a total 50,000 replications. The simulations show an increase in the import of seafood slightly smaller than the shift in the import demand. The probability of not detecting adulteration in seafood import declines be about 0.10 percent. The decline of the quality of seafood imports is caused by a large increase in the quantity of the low quality input (33 percents) paired with a small increase in the quantity of high quality input (less than 2 percents). Together, the quantity and quality effects cause an average increase in the number of import refusals of 33 percents. Of the increase in the number of import refusals, using expression (**??**), 31.04 percent is caused by the decline in quality and 2.01 percent is caused by the increase in quantity of fish and seafood imports.

Table 3. Outcome of simulations for the Deepwater Horizon incident (percentage change)

	Mean	Median	s.e.	90% c.i. 5%	95%
EQ	1.97	1.97	0.01	1.95	1.99
EP	0.04	0.04	0.02	0.03	0.07
Ex^h	1.84	1.85	0.06	1.72	1.90
Ex^l	33.00	17.30	40.68	5.35	116.81
Ew^h	0.04	0.04	0.02	0.03	0.07
Ew^l	0.00	0.00	0.00	0.00	0.00
Ef	-0.09	-0.08	0.05	-0.18	-0.04
EIR	33.05	17.35	40.69	5.39	116.88

The simulations show a small but significant increase in adulteration. Keeping the rate of inspection constant, the simulations show a significant increase in the expected number of import refusals. Thus, the simulations show that although that

the closing of fisheries in the Gulf of Mexico had a small effect on demand, it was sufficient to impact the quality of fish and seafood imports.

My static model applies to a problem with dynamic aspects. The value for the elasticity of supply for the high quality input and the assumption of fixed inspection rate limit the length of run of the model. Other characteristics of the fish and seafood industry also matter. In the case of fish and seafood, which is a storable product, there are delays between the closing of fisheries and the realization of new import demand. This new demand impacts import quantities, again, with some delays as it takes time to organize new shipments. Thus, it should be after several weeks that new imports of lower quality arrive in the United States. As it may take time for FDA to detect this new risk, an increase in the import refusals should be observed several weeks after the closing of fisheries in the Gulf of Mexico.

Empirical evidence of the impacts of Deepwater Horizon incident

This section complements the simulations by showing empirical evidence of the effects of the Deepwater Horizon incident on imports of fish and seafood. The objective is not estimate a full blown econometric model that explains what drives import refusals such as in Baylis, Martens, and Nogueira (2009). Rather, the objective is to verify whether the impacts of the Deepwater Horizon incident are similar to those predicted by the simulation model and determine when these impacts occurred, if any.

FDA (2012) provides data about all shipments of food, drugs and medical devices refused entry in the United States. The data cover the period between January 2, 2002 and October 24, 2012. The dataset includes information about the country of origin, the port of entry, product code, product description and lists the charges that motivated rejection. The dataset, however, does not include information regarding the quantity and the value of products refused entry. Here, I focus on the import of

fish and seafood product, which is code 16 according to FDA industry classification system.

Between January 2, 2002 and October 24, 2012, FDA refused entry for 22,682 shipments of fish and seafood. The most common origin of refused shipments were Indonesia (3,008), Vietnam (2,931), China (2,423), Philippines (1,251) and Thailand (1,194). The most commonly refused products were shrimp (4,081), tuna (2,802), miscellaneous fish products (2,210), salmon (924) and eel (880). The most common charges were filth (8,997), *salmonella* (5,840), failure to file about scheduled process (1,550), unapproved animal drugs (1,422) and lack of registration for low acid canned food (1,060).

I aggregate the data to provide the weekly number refused shipments. This aggregation yields a time series that shows how import refusals have evolved. The count of the number of weekly refused shipments is different than the weekly quantity (e.g. by weight or volume) of refused imports but is an appropriate proxy if the number of import refusals is not correlated with import shipment size. The grey line in figure 2 shows the weekly number of import refusals for seafood. The thick black line is a smoothing of the refusals data using a Loess regression.[18] The two vertical lines in figure 2 are respectively the closing of certain areas of the Gulf of Mexico to fisheries on May 2, 2010 and the full re-opening of fisheries on April 19, 2011.

