Price and Welfare Effects of the Food Safety Modernization Act Produce Safety Rule

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Abstract:

Implementation of the U.S. Food Safety Modernization Act (FSMA) Produce Safety Rule is expected to cost about 1.1 percent of revenue for covered farms producing raw and minimally processed fruits and vegetables in the United States. To simulate the price and welfare effects of the rule, we develop an equilibrium displacement model for 18 fruits and 20 vegetable commodities, drawing on recent estimates of the rule's commodity-level cost of compliance. We find that consumer and farm prices increase by 0.49 and 1.46 percent respectively for fruits and 0.14 and 0.55 percent respectively for vegetables. Costs associated with the rule's implementation across these commodities are estimated to reduce producer welfare by 0.86 percent for fruits and 0.59 percent for vegetables and these estimates would not change substantially if only individual commodity groups were to enact the rule's measures unilaterally. We also compare our estimates of the cost to producers of implementing the rules with potential benefits to producers from the avoidance of outbreak costs.

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JEL codes: Q11, Q13, Q18, L51, Q17

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The 2011 passage of the Food Safety Modernization Act (FSMA) marked the most comprehensive legislative change to the authority of the Food and Drug Administration (FDA) to regulate food since the 1930s (Johnson, 2011, 2014). The law empowered the FDA to impose new regulatory requirements on food producers and handlers, to expand requirements for and inspections of imports, and to issue mandatory recalls of food. Additionally, for the first time, the FDA was empowered to regulate production practices at the farm level. While certain retailers and producer groups have independently coordinated heightened requirements for improved food safety in production (Calvin et al., 2017; Adalja and Lichtenberg, 2016), the Produce Safety Rule is broadly applicable to nearly all produce – both imported and domestically produced – that is sold fresh (unprocessed) in the United States. A detailed description and analysis of the Produce Safety Rule can be found in Anonymous (2017).

The costs of compliance with the FSMA Produce Safety Rule are substantial, decreasing as a share of revenue, and variable across commodities. This suggests that implementing the Produce Safety Rule will have differential effects across different types of producers and important implications for the relative prices of foods sold at retail. This article uses retail grocery store data at the national level to estimate demand systems for 18 fresh-fruit and 20 fresh-vegetable commodities affected by the FSMA Produce Safety Rule. Using existing estimates of supply elasticities, farm prices as shares of retail prices, and the compliance costs of FSMA as they vary by farm size (Anonymous, 2017), we then estimate cost pass-through and welfare effects of the Produce Safety Rule. Fruit and vegetables are often thought to be substitutes for each other at the commodity level, suggesting that specific commodity groups that independently implemented commodity-specific food-safety practices could lose welfare when consumers substituted to other commodities that were relatively lower in price. We find that the offsetting benefits associated with substitution in demand are small in magnitude and that any benefit a commodity group might gain from exemption from the Produce Safety

Rule would stem primarily from avoiding the direct costs of compliance rather than through the higher prices of other fruits and vegetables. Along with Bovay and Sumner (2017), this article is the first to analyze the economic implications of FSMA implementation.

The next section of this article gives background on the FSMA Produce Safety Rule and the economics of food-safety regulation. We then outline the models used in the simulation analysis. Next, we describe the data used to simulate supply shifts, the data used for demand system estimation and the demand system estimation itself. Finally, we describe simulated effects on prices and welfare and discuss their implications of our analysis.

Background

The Food Safety Modernization Act was signed into law in early 2011, and the FSMA Produce Safety Rule is one of several major rules developed by FDA as a consequence of the legislation. In this section, we describe the regulatory requirements of the Produce Safety Rule and discuss the economic literature on food-safety regulation.

The FSMA Produce Safety Rule

Since the passage of FSMA in 2011, its potential effects on both costs for small farms and market structure have been much discussed, although it has not been studied extensively in the economics literature. The Produce Safety Rule imposes costs on growers by mandating practices to curtail microbial contamination of fresh produce in five main areas: (1) testing of agricultural water, (2) use of biological soil amendments, (3) requirements regarding worker health and hygienic practices, (4) prevention of animal intrusion, and (5) documentation of sanitary standards. Compliance with the Produce Safety Rule will be required beginning in January 2018 for growers of covered commodities with annual food sales of more than \$500,000. Rquirements for smaller growers are phased in 2019 or 2020.[1]

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[1] Growers of sprouts from beans or seeds were required to implement the Produce Safety Rule starting in January 2017.

In its Regulatory Impact Analysis, FDA (2015b) estimated somewhat disaggregated costs of compliance by farm size. After accounting for exemptions, the FDA estimates suggest that the costs of compliance to be 6.8 percent for very small, 6.0 percent for small farms, and 0.9 percent for large farms, as defined by the value of sales (Anonymous, 2017).[2] By definition, large farms have a greater value of sales than small farms, so the Produce Safety Rule is estimated to cost only 1.1 percent across all farms (Anonymous, 2017). However, the differential effects of compliance, across farm sizes and commodities, are expected to have important effects on prices and market structure.

Farms producing fruits or vegetables that will undergo processing that mitigates microbial pathogen risk are exempted from most elements of the Produce Safety Rule, as the "kill step" obviates the need for the Produce Safety Rule's measures, which are primarily oriented towards controlling microbial growth. Similarly, the rule applies only to raw agricultural commodities (RACs).[3] While RACs included most fruits, certain vegetables (including asparagus, beets, and sweet corn) were exempted on grounds that they are "rarely consumed raw in the United States" FDA (2015a, p. 37).[4]

While consumers bear the direct effects of food-safety problems that lead to illnesses, food-safety risks are affected by the actions of multiple agents in the food supply chain (along with the actions of consumers themselves). Because the producers', processors', and handlers' actions cannot be easily determined by observing the final product, moral hazard is possible at multiple points in the supply chain (Hölmstrom, 1979; Cooper and Ross, 1985; Starbird, 2005b,a). Further complicating analysis is the potential for consumer behavior to offset risks introduced at the farm-level, for example by washing or cooking raw ingredients. Peltzman (1976) emphasized that in cases where multiple agents (upstream and downstream)

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[2] Farms with less than $25,000 in fresh produce sales, along with farms selling locally with sales less than $500,000, were excluded from coverage.

[3] RACs are agricultural commodities primarily consumed in a raw state.

[4] Proposed and revised versions of the Produce Safety Rule in 2013 and 2014 led to predictable discussions of goods to be added or removed from the list of exemptions. Commodities removed from the list of exempted commodities included: artichokes, Brussels sprouts, plantains, and several root vegetables (e.g., parsnips, taro, turnips, and yams). Commodities added to the list of exemptions included: dates, dill, peppermint, pecans, sour cherries, and several types of beans (navy, black, and great Northern).

can affect the risk associated with end product use, mandating safety measures for upstream producers can cause downstream agents to reduce risk-mitigating behavior. For instance, consumers may be less likely to cook or throw out old produce items if they believe the probability of illness has been reduced by actions taken by farmers or processors.[5] While the reduced need for offsetting behavior is a potential consumer benefit, it may also lead to an over-estimation of the effect of regulations on the number of illnesses if such estimation assumes that consumer behavior did not change following implementation of a regulation (Miljkovic, Nganje, and Onyango, 2009).

Winfree and McCluskey (2005) described how the food-safety reputation of a commodity or industry can act as a common-property resource and how a food-borne illness outbreak associated with one good or brand might potentially depress demand for a related one. Spillovers of demand shocks appear to be common within produce, especially when traceability is poor and misidentification of the outbreak's source is possible.[6] Calvin (2004) noted that, following a 1996 foodborne ilness outbreak, the CDC initially warned consumers against consuming strawberries from California only to later attribute the source of the outbreak to raspberries from Guatamela. The European Union paid €210 million ($250 million) for damages incurred by Spanish vegetable farmers following EU officials incorrectly implicating those industries in an outbreak later attributed to German sprouts (Reuters, 2011). In a similar manner, U.S. tomato farmers were implicated in a 2008 *Salmonella* outbreak later attributed to sprouts (Arnade, Kuchler, and Calvin, 2013). In each of these cases, producers of otherwise safe products suffered severe demand decreases and large monetary losses from outbreaks ultimately attributed to other producers (in fact, producers of entirely different commodities). As consumers begin avoiding commodities thought to be unsafe, they may substitute to similar commodities (thought to be safe). In particular, Arnade, Calvin, and Kuchler (2009) found that alternative leafy greens (e.g., bulk lettuce) were shock substitutes,

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[5] Triple-washed salad greens are an illustrative example.