Figure 2 shows that the weekly number of import refusals for seafood was relatively stable before the closing of fisheries in the Gulf of Mexico. The number of import refusals was on average about 40 refusals per week between 2002 and 2005. The number of refusals per week then declined and remained stable at an average of about 33 refusals per week between 2006 and 2010. Shortly after the closing of

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[18]Loess regression is a class of local regression that weighs nearby variables according to their distance from the location where a regression takes place. As such, it provides a smoothing method for the weekly import refusals.
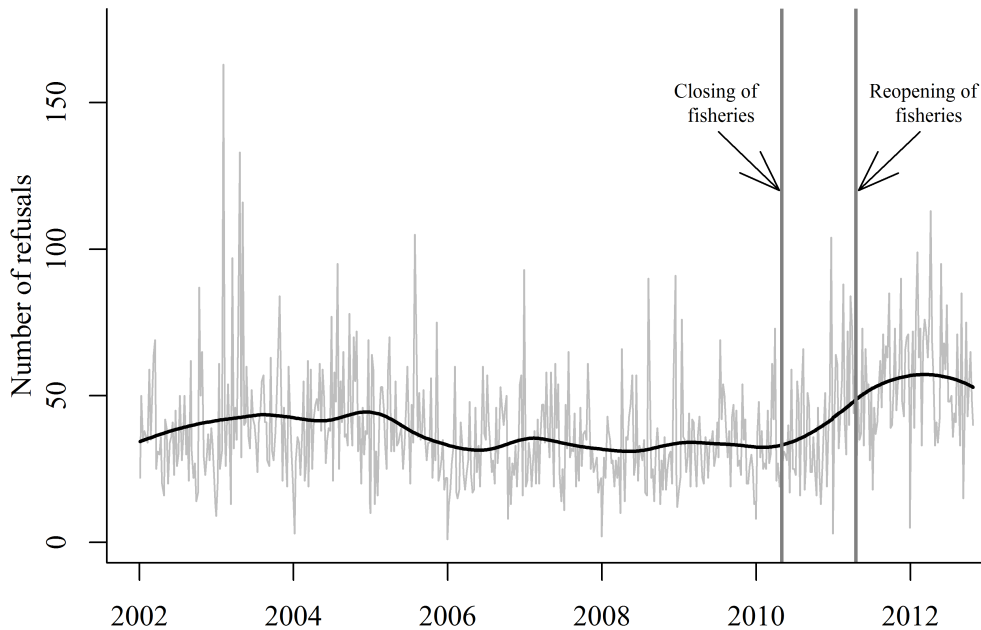
Note: The grey line is the weekly number of import refusals for seafood. The thick black line is a smoothing of the refusals data using a Loess regression.

Figure 2. Weekly number of US import refusals of fish and seafood

fisheries, the number of refusals increased and at its maximum, it averaged about 55 refusals per week.

The increase in the number of refusals occurred several weeks after the ban on fisheries, reflecting the dynamic aspects of demand, supply and inspections. The number of import refusals continued to increase well passed the resumption of fisheries in the Gulf of Mexico. This may be due to FDA increasing its oversight of seafood imports following the increase in the number of import refusals.

To provide additional evidence, I performed structural break tests on the weekly number of import refusals using the *strucchange* package in R (Zeileis et al. 2002, 2003), which implements the algorithm to find breakpoints in a time series as described in Bai and Perron (2003). Here, the procedure tests for structural breaks in the average weekly import refusals. Table 4 shows that the structural break tests find two breakpoints. The first break occurred on November 10, 2005 and is obviously

unrelated to the Deepwater Horizon incident. The second break is on December 8, 2010, with a 95% confidence interval that covers the period between September 22, 2010 and January 6, 2011. The tests outcomes fit well with graphical evidence in figure 2 and the sequence of events of the incident and its impacts.

Table 4. Structural breaks in import refusals for seafood

		95% c.i.	
	Break date	2.5%	97.5%
Break 1	2005-11-10	2005-04-28	2007-01-26
Break 2	2010-12-08	2010-09-29	2011-01-06

Note: The test for structural change was performed using the *strucchange* package in R (Zeileis et al. 2002, 2003).

Regression outcomes in table 5 show means for the weekly number of import refusals for fish and seafood in the periods delimited by the structural break tests. Before the first break in November 2005, FDA refused entry to about 41 shipments per week. The number weekly refusals of seafood shipments then decline to almost 33 per weeks until December 2010. The number of refused shipments then grew by 23 (a 66% increase) to 54 refusals per week.

Table 5. Means of seafood import refusals by period

	Mean	s.e	t value
Before 2005-11-10	41.40	1.29	32.09
Between 2005-11-10 and 2010-12-08	32.76	1.12	29.17
After 2010-12-08	54.45	1.82	29.96

Figure 2, tables 4 and 5 show evidence consistent with the outcome of the simulations for import refusals. My empirical approach does not account for other covariates that could have impacted the number of import refusals. In particular, the increase in import refusals could be due to increase in oversight by FDA of all food imports. In appendix, I show a graph of the weekly import refusals by FDA

for all food imports and test for structural break in the total food import refusals. The graph of the weekly number of import refusals for all food categories increase only slightly after the closing of fisheries. The structural break test finds a break at the end of December 2010, for which the break date is not statistically different than the break on fish and seafood import refusals. The increase in the weekly refusals of all food products is the same size as the increase in the weekly refusals of fish and seafood. This suggests that the increase in the number of refused shipments of fish and seafood was not due to an increase in FDA inspection rate for all food but by more refusals of fish and seafood.

In addition, I provide graphical evidence in appendix that the Deepwater Horizon incident had no impact on import quantities of seafood. This is consistent with the simulations that show a small increase in imports.

Summary and conclusions

The inspection of food imports has long been an issue. 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 often take the blame for the entry of adulterated product.

Border inspection agencies like FDA allocate their inspection efforts on the basis of their knowledge 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.

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 model highlights the role for economic variables in risk assessment by inspection agencies, in particular with respect to forecasting the risks adulteration. Thus, an implication is that economic variables can be used as leading indicators to detect new threats of adulteration.

The model offers a framework that can be used to identify adulteration risk for products other than food such as drugs or medical devices. With a few modifications, the model can also help guide inspection of domestic facilities.

I show an application of the model using US imports of fish and seafood after the oil spill in the Gulf of Mexico in April 2010. The simulations show a significant increase in the number of import refusals but a small increase in import quantities. Data on refusals of fish and seafood imports agree with the simulations and show a significant increase in the weekly refusals of imports a few months after the closing of fisheries in the Gulf of Mexico.

There is still much to learn about the quality of food imports. The model provides a framework to build future empirical investigations of import refusals data. The main challenge in using those data is to find suitable instruments for import inspection effort. With appropriate instruments, econometric models could provide more evidence of the role of economics in detecting adulteration in food imports.

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Appendix

A.1 Model solutions

Table A.1 shows the solutions for comparative statics. These solutions express percentage changes variables EQ, EP, Ex^h, Ex^l, Ew^h and Ew^l as functions of model shifters α, β^h, β^l, and Er.

A.2 Weekly refusals of all food products

This appendix considers the weekly number of import refusals for all food products. To limit the analysis to food imports, I use all refusals with an industry code below 45, which captures according to FDA classification system all imports of food.

Figure A.1 shows the weekly import refusals for all food products. The weekly import refusals for food follows a pattern similar to the weekly import refusals for seafood. This reflects that seafood constitutes a significant share of the refusals of food. Figure A.1 shows a small increase in the number of import refusals following the closing of fisheries in the Gulf of Mexico. The weekly import refusals increase from about 190 before the incident, to about 210 after the incident. The size of that increase in weekly import refusals corresponds to the increase in the refusals for seafood. This suggests that the increase in the number of refusals for seafood was not motivate by FDA employing more resources to monitor all food imports but rather by more refusals of seafood imports.