[6] For this reason, the FSMA mandated that the Government Accountability Office study mechanisms for compensating producers harmed by FSMA-authorized FDA recalls later found to have incorrectly identified the source of an outbreak.

in that demand for the alternatives increased as consumers avoided buying spinach in the wake of an *E. coli* outbreak in 2006.

For these reasons, some fruit and vegetable producers and retailers have developed food safety plans independently of FDA regulation to improve consumer quality assurance. These plans are typically voluntary in nature and, in some cases, may be widely subscribed to among segments of producers. For instance, approximately 99 percent of California producers subscribed to the Leafy Greens Marketing Agreement developed in response to the 2006 spinach outbreak (Calvin et al., 2017). Adalja and Lichtenberg (2016) found that producer organizations are more likely to adopt food-safety guidelines if their members represent a larger share of the market or have recently experienced a negative food-safety event. Unfortunately, the tendency for food-safety measures to be adopted after outbreaks or recalls complicates understanding how observable food-safety investments affect unobservable food-safety perceptions (and the related effect of perceptions on demand).

Even if the demand for a commodity is entirely unaffected by food-safety actions of other producers, an exempted commodity group may still benefit from the enactment of comprehensive safety rules mandated for other producers through simple price effects that encourage potential substitution to similar, but now relatively lower-priced, commodities. Under these same conditions, commodity groups that undertake such measures would benefit from comprehensive enactment of the Produce Safety Rule because it mitigates the potential for substitution effectsinduced by changes in relative prices. In light of these potential substitution effects, this paper presents estimates of both the value of each commodity's potential exemption from the Produce Safety Rule and the benefit producers of each commodity gain from the rule's comprehensive enactment, relative to a unilateral producer-group decision to adopt equivalent private standards.

The Benefits of Food-Safety Regulation

While costly from a production standpoint, the Produce Safety Rule directly benefits consumers by reducing the likelihood and severity of food-borne illness. The Centers for Disease Control and Prevention attributed 46 percent of food-borne illnesses with a known food vehicle in the period 1998–2008 to produce (Painter et al., 2013). Total costs of food-borne illness—including hospitalization, loss of life, lost wages, and discomfort—are estimated to cost \$3,360 per case and \$36 billion annually (Minor et al., 2015). Most of these direct costs of illness are borne by consumers because liability-based lawsuits are often difficult to establish and outbreaks often cannot be directly traced to their source (Buzby, Frenzen, and Rasco, 2001; Buzby and Frenzen, 1999).

In its comparison with different scenarios for the Rule's costs, the FDA's Regulatory Impact Analysis only assessed human health benefits arising from averted illness as a result of safety measures mandated by the Produce Safety Rule, not market effects to producers. In practice, however, the Produce Safety Rule is also likely to provide some benefits to producers by reducing demand disruptions, recall costs, and liability costs and increasing consumer quality assurance. Parsing the linkage between the objective risks of food-borne illness associated with a food and consumers' subjective assessments of that food's value and desirability is a difficult process. Across foods, differences in the risks of food-borne illness are small and difficult to distinguish. Consumer risk preceptions are unlikely to change under ordinary circumstances but shocks, in the form of recall announcements or media attention, may cause large and likely disproportionate demand responses that recede over time.[7] A large literature finds that, in general, consumer demand and related output prices fall in response to negative media coverage (Mazzocchi, 2006; Carter and Smith, 2007; Piggott and

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[7] In the absence of a food safety shock, consumers' willingness to pay for a specific product's improved safety may be difficult to distinguish from separate but distinct quality and brand features. Following a food safety event, however, consumers likely overweight more readily available (i.e., more recent and proximate) information in forming expectations of the (health) risk (see Kahneman, 2011, p. 316). The reduced consumer demand that follows a food-safety event can vary in scope and duration, often for idiosyncratic reasons. Characterizing food safety as a common-property resource does not preclude the idea that food safety investments affect demand by mitigating the size and scope of demand shocks.

Marsh, 2004; Marsh, Schroeder, and Mintert, 2004), but that the size and duration of such shocks varies.[8]

Producer costs, however, extend beyond demand and price effects to include liability, recall or other costs. While recalls became more common across all foods (including fruits and vegetables) between 2004 and 2013, Page (2017) argued that this increase is more likely due to improvements in technologies and practices (such as faster detection methods and more frequent safety audits) and legal changes than due to declines in the underlying safety of foods. Recalls of fresh produce are far more likely (92 percent) than meat, poultry and seafood recalls (40 percent) to be caused by bacterial contamination (e.g., *Salmonella*, *Listeria moncytogenes*). Notably, fruit and vegetable recalls spiked in 2012 following *Salmonella* outbreaks in cantaloupe and imported mangos.

Public data on the size and frequency of liability payments is sparse, but available sources suggest they are small relative to the size of total damages (Buzby and Frenzen, 1999; Buzby, Frenzen, and Rasco, 2001). A distinct literature estimates the size and duration of decreases in company valuations following food safety events, a method that conceptually should factor in all forms of producer costs (Lusk and Schroeder, 2002; Thomsen and McKenzie, 2001; Wang et al., 2002; Salin and Hooker, 2001).[9] The same event study methodology has, conversely, been used to estimate the value to companies of implementing FSMA itself. Using data on stock-market returns for large food companies following signing of the FSMA legislation, Johnson and Lawson (2016) suggested that the expected costs of compliance with

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[8] For produce markets in particular, Arnade, Calvin, and Kuchler (2009) found that leafy greens are shock substitutes in that consumers substituted towards lettuce and other leafy green vegetables following the well-publicized 2006 *E. coli* outbreak in spinach and that retail expenditures on bagged spinach decreased 20 percent over a 68-week period. Rejesus, Safley, and Strik (2014) and Bovay and Sumner (2017) applied these findings to estimate the value to blackberry producers of technology that prevents food-borne illness outbreaks and to model demand responses to food-borne illness outbreaks in the fresh-tomato market, respectively.

[9] While recalls can mitigate larger retail liability costs when products are known to be unsafe, the size and scope of a recall may act as a signal of the size of the underlying food-safety risk. Pouliot and Sumner (2012) find that food traceability investments that limit the size and scope of recalls and its associated demand shocks. While ex post producer liability costs of foodbourne illness shift the incidence of damages from producers to consumers, Pouliot and Sumner (2008) find that traceability increases the incentives for firms to improve food quality and safety by increasing liability costs.

FSMA exceeded expectations about benefits to firms through increased demand.

Modeling Setup

We use estimates of the commodity-level costs of compliance with FSMA to develop estimates of the welfare effects and cost pass-through of 18 fruits and 20 vegetables. Specifically, we our model to estimate market conditions before and after the producers undertake costs associated with the rule. To characterize demand, we estimate a two-stage Quadratic Almost Ideal Demand System (QUAIDS) model (Banks, Blundell, and Lewbel, 1997). In the first stage, consumers choose between a fruit aggregate, a vegetable aggregate and a numeraire good. In the second stage, consumers choose between individual fruit and vegetable options respectively. To isolate the effects of the increase in costs, we initially assume that the demand for goods is unaffected by the regulation. To characterize supply, we draw on estimates of wholesale shares of retail prices from the USDA Economic Research Service (Stewart, 2006) and farm-level commodity supply elasticities from various sources. The welfare effects and the extent of cost pass through can be inferred directly from the estimates of the market equilibria before and after the rules are enacted. We then compare our estimates of the producer costs of the Produce Safety Rule to estimates of producer benefits of the rule in terms of reduced demand disruptions .