I performed a test for structural change using the *strucchange* package in R. Table A.2 reports the results. The statistical procedure finds only one break at the end of December 2010. The 95% confidence interval covers the period June 30, 2010 and February 10, 2012. That confidence interval overlaps the confidence interval for the structural break on import refusals for seafood (shown in table 4 in the text), bringing evidence that the breaks occurred at the same time.
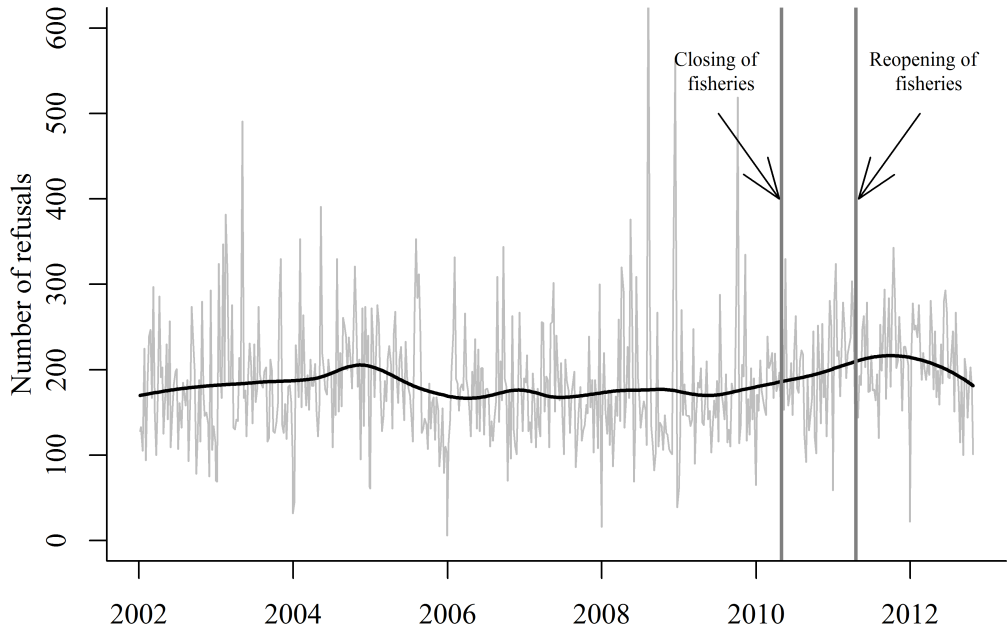
Table A.1. Solutions of comparative statics

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

$$EP = \frac{-\alpha\left[\sigma + \varepsilon^h(1-\tau) + \varepsilon^l\tau\right] + \beta^h\tau(\varepsilon^l+\sigma) + \beta^l(1-\tau)(\varepsilon^h+\sigma) + Er\left[\sigma(\varepsilon^h\theta^h\tau + \varepsilon^l\theta^l(1-\tau)+\rho) + \varepsilon^h\varepsilon^l(\theta^h\tau + \theta^l(1-\tau)) + \rho(\varepsilon^h(1-\tau)+\varepsilon^l\tau)\right]}{D}$$

$$Ex^h = \frac{\alpha\varepsilon^h(\varepsilon^l+\sigma) - \beta^h\left[\eta\sigma + \varepsilon^l(\eta\tau - \sigma(1-\tau))\right] - \beta^l\varepsilon^h(\eta+\sigma)(1-\tau) - Er\varepsilon^h\left[(\eta\theta^h+\rho)\sigma + \varepsilon^l(\rho+(\theta^l-\theta^h)\sigma(1-\tau)+\eta(\theta^l(1-\tau)+\theta^h\tau))\right]}{D}$$

$$Ex^l = \frac{\alpha\varepsilon^l(\varepsilon^h+\sigma) - \beta^h\varepsilon^l\tau(\eta+\sigma) - \beta^l\left[\eta\sigma + \varepsilon^h(\eta(1-\tau)-\sigma\tau)\right] - Er\varepsilon^l\left[(\eta\theta^l+\rho)\sigma + \varepsilon^h(\rho+(\theta^h-\theta^l)\sigma\tau + \eta(\theta^l(1-\tau)+\theta^h\tau))\right]}{D}$$

$$Ew^h = \frac{\alpha(\varepsilon^l+\sigma) - \beta^h\left[\varepsilon^l - \eta(1-\tau)+\sigma\tau\right] - \beta^l(\eta+\sigma)(1-\tau) - Er\left[(\eta\theta^h+\rho)\sigma + \varepsilon^l(\rho+(\theta^l-\theta^h)\sigma(1-\tau)+\eta(\theta^l(1-\tau)+\theta^h\tau))\right]}{D}$$

$$Ew^l = \frac{\alpha(\varepsilon^h+\sigma) - \beta^h\tau(\eta+\sigma) - \beta^l\left[\varepsilon^h + \sigma(1-\tau)-\eta\tau\right] - Er\left[(\eta\theta^l+\rho)\sigma + \varepsilon^h(\rho+(\theta^h-\theta^l)\sigma\tau + \eta(\theta^l(1-\tau)+\theta^h\tau))\right]}{D}$$

where

$$D = \sigma(-\eta + \tau\varepsilon^h + (1-\tau)\varepsilon^l) - \eta((1-\tau)\varepsilon^h + \tau\varepsilon^l) + \varepsilon^h\varepsilon^l > 0$$

Note: The grey line is the weekly number of import refusals for food. The thick black line is a smoothing of the refusals data using a Loess regression.

Figure A.1. Weekly number of US import refusals for all food products

Table A.2. Structural breaks in import refusals for all food products

	Break date	95% c.i. 2.5%	95% c.i. 97.5%
Break 1	2010-12-30	2010-06-30	2012-02-10

Note: The test for structural change was performed using the *strucchange* package in R (Zeileis et al. 2002, 2003).

Table A.3 shows means for the number of weekly import refusals for food before and after the structural break date identified in table A.2. The weekly the number of import refusals increases by about 30. That increase, is not statistically different than the increase in the number of import refusals for seafood alone. As the date of the structural breaks for seafood import refusals and all food import refusals coincide and that the change in the number of import refusals are not different, this provides evidence that the increase in the number of refusals for all food was caused by an increase in the number of refusals for seafood.

**Table A.3. Mean of food import refusals by period**

	Estimate	s.e	t value
Before 2010-12-30	180.09	3.20	56.36
After 2010-12-30	210.33	7.07	29.75

A.3 Import quantities of seafood

In addition to an increase in seafood import refusals, the simulations show a small increase in import quantities. I show in this section evidence of the impact of the Deepwater Horizon incident using monthly import data from United States International Trade Commission (USITC) from January 2002 to August 2012 (United States International Trade Commission 2012). I collected the total import quantity in thousand kilograms for HTS code 03: Fish and Crustaceans.

Figure A.2 shows monthly import quantities for fish and seafood in thousand kilograms. Import increased from 2002 to 2006 and then slightly declined until 2008. Imports then grew again to reach a peak in early 2010. Since the middle of 2010, US imports of seafood have significantly declines.

Figure A.2 shows no apparent evidence of an increase in imports following the Deepwater Horizon incident. In particular, between the closing and the reopening of fisheries in the Gulf of Mexico, the smoothing of the import quantity show stable
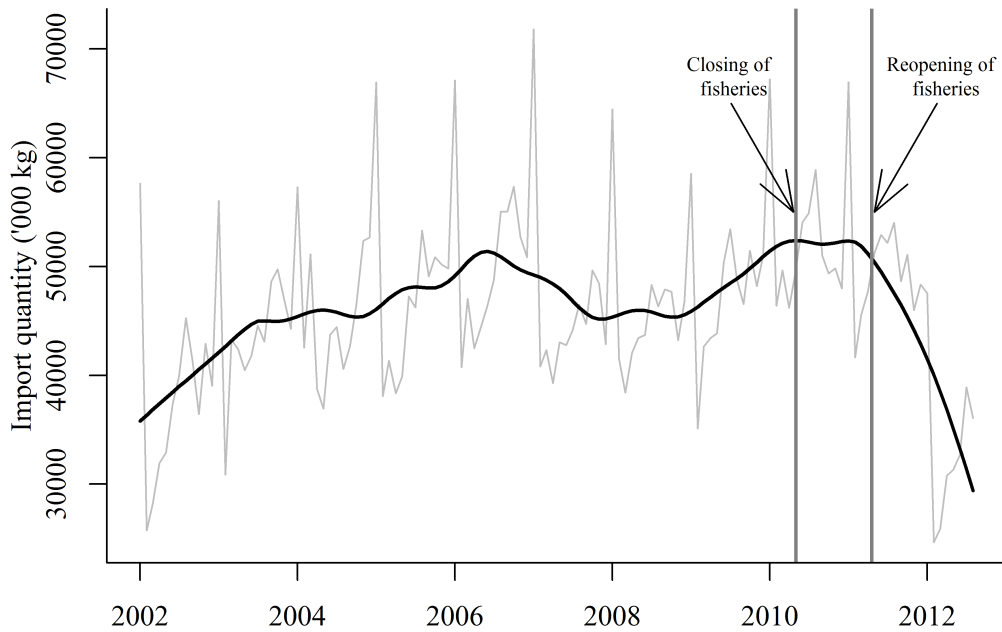
Note: The grey line is the monthly import quantities of fish and seafood. The thick black line is a smoothing of the import quantities using a Loess regression.

Figure A.2. US monthly imports of seafood ('000 kg)

imports. This is consistent with the simulations that show only a small increase in the import quantities. Observe however that imports of fish and seafood then sharply decline. This may be a response to more scrutiny by FDA of imports of fish and seafood.