Equilibrium Displacement Model

Equilibrium displacement models (EDMs) have wide application within applied policy analysis, including analysis of the economic effects of agricultural policies, to allow for comparative static analysis of a market event across upstream and downstream elements of the supply chain (see, e.g., Wohlgenant, 1989; Davis and Espinoza, 2000; Alston et al., 2007; Okrent and Alston, 2012). First, an initial market equilibrium is assumed to hold across the linked markets under consideration where supply and demand relationships are explicitly specified. Next, a reduced form of the model is derived, typically by translating key supply and demand relationships to more easily manipulated elasticity relationships. Then, a exogenous market shock, policy or restriction is simulated to show how the equilibrium moves from an initial state to new state after the shock. Finally, relevant welfare or policy metrics are developed which describe the event.

With our model, we assume that each retail food (Q) requires two production inputs, farm-level (unprocessed wholesale) food (X) and marketing inputs (MI). For instance, to sell an apple at the retail level, a grocery store purchases wholesale apples from farmers and marketing inputs (store space, shelving, cashier labor, electricity, advertising, delivery trucks, etc.). We consider N goods within our model and the one-to-one correspondence allows N to index retail food (Q_N), wholesale food (X_N), and the specific marketing input requirement of retail food (MI_N). The prices of Q_N, X_N, and MI_N are denoted respectively as P_N, W_N, and PMI_N, all being $N \times 1$ in dimension. The A_N term captures any potential demand increase associated with food being safer for having adopted the FSMA mandated measures.

For retail food, we define the demand function as Q_N^D in (1) and the cost function as C_N in (2), where constant average costs are assumed for each good. Furthermore, if retail markets are competitive, price equals average cost, which implies the latter expression in (2). For wholesale foods, define the demand function as X_N^D in (3) and the supply function as X_N^S in (4). As an input, wholesale food's demand function can be defined as the derivative with respect to W of the retail food cost function in (2). The assumption that markets are competitive and that price equals costs at the retail level fixes the retail surplus at the constant level of zero.

The added costs of implementing FSMA regulations for wholesale producers is modeled as a percentage reduction in the prices farmers receive at the wholesale level, h_n. For example, if the cost of implementing FSMA regulations is 2.7% for watermelons, then farmers receive 97.3% of the prices paid (W). Hence, we define wholesale food supply X_N^S as a function of W_N and h_N. For marketing inputs, we define the demand function as MI_N^D in (5) and the supply function as MI^S in (6). Like the demand for individual wholesale foods, the demand for marketing inputs is the derivative of the retail food cost function in (2) with respect to PMI. The supply of marketing depends solely on PMI. These equations are, collectively:

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\begin{aligned}
Q_N^D &= Q_N^D\left(P_N, A_N\right) && \text{Retail Food Demand} && (1)\\
C_n &= c_n\left(W_n, PMI\right) \times Q_n && \text{Retail Food Cost} && (2)\\
P_n &= c_n\left(W_n, PMI\right) && && \\
X_n^D &= \frac{\partial c_n}{\partial W_n} \times Q_n && \text{Wholesale Food Demand} && (3)\\
&= g_n\left(W_n, PMI\right) \times Q_n && && \\
X_n^S &= X_n^S\left(W_n\left(1-h_n\right)\right) && \text{Wholesale Food Supply} && (4)\\
MI_n^D &= \frac{\partial c_n}{\partial PMI} \times Q_n && \text{Marketing Input Demand} && (5)\\
&= h_n\left(W_n, PMI\right) \times Q_n && && \\
MI^S &= MI^S\left(PMI\right) && \text{Marketing Input Supply} && (6)
\end{aligned}
$$

Appendix A shows how equations (1) through (6) can be represented in terms of elasticities and cost shares following total differentiation. Specifically, where:

η_N are the Marshallian demand elasticities for retail food (Q),

γ_N are the Hicksian demand elasticities for the inputs (X),

γ_{MI} are the Hicksian demand elasticities for the marketing input (MI),

ε_N are the elasticities of wholesale food supply, and

s_N are the cost shares of X in the production of Q.

To reorganize equations (1) through (6) into matrix form, denote $d\ln$ as the change in a variable's log value (so that $d\ln P = \frac{dP}{P}$, $d\ln Q = \frac{dQ}{Q}$, and so on). Let β_N be an $N \times 1$ matrix with each element equaling $\beta_n = \ln(1-h_n)$ where h_n is the percentage cost shift for commodity n. For simplicity, we assume that $\partial Q_n^D / \partial A_n = 0$ for all commodities and that the supply of marketing inputs is perfectly elastic (a specification that allows us to eliminate an equation from the matrix solution). These rearrangements of equations (1) through (6) and assumptions yield equations (7) through (11):

$$d\ln Q_N - \eta_N d\ln P_N = 0 \tag{7}$$

$$d\ln P_N - s_N d\ln W_N = 0 \tag{8}$$

$$d\ln X_N - \gamma_N d\ln W_N - d\ln Q_N = 0 \tag{9}$$

$$d\ln X_N - \varepsilon_N d\ln W_N = \varepsilon_N \beta_N \tag{10}$$

$$\gamma_N d\ln W_n + d\ln Q_N - d\ln MI_N = 0. \tag{11}$$

Additionally, where σ is the elasticity of substitution between X_N and MI for each Q_N, γ_n and γ_{mi} can specified as $-\left(1-s_n\right)\sigma_{MI}$. Equations (7) through (11) can then be represented as $AZ = D$ where:

$$A = \begin{bmatrix} I_N & -\eta^N & 0_N & 0_N & 0_N \\ 0_N & I_N & 0_N & -s_N & 0_N \\ -I_N & 0_N & I_N & \left(I_N - s_N\right)\sigma_n & 0_N \\ 0_N & 0_N & I_N & -\varepsilon_N & 0_N \\ -I_N & 0_N & 0_N & \left(I_N - s_N\right)\sigma_{MI} & I_N \end{bmatrix},$$

$$Z = \begin{bmatrix} d\ln Q_N & d\ln P_N & d\ln X_N & d\ln W_N & d\ln MI_N \end{bmatrix}', \text{ and}$$

$$D = \begin{bmatrix} 0 & 0 & 0 & \varepsilon_N\beta_N & 0 \end{bmatrix}'.$$

Each element in A is itself an $N \times N$ matrix while each element in Z and D are $N \times 1$. In our model, the FSMA regulations cause the β terms to shift from 0 to $\ln\left(1-h_n\right)$. The solution for Z is obtained as:

$$Z = A^{-1} \times D. \tag{12}$$

The solution for Z provides can be used in conjunction with the initial equilibrium (Q_0,

P_0, X_0, W_0, and MI_0) to calculate new equilibrium retail quantities ($(1 + d\ln Q) \times Q_0$) and prices ($(1 + d\ln P) \times P_0$), wholesale (farm) quantities ($(1 + d\ln X) \times X_0$) and prices ($(1 + d\ln W) \times W_0$), and marketing inputs ($(1 + d\ln MI) \times MI_0$).

Welfare Changes

The new equilibrium values are also used to calculate the welfare changes in terms of the (retail) consumer surplus (CS_n) and (farm) producer surplus (PS_n). Our assumption that the supply of marketing inputs is perfectly elastically supplied precludes the possibility of a marketing input supplier surplus. The general formulas for the producer and consumer surplus are:

$$\begin{aligned} dCS_n &\approx P_{0,n} d\ln P_n \times (Q_{0,n} \times (1 + 0.5 d\ln Q_n)) \\ &\approx E_{0,n}(d\ln P_n \times (1 + 0.5 d\ln Q_n)) \qquad (13) \\ dPS_n &\approx W_{0,n} \times (d\ln W_n - h_n) \times (X_{0,n} \times (1 + 0.5 d\ln X_n)) \\ &\approx R_{0,n} \times (d\ln W_n - h_n) \times (1 + 0.5 d\ln X_n), \qquad (14) \end{aligned}$$

where $E_{0,n}$ is consumer expenditure for the n^{th} good ($P_{0,n} \times Q_{0,n}$) and $R_{0,n}$ is farm revenue from the n^{th} good. Summing across all N goods, equations (13) and (14) yield:

$$\Delta CS_N \approx E_{0,N} \sum_N (w_n \times (d\ln P_n \times (1 + 0.5 d\ln Q_n)) \qquad (15)$$

$$\Delta PS_n \approx \sum_N R_{0,n} (d\ln W_n - h_n)(1 + 0.5 d\ln X_n), \qquad (16)$$

where $E_{0,N}$ is consumer expenditure across all N goods ($P_{0,N} \times Q_{0,N}$) and w_n is the average share of consumer expenditure for the n^{th} goods.

Cumulatively across all goods, the change in consumer surplus as a share of all consumer spending ($cs \approx \sum_n dCS \times E$) and producer surplus as a share of all farm revenue ($ps \approx$

$\sum_n dPS \times R$) are:

$$\Delta cs \approx \sum_N -(d\ln P_n \times (1 + 0.5d\ln Q_n)) \tag{17}$$

$$\Delta ps \approx \sum_N ((d\ln W_n - h_n)(1 + 0.5d\ln X_n)). \tag{18}$$

Cost Pass-Through

For an individual commodity, the cost of implementing FSMA on farms is borne by both retail consumers, who pay higher prices, and farm producers, who incur additional costs not recouped through increased demand. Specifically, the shares of that price increase transmitted to consumers and producers are CPT and FPT, or:

$$CPT_n \approx d\ln P_n/h_n \tag{19}$$

$$FPT_n \approx -d\ln W_n/h_n. \tag{20}$$

Typically, CPT will be smaller than FPT as the potential of consumer substitution away from a good further mutes the initial price change. However, in some cases, substitution effects may potentially cause demand substitution to a particular good. As a matter of theory, CPT can be greater than FPT.

Valuing Exemptions and Comprehensive Implementation

As discussed, a few dozen produce commodities are considered “rarely consumed raw” and are, consequently exempted from the Produce Safety Rule. We estimate the change in producer surplus if commodities were to be exempted from coverage under the Produce Safety Rule. We also estimate the producer surplus loss from the full implementation of the FSMA Produce Safety Rule, across all commodity groups, relative to the unilateral decision of a single industry to require that its members adopt FSMA-like food-safety standards.[10]

The value to producer group n of (a counterfactual) exemption from FSMA is calculated as the difference between the change in producer surplus when setting $h_n = 0$ (while leaving the other costs shift values unchanged) and the change in producer surplus under β. Specifically, the value of an exemption (VE) for commodity n is:

$$VE_n = \Delta PS_n(\beta_{\beta_n=0,\cancel{n}} = \beta_n) - \Delta PS_n(\beta). \tag{21}$$

If similar fresh fruits and vegetables are substitutes, then the value of the exemption, in terms of the change in producer surplus, will exceed the savings in costs associated with compliance. If substitute commodities are covered by the FSMA Produce Safety Rule, their prices would rise upon implementation and demand for the exempt commodities would increase.

For similar reasons, comprehensively enacting FSMA regulations across all commodities will have a small negative impact on producer welfare (compared to the unilateral adoption of similar standards) if substitution effects are strong. Formally, the value of comprehensive enactment (VCE) for each producer group n is:

$$VCE_n = \Delta PS(\beta) - \Delta PS_n(\beta_n = \beta_n | \beta_{\cancel{n}} = 0). \tag{22}$$

In our estimation section, we discuss how the VC and VCE terms are identical owing to the independent and linear substitution effects.

Parameters Used for Simulating Supply Shifts

To simulate shifts in the supply of produce commodities as a result of implementing FSMA, we draw on estimates of the costs of complying with FSMA, estimates of farm price shares

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[10] See Bovay (2017) for discussion of the collective adoption of food-safety standards in the absence of federal regulation.

of retail prices, estimates of price elasticities of supply, and estimates of elasticities of substitution in supply. We now describe these estimates.

Farm Costs of Implementing the FSMA Produce Safety Rule

The FDA's Regulatory Impact Analysis (FDA, 2015b) estimates differences in compliance costs between farm sizes, but not between commodities. In our simulations, we use new estimates of the recurring costs of complying with FSMA as they vary by commodity, developed by Anonymous (2017) based on FDA's estimates by farm size. Using detailed data from the USDA National Agricultural Statistics Service's 2012 Census of Agriculture, Anonymous (2017) first calculated the share of each regulated farm's acreage used for growing each produce commodity. Then, assuming that each commodity's distribution of acreage is equal to the distribution of production across farm sizes, Anonymous (2017) estimated average costs of implementing the Produce Safety Rule, by commodity, based on the distribution of farm size (sales) for each commodity. Anonymous (2017) noted that compliance costs will differ based on each commodity's current state of food-safety practices which depends on local idiosyncrasies, state laws, and agreements already in place between producer groups or producers and retailers, and that FDA's cost estimates may therefore be overestimates.

Table 2 shows the estimates the cost of implementation for the 18 fruits and 20 vegetables considered in this study, which enter our model as h_n (see equations 4 and 5). Among vegetables, the three varieties of lettuce (romaine, leaf, and head) have the lowest implementation costs at 0.3 to 0.4 percent of revenue while snap beans and sweet corn have the highest, at 3.2 percent.[11] Among fruits, honeydew has the lowest cost of implementation, at 0.7 percent, while mangos and pears have the highest at 6.1 and 4.9 percent, respectively. Table 2 also indicates the share of the domestically consumed good that is imported and whether the commodity is covered or exempted from the final Produce Safety Rule. *Our later simulation framework discusses the value of exemptions for specific commodities.*

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[11] Costs are estimated as a share of revenue; perfect competition is assumed in the simulation analysis that follows.

Cost Shares

To estimate the share of the retail commodity's costs that is derived from the cost of wholesale agricultural costs, we divide the wholesale price by the retail price index. We obtain wholesale prices from the USDA's Agricultural Marketing Service while retail prices are calculated as a weighted average of observed prices within our IRI InfoScan retail scanner dataset. Table 2 provides estimates of these cost shares. In general, our shares are higher than those found by Stewart (2006). By construction, the share of the retail price attributable to marketing inputs is the residual share $(1 - s_n)$ in our two-input production function.

Elasticities of Supply

To parameterize the elasticity of supply and the elasticity of input substitution, we reviewed the extant literature. While supply elasticities have been estimated for many of the goods we consider, estimation methods and the data used within the analyses vary considerably across goods. For instance, a common method for estimating supply response is to regress current production of the commodity on an estimate of the expected price, which is itself based on lagged prices. These specifications are typically specific to the region or country and can be sensitive to modeling choices on how price expectations are formed.

Then, this relationship can be used to determine the amount that supply changes in response to a change in the expected average price both in the short run and the long run. Estimated values of supply elasticities vary considerably, as seen in Tables 3 and 4. For example, supply elasticity estimates for carrots range from 0.02 to 6.67. Because of the tremendous variation in estimated supply elasticities and concerns about the reliability of these estimates, we conducted our simulations with three different values for the elasticity of supply (high, medium, and low values), and used the same values for multiple commodities rather than applying the commodity-level estimates from the literature.[12] Orchard and certain perennial vegetables (asparagus and artichokes) often require several years before

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[12] cf. Bovay and Sumner (2017).

they begin bearing. For these crops, we used 0.8, 0.5, and 0.2 as the high, medium, and low values of the supply elasticity. Annual crops can potentially show quicker adjustment to the price changes. For annual crops, we used 1.0, 0.7, and 0.4 as the high, medium, and low values of the supply elasticity. Tables 3 and 4 detail our specifications for these different scenarios.[13]

Elasticities of Substitution in Supply

To our knowledge, only Wohlgenant (1989) has systematically estimated the elasticity of substitution between agricultural commodity production and marketing inputs for vegetables, and only for vegetables as a broad aggregate category. Instead, analysts using EDMs often assume that marketing inputs and wholesale commodities are used in fixed proportions which implies that the elasticity of substitution is zero (see, e.g., Okrent and Alston, 2012). Besides making the models tractable, the fixed proportions assumption is intuitively appealing: selling one retail apple require one wholesale apple as an input. However, fixed proportions in production is a limiting case, and any departure from it ($\sigma > 0$) will tend to make the wholesale demand for the commodity more elastic and dampen the retail-level price increase of a FSMA cost shift. We assumed the elasticity of substitution (σ) was 0.54 for all vegetables (based on Wohlgenant, 1989) and 0 for all fruits.

Demand Model and Data

We use IRI InfoScan retail scanner data to estimate the elasticities of demand for goods in our model using a two-stage budgeting model. In the first stage, consumers allocates total expenditures between the fruit group, the vegetable group, and a numeraire good. In the second stage, consumers allocate fruit and vegetable expenditures to products within 18 fruit categories and 20 vegetable categories. In each stage, we estimate the QUAIDS model

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[13] We assume that all cross-price elasticities of supply are zero so that all the off-diagonal elements of ε_N are zero.

(Banks, Blundell, and Lewbel, 1997).

IRI Store Panel Data

Fruit and vegetable sales data come from the IRI InfoScan retail scanner data that the USDA Economic Research Service (ERS) acquired to support its food market and policy research. Our sample covers 65 quadweeks (i.e., 4-weekly periods) between January 6, 2008 and December 29, 2012. In InfoScan, there are 65 markets and 8 standard whitespaces (i.e., remaining areas). We dropped the Green Bay, WI market from the sample due to insufficient retail data for the study period. This gives a balanced panel dataset with 4,680 market-quadweek observations. The InfoScan dataset at ERS contains barcode-level point of sale data. Some retailers provided sales data at the store level but others only at the Retail Market Area (RMA) level.[14] We aggregate store-level data to the IRI market level. For RMA-only retailers, IRI reports the number of stores and addresses under each RMA. To impute IRI market-level sales for these retailers, we divided RMA-level sales by the number of stores to get average sales per store and allocate RMA sales to each IRI market based on the number of stores the retailer has in each IRI market.

Fruit and vegetable items in InfoScan are recorded with or without per-unit weight information. Items without the weight information are called random-weight items. To impute volume sales for a random-weight item, we divided its dollar sales by the price of a similar nonrandom-weight item from the same market and time period. This method assumes that random-weight items have the same price as their nonrandom-weight counterparts. Although imperfect, this seems to be the only feasible method for including random-weight produce scanner data into a demand analysis. Summary statistics on the data used in our demand estimation are provided in Tables 5 and 6.

To reduce the unit value bias (Deaton, 1988), we created a Fisher-Ideal price index for each fruit and vegetable category. The Fisher-Ideal price index is a superlative index that

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[14] The exact RMA definition varies from one retailer to another but a typical RMA contains a cluster of counties.

approximates the true cost of living index for a class of expenditure function (Diewert, 1976). This allows us to account for within-category product substitution without explicitly estimating a product-level demand model for each fruit and vegetable category (Zhen et al., 2011). We constructed the Fisher-Ideal price index for category j in market m and quadweek t:

$$p_{mjt} = \sqrt{\frac{\left(\frac{\sum\left(p_{mkt}q_{k0}\right)}{\sum\left(p_{k0}q_{k0}\right)}\right)}{\left(\frac{\sum\left(p_{mkt}q_{kmt}\right)}{\sum\left(p_{k0}q_{kmt}\right)}\right)}}, \tag{23}$$

where p_{mkt} and q_{mkt} are the price and per capita sales volume of product k in market m and quadweek t, respectively, and p_{k0} and q_{k0} are the base price and per capita volume of product k set at their sample means. Within each category, we defined product at the brand (name brand, no brand, private label), organic (organic, nonorganic), and type (canned, fresh, frozen) levels. This yields a maximum of 18 unique products within a category. The actual number of products vary across categories because not all fruits and vegetables are available canned or frozen.

Demand Model

Compared with the almost ideal demand system (AIDS), the QUAIDS model has more flexible Engel curves but retains the exact aggregation property of AIDS so that market-level data can be used to make inferences about consumer behavior. The conditional budget share equation within the fruit group is:

$$w_{mit} = \alpha_{mit} + \sum_{j=1}^{n}\left[\gamma_{ij} \times \ln p_{mit} + \beta_i \frac{\ln x_{mt}}{a(p_{mt})}\right] + \frac{\lambda_i}{b(p_{mt})} \times \left[\ln\left[\frac{x_{mt}}{a(p_{mt})}\right]\right]^2, \tag{24}$$

where w_{mit} is the expenditure share of fruit category i in market m and time t, p_{mit} is the price index of category j, n is the number of fruit categories within the group, x_{mt} is total fruit expenditure, and α, γ, β, and λ are parameters. The $a\left(p_{mt}\right)$ and $b\left(p_{mt}\right)$ terms are defined as:

$$\ln\left(a\left(p_{mt}\right)\right) = a_0 + \sum_{i=1}^{n}\left(a_{i,0}\right) \times \ln\left(p_{mit}\right) + 0.5\sum_{i=1}^{n}\sum_{j=1}^{n}\left[\gamma_{ij}\ln\left(p_{mit}\right)\ln\left(p_{mjt}\right)\right] \tag{25}$$

and

$$b(p_{mt}) = \prod_{i=1}^{n} {p_{mit}}^{\beta_i}, \tag{26}$$

respectively. We assume the intercept α_{mit} to be a linear function of market and seasonal fixed effects as

$$\alpha_{mit} = \alpha_{i0} + \sum_{i=2}^{72}\alpha_{il} \times market_{ml} + \sum_{r=2}^{13}\alpha_{ir} \times season_{tr}, \tag{27}$$

where $market_{ml}$ and $season_{tr}$ are dummy variables for market l and the r^{th} time period within a year, respectively.

Demand Estimates

Appendix Tables 1, 2, and 3 provide estimates of the parameters used in the QUAIDS and the EDM.[15] Tables 7, 8, and 9 provide the own- and cross-price elasticities of our demand model for fruits, vegetables and the commodity aggregates, along with the expenditure elasticities. In these tables, the diagonal terms (in bold font) are the own-price elasticities of demand and are all of the expected sign (negative) for normal goods. Appendix Tables 4 and 5 provide the standard errors for the elasticity estimates.[16]

For all fruits and vegetables considered in our analysis, income elasticities are positive but less than one, indicating that these are necessities. Fruits and vegetables are substitutes where their cross-price elasticities are positive and complements where their cross-price elasticities are negative. While there is no a priori theoretical reason for why fruits or vegetables

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[15] Appendix Tables 1–6 are submitted with this manuscript in Excel format.

[16] Owing to the large panel nature of the IRI Storescan dataset, nearly every term in Appendix Tables 4 and 5 is significantly different from zero.

would necessarily be complements or substitutes, the finding that many of these goods are complements has strong implications for our analysis regarding the value of FSMA exemptions. A FSMA rule that raises the cost (and price) of substitutes for an exempted fruit or vegetable commodity would necessarily benefit producers of the exempted commodity by increasing demand for the exempted commodity. On the other hand, if fruit and vegetable commodities are often complements, then FSMA-induced cost shifts may potentially reduce the welfare of producers of exempted goods.

Simulation Results

We use the EDM framework, with assumptions about commodity-level farm and price shifts based on Anonymous (2017), assumptions about farm prices as a share of the retail dollar based on Stewart (2006), and demand parameters from the QUAIDS model to simulate market-equilibrium effects of FSMA implementation. We draw conclusions about the effects on producers, retail prices, and consumer welfare, and discuss the counterfactual welfare effects of (1) unilateral adoption of FSMA-like practices and (2) exemptions for individual commodities.

Producer Welfare Effects of FSMA Regulation Costs

Equation (14) and the market-equilibrium shifts are used to calculate the producer welfare effect under the assumption that improved food-safety outcomes as a result of the FSMA regulations do not affect the demand for regulated commodities.[17] Estimated shifts in consumer surplus are presented in Tables 10 and 11. Fruit and vegetable farmer welfare is simulated to fall by 0.86 and 0.55 percent on average, respectively. Among fruits, producer surplus

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[17] Improved food safety may also plausibly increase demand for a good. However, this (hypothesized) effect is subtle and difficult to identify. Bovay (2017) estimated wholesale demand for fresh-market tomatoes before and after members of that industry adopted Good Agricultural Practices, standards for on-farm food-safety practices that closely resemble the effect of the Produce Safety Rule, and found no evidence of increased demand for tomatoes from regions that had collectively adopted GAPs, after the date of required GAPs adoption. We know of no existing estimates of positive demand for foods grown under better food-safety practices.

losses were highest for avocados and lowest for tangerines and honeydew. Among vegetables, producer surplus losses were highest for snap beans and lowest for the three lettuce varieties (excluding the three vegetables included in our simulation analysis that were exempted from the regulations).[18] Tables 12 and 13 provide the consumer and producer welfare estimates under our alternative supply specifications for our three different values (high, middle, and low) for the elasticity of supply.

Cost Pass-Through of FSMA

To calculate the pass through of costs of FSMA compliance to consumers, we first use the EDM to calculate the effects on the variables $d \ln P$, $d \ln Q$, $d \ln W$, and $d \ln F$ from the cost shift embedded in the β term in equation (10), and then use equations (19) and (20) to calculate specific Cost Pass-Through (CPT) and Farm Pass-Through (FPT) values. These values are given for fruits and vegetables in Tables 10 and 11.

The estimated CPT varies across commodities. For the fruits in our study, farm prices rise by 63.8 percent of the farm cost of implementing the regulations while consumer prices rise 20.2 percent of the farm cost. For the vegetables in our study, farm prices rise by 49.4 percent of the farm cost of implementing the regulation while consumer prices rise by 12.2 percent of the farm cost. CPT is not calculated for asparagus, kale, and sweet corn as these vegetables were exempted from the final FSMA Produce Safety Rule.

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[18] It is important to note that our analysis does not disaggregate welfare effects for foreign and domestic producers and does not consider costs for foreign producers under the Foreign Supplier Verification Program, assuming instead that foreign producers' costs are identical to U.S. producers' costs for the same commodity. The disaggregated data on distribution of farm acreage and sales is only available for the United States, and accurate simulation of the costs of implementing FSMA in other countries, using the same methods, would have required farm-level data or gross simplifying assumptions, as in Bovay and Sumner (2017). When import shares are large, as in the cases of the fruits avocados, mangos, and bananas, and the vegetables artichokes, cucumbers, peppers, and tomatoes (see Table 2), the producer surplus loss will fall more significantly on foreign suppliers.

Value of Comprehensive Enactment and Exemptions

Producers of commodities that are exempt from the FSMA Produce Safety Rule may benefit when producers of substitute commodities face a cost increase. Under this same logic, the comprehensive enactment of the Produce Safety Rule offsets some of the producer surplus loss faced by producers of individual commodities since it causes the price of substitute goods to rise. Appendix B shows that the effect of the regulation on the new equilibrium can be decomposed into two effects. The total effect of the regulation is equal to the sum of the direct effects of the cost increase and the indirect effect from raising costs facing producers of other commodities (the comprehensive enactment effect). The value of an exemption is the total effect minus the direct effect.

Tables 14 and 15 provide estimates of the new equilibrium in the counterfactual case in which each commodity group unilaterally undertook collective standards for food safety with the same costs as the FSMA Produce Safety Rule.[19] Values for kale, asparagus, and sweet corn are omitted because they were excluded from coverage under the final Produce Safety Rule. Surprisingly, the average values for producer welfare losses are larger for both fruits and vegetables under comprehensive enactment although the difference is small. Specifically, for fruits, producer welfare falls by 0.86 percent under comprehensive enactment but 0.83 percent under unilateral enactment. Similarly, for vegetables, producer welfare falls by 0.55 percent under comprehensive enactment but 0.50 percent under unilateral enactment. The lack of a significant benefit from comprehensive enactment is explained by our finding that fruit and vegetable commodities are relatively weak substitutes and, in many cases, complements. The estimated effects of unilateral enactment on producer and consumer surplus for specific commodities are also listed in Tables 14 and 15. To the extent that the effects of unilateral and comprehensive enactment are roughly equal, these findings imply that, on average, the value of an exemption to a producer group is mostly due to the direct effect (i.e., the effect

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[19] Effects of unilateral actions on producers of other commodities were estimated to be small and are omitted from our tables owing to space constraints. These values are available upon request.

of the direct cost of the regulation) rather than substitution to consumption of relatively cheaper commodities.

Comparison of Costs and Indirect Benefits to Producers

As discussed in previous sections, we find that the Produce Safety Rule will cost producers about 0.86 percent of total revenue for fruit and 0.55 percent of total revenue for vegetables. In most cases, however, the rule provides these same producers indirect benefits by reducing the likelihood of food safety events involving recall costs, liability costs and reduced demand. If these indirect benefits outweigh the direct costs, producer groups may undertake the rule's actions voluntarily.

We use recent historical evidence on the demand response to outbreaks of food-borne illness caused by produce commodities to suggest the magnitude of public-health benefits from FSMA implementation. Between 2003 and 2012, the FDA (2015) reported an annual average of 4.8 outbreaks resulting in 629 illnesses, 104 hospitalizations and 4.5 deaths for produce commodities covered by FSMA, not including sprouts. FDA (2015b, p. 58) estimates that the Produce Safety Rule will reduce the risk of contamination for covered produce by 56.4 percent. If outbreaks occur with a 12.6 percent probability for a generic produce commodity[20] and the typical outbreak reduces producer revenue by 10 percent for one year, then the Produce Safety Rule may reduce producer losses by approximately 0.712 percent on an annual basis ($= 56.4\% \times 12.6\% \times 10\%$). If a typical outbreak reduces producer revenue by 20 percent for a year, then the Produce Safety Rule may reduce producer losses by approximately 1.424%. These values are roughly comparable to our estimates of the cost of the Produce Safety Rule, 0.86 percent for fruit producers and 0.55 percent for vegetable producers. However, outbreaks that reduce revenues by 10 or 20 percent are extraordinary events. Although Arnade, Calvin, and Kuchler (2009) found that the major outbreak of *E. coli* in bagged spinach from California in 2006 reduced expenditures on bagged spinach by

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[20] 4.8 outbreaks per year, divided by the 38 produce commodities under study in this article.

$202 million (20 percent of revenue) over the following 68-week period, event studies tend to focus on prominent and severe outbreaks for which demand effects can be readily identified. In terms of market disruption, the spinach outbreak was particularly severe because there were few actions consumers could have undertaken at home (short of cooking) that would have reduced the underlying health risk.

Conclusion

While its public health benefits are large and tangible, the requirements for on-farm food-safety practices under the Food Safety Modernization Act are expected to impose substantial costs on producers. Using new findings on the size and distribution of regulatory costs across producers, we estimate that, absent any offsetting effect on consumer demand, the implementation costs of the Produce Safety Rule will reduce producer welfare by 0.86 percent for fruit and 0.55 percent for vegetables. Commodity producers are unable to fully pass along the increased cost of production to buyers. Specifically, for fruits, farm prices are estimated to rise by 63.8 percent of the farm cost of implementing the regulation while consumer prices are estimated to rise by 20.2 percent of the farm cost. For vegetables, farm prices rise by 49.4 percent of the farm cost of implementing the regulation while consumer prices rise by 12.2 percent of the farm cost.

The comprehensive enactment of a cost-raising regulation across producers of similar goods has the potential to cause less producer welfare loss than the unilateral enactment of the same regulation by individual producers. We find this effect to be negligible for the fruits and vegetables covered by the Produce Safety Rule because specific fruits and vegetables are found to be both substitutes and complements in our estimates at the individual commodity level. For similar reasons, producers of fruit and vegetable commodities exempted from the rule primarily benefit from avoiding implementation costs rather than from shifts in demand when other commodity prices increase.

Estimating the benefits to producers of the reduced likelihood of food-safety problems once the rule is enacted is difficult. While event studies have shown that certain outbreaks caused large and prolonged demand shocks for certain commodities, these studies are selective and may not be generalizable to fruits and vegetables as a whole. Under certain assumptions on the severity and likelihood of outbreaks causing demand reductions following the rule, we find that these offsetting producer benefits may be comparable to our estimated costs in certain scenarios, supporting previous analyses that show when producer groups may voluntarily undertake efforts to improve food safety. Substantial uncertainty surrounds the estimation of producer benefits of improvements that prevent food safety events and their associated market disruptions. Understanding these effects is increasingly important as regulatory initiatives seek to ensure the safety of foods in increasingly long and distant supply chains.

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Table 1: Estimated Average Costs of Implementing FSMA by Category

	Regulatory Component	Estimated Annual Costs of Compliance	Share of Total Cost
1.	Agricultural Water	\$49m	13.70%
2.	Fertilizer Compost of Animal Origin	\$9m	2.50%
3.	Worker Health/Hygiene Measures	\$81m	22.60%
4.	Animal Intrusion Measures	\$38m	10.60%
5.	Sanitary Standards (Equip., Tools, Bldgs.)	\$59m	16.50%
6.	Recordkeeping and Other Costs	\$122m	34.10%
	Total (Excluding Sprouts Rule)	\$358m	100%

Source: FDA (2015b).

Table 2: Estimates of FSMA Produce Safety Rule Cost Shifts by Commodity

Fruit	Cost Shift	Import Share	Wholesale Cost Share	Exempt?	Vegetables	Cost Shift	Import Share	Wholesale Cost Share	Exempt?
1. Apples	2.2%	7.5%	80.98%	No	1. Artichokes	0.4%	80.5%	16.60%	No
2. Apricots	2.2%	3.5%	32.34%	No	2. Asparagus	0.0%	NA	38.24%	Yes
3. Avocados	3.5%	81.4%	33.00%	No	3. Broccoli	0.4%	19.5%	24.13%	No
4. Bananas	3.5%	99.9%	33.00%	No	4. Cabbage	1.6%	8.2%	10.15%	No
5. Cantaloupes	1.4%	43.6%	20.46%	No	5. Carrots	1.0%	15.1%	38.89%	No
6. Cherries, Sweet	2.7%	7.9%	8.78%	No	6. Cauliflower	0.4%	14.1%	63.94%	No
7. Grapefruit	1.7%	2.9%	79.44%	No	7. Celery	0.4%	6.1%	10.68%	No
8. Grapes	2.1%	46.1%	38.78%	No	8. Cucumbers	2.1%	73.5%	9.93%	No
9. Honeydew	0.7%	42.0%	19.89%	No	9. Kale	0.0%	NA	18.00%	Yes
10. Mangos	3.6%	99.9%	33.00%	No	10. Lettuce (Head)	0.3%	6.9%	15.97%	No
11. Nectarines	1.2%	8.7%	34.43%	No	11. Lettuce (Leaf)	0.4%	5.4%	10.60%	No
12. Oranges	2.2%	12.5%	78.94%	No	12. Lettuce (Romaine)	0.3%	5.4%	11.26%	No
13. Peaches	2.3%	8.7%	31.28%	No	13. Onions (Bulb)	1.7%	18.3%	53.33%	No
14. Pears	3.0%	19.8%	46.87%	No	14. Peppers (Bell)	1.3%	59.3%	14.33%	No
15. Plums	2.3%	26.9%	28.60%	No	15. Peppers (Chile)	2.6%	NA	14.33%	No
16. Strawberries	1.3%	12.6%	36.22%	No	16. Snap Beans	3.0%	31.4%	49.80%	No
17. Tangerines	1.3%	28.0%	78.94%	No	17. Spinach	0.8%	4.8%	18.00%	No
18. Watermelons	2.7%	32.9%	57.94%	No	18. Squash	2.5%	NA	12.16%	Yes
					19. Sweet Corn	0.0%	NA	20.46%	Yes
					20. Tomatoes	1.1%	52.5%	29.01%	No
Average	2.33%				Average	1.15%			
Max	3.57%				Max	4.55%			
Min	0.70%				Min	0.31%			

Sources: Anonymous (2017); Stewart (2006).

Table 3: Supply Elasticities for Fruits

Fruits	Supply Elasticities Used in Simulations			Range of Empirical Estimates	Sources
	Low	Med.	High		
1. Apples	0.2	0.5	0.8	[0.76, 1.31]	F
2. Apricots	0.2	0.5	0.8	NA	
3. Avocadoes	0.4	0.7	1	0.05	K
4. Bananas	0.4	0.7	1	NA	
5. Cantaloupes	0.4	0.7	1	[0.03, 0.17]	A,G
6. Cherries, Sweet	0.2	0.5	0.8	NA	
7. Grapefruit	0.2	0.5	0.8	NA	
8. Grapes	0.2	0.5	0.8	NA	
9. Honeydew	0.4	0.7	1	[0.20, 1.16]	J
10. Mangoes	0.4	0.7	1	NA	
11. Nectarines	0.2	0.5	0.8	NA	
12. Oranges	0.2	0.5	0.8	NA	
13. Peaches	0.2	0.5	0.8	[0.80, 1.20]	F
14. Pears	0.2	0.5	0.8	0.29	L
15. Plums	0.2	0.5	0.8	NA	
16. Strawberries	0.4	0.7	1	[0.68, 1.40]	F
17. Tangerines	0.2	0.5	0.8	NA	
18. Watermelons	0.4	0.7	1	[0.14, 0.60]	G,J

Sources:

A. Seale, Zhang, and Traboulsi (2013)
F. Onyango and Bhuyan (2000)
G. Ornelas and Shumway (1993)
J. Buxton (1992)
K. Peterson and Orden (2008)
L. Wann and Sexton (1992)

Table 4: Supply Elasticities for Vegetables

	Supply Elasticities Used in Simulations			Range of Empirical	
Fruits	Low	Med.	High	Estimates	Sources
1. Artichokes	0.2	0.5	0.8	NA	
2. Asparagus	0.2	0.5	0.8	[0.17, 1.11]	F,J
3. Broccoli	0.4	0.7	1	[0.12, 3.77]	J
4. Cabbage	0.4	0.7	1	[0.39, 0.93]	F,G
5. Carrots	0.4	0.7	1	[0.02, 6.67]	G,J
6. Cauliflower	0.4	0.7	1	[0.22, 4.35]	J
7. Celery	0.4	0.7	1	[0.10, 0.23]	J
8. Cucumbers	0.4	0.7	1	[0.14, 1.11]	F,J,H
9. Kale	0.4	0.7	1	[0.56, 0.77]	
10. Lettuce (Head)	0.4	0.7	1	[0.32, 0.39]	J,D,E,F
11. Lettuce (Leaf)	0.4	0.7	1	[1.19, 1.19]	J,D,E,F
12. Lettuce (Romaine)	0.4	0.7	1	NA	J,D,E,F
13. Onions (Bulb)	0.4	0.7	1	[0.10, 1.13]	A,G,H
14. Peppers (Bell)	0.4	0.7	1	[0.12, 3.5]	F,H
15. Peppers (Chile)	0.4	0.7	1	NA	
16. Snap Beans	0.4	0.7	1	[0.12, 0.75]	
17. Spinach	0.4	0.7	1	[0.28, 2.80]	A,F,
18. Squash	0.4	0.7	1	[0.12, 0.12]	H
19. Sweet Corn	0.4	0.7	1	[0, 1.06]	F,J,C
20. Tomatoes	0.4	0.7	1	[0.04, 0.72]	A,B,H,L, F,J,I,J

A. Seale, Zhang, and Traboulsi (2013)
B. Russo, Green, and Howitt (2008)
C. Mérel, Simon, and Yi (2011)
D. Clevenger and Shelley (1974)
E. Hammig and Mittelhammer (1980)
F. Onyango and Bhuyan (2000)
G. Ornelas and Shumway (1993)
H. Málaga, Williams, and Fuller (2001)
I. Hammig and Mittelhammer (1982)
J. Buxton (1992)
L. Wann and Sexton (1992)

Table 5: Descriptive Statistics Of IRI Storescan Data Used in Demand Estimation (Fruit)

	Per capita quantity (lb/quadweek)		Per capita expenditures ($/quadweek)		Unit Value ($/lb)		Expenditure Share
Fruits	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	
1. Apples	1.68	0.70	0.66	0.27	0.40	0.07	19.7%
2. Apricots	0	0.01	0.01	0.01	2.09	0.75	0.2%
3. Avocados	0.15	0.11	0.15	0.10	1.29	1.03	4.6%
4. Bananas	3.19	1.28	0.51	0.20	0.17	0.06	15.2%
5. Cantaloupes	0.33	0.37	0.10	0.07	0.79	1.41	3.0%
6. Cherries, Sweet	0.09	0.17	0.14	0.21	2.77	1.18	4.1%
7. Grapefruit	0.29	0.25	0.04	0.02	0.15	0.04	1.1%
8. Grapes	0.60	0.33	0.48	0.20	1.18	2.21	14.4%
9. Honeydew	0.08	0.09	0.02	0.01	0.78	1.33	0.5%
10. Mangos	0.03	0.06	0.04	0.03	3.07	2.12	1.1%
11. Nectarines	0.08	0.16	0.05	0.06	0.81	0.46	1.5%
12. Oranges	1.27	0.99	0.17	0.09	0.19	0.15	5.0%
13. Peaches	0.16	0.16	0.16	0.11	1.26	0.37	4.7%
14. Pears	0.19	0.13	0.10	0.05	0.64	0.28	2.9%
15. Plums	0.09	0.21	0.04	0.04	0.97	0.70	1.2%
16. Strawberries	0.21	0.16	0.39	0.23	2.19	0.73	11.7%
17. Tangerines	0.36	0.42	0.12	0.12	0.39	0.10	3.5%
18. Watermelons	3.05	4.50	0.18	0.19	0.21	0.20	5.5%

Table 6: Descriptive Statistics Of IRI Storescan Data Used in Demand Estimation (Vegetables)

	Per capita quantity (lb/quadweek)		Per capita expenditures ($/quadweek)		Unit Value ($/lb)		Expenditure Share
Vegetables	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	
1. Artichokes	0.01	0.01	0.02	0.02	3.02	0.75	0.7%
2. Asparagus	0.04	0.04	0.10	0.05	3.19	1.53	3.3%
3. Broccoli	0.13	0.06	0.18	0.09	1.56	0.54	6.2%
4. Cabbage	0.05	0.03	0.07	0.03	1.70	0.72	2.3%
5. Carrots	0.34	0.18	0.22	0.10	0.68	0.13	7.4%
6. Cauliflower	0.08	0.04	0.05	0.02	0.65	0.38	1.6%
7. Celery	0.06	0.03	0.11	0.06	1.74	0.55	3.6%
8. Cucumbers	0.06	0.05	0.13	0.08	2.31	0.69	4.3%
9. Kale	0	0	0.01	0.01	2.17	0.72	0.2%
10. Lettuce (Head)	0.10	0.04	0.12	0.05	1.32	0.24	4.2%
11. Lettuce (Leaf)	0.02	0.01	0.04	0.04	2.70	1.98	1.4%
12. Lettuce (Romaine)	0.04	0.02	0.09	0.05	2.54	0.48	3.0%
13. Onions (Bulb)	1.02	0.44	0.28	0.13	0.29	0.13	9.4%
14. Peppers, Bell	0.09	0.06	0.22	0.12	2.81	1.01	7.6%
15. Peppers, Chile	0.03	0.23	0.02	0.02	2.97	1.12	0.8%
16. Snap Beans	0.15	0.09	0.17	0.09	1.20	0.26	5.7%
17. Spinach	0.02	0.01	0.05	0.03	2.37	0.47	1.8%
18. Squash	0.36	1.10	0.12	0.09	2.55	1.73	3.9%
19. Sweet Corn	0.19	0.11	0.23	0.11	1.25	0.26	7.9%
20. Tomatoes	0.46	0.23	0.72	0.31	1.67	0.40	24.5%

Table 7: Unconditional Price and Expenditure Elasticities of Demand for Fruit and Vegetable Aggregate Groups

Elasticity	Fruit	Vegetable	Numeraire	Expenditure
Fruit	**-1.0746**	0.0092	0.8185	0.2469
	(0.0171)	(0.0107)	(0.0371)	(0.0278)
Vegetable	0.0105	**-1.1162**	0.9397	0.1661
	(0.012)	(0.0171)	(0.0359)	(0.0254)
Numeraire	0.0001	0.0002	**-1.0035**	1.0032
	(0.00004)	(0.00004)	(0.00011)	(0.00008)

Note: Standard errors in parentheses.

Table 8: Unconditional Expenditure and Price Elasticities of Demand for Fruits

Elasticity of Demand for	With Respect to Total Fruit Expenditure	With Respect to Price of																	
		Apples	Apricots	Avocados	Bananas	Cantaloupe	Cherries	Grapefruit	Grapes	Honeydew	Mangos	Nectarines	Oranges	Peaches	Pears	Plums	Strawberries	Tangerines	Watermelons
Apples	0.22	**-0.96**	0.6	-0.16	-0.12	-0.06	0.15	-0.09	-0.02	-0.31	-0.35	0.04	-0.09	0.31	0.03	0.05	-0.09	0.17	-0.05
Apricots	0.046	0	**-1.19**	0.01	0	-0.01	0	-0.03	0	0.02	0	0	-0.01	0	0	0	-0.01	0.02	0.01
Avocacos	0.238	-0.03	0.17	**-1.04**	-0.01	0.05	0.02	0.05	0	0.05	0.02	0.07	0.01	-0.02	0.03	-0.01	0.05	-0.03	-0.02
Bananas	0.278	-0.05	0.21	-0.02	**-0.99**	0.08	0.11	-0.03	-0.04	0.12	-0.07	0.04	-0.02	-0.16	0	-0.09	0.07	0.13	-0.14
Cantaloupes	0.292	0	-0.15	0.03	0.01	**-1.09**	0.03	0.01	-0.01	0.02	0.02	-0.09	0.01	0.01	-0.03	0	0	-0.01	-0.03
Cherries	0.137	0.01	-0.07	0	0	0.02	**-1.44**	0	0.01	-0.07	0.15	0.13	-0.01	0.05	0.02	0.03	0.03	-0.02	-0.01
Grapefruit	0.281	0	-0.16	0.01	0	0	0.01	**-1.24**	0	0.04	0	0.03	0	0.02	0.01	0.01	0	-0.01	-0.01
Grapes	0.258	0.01	0.2	0	-0.05	-0.07	0.1	0.02	**-1.04**	-0.01	0.02	-0.05	-0.03	0.03	0.01	-0.01	0.02	-0.05	-0.05
Honeydew	0.261	-0.01	0.05	0.01	0	0	-0.01	0.01	0	**-0.95**	0	0	-0.01	0	0	0.01	0	0	0.00
Mangos	0.273	-0.01	0.03	0.01	0	0.01	0.05	0	0	-0.01	**-1.12**	0.05	-0.01	0.03	-0.03	-0.02	0	0.02	0.00
Nectarines	0.211	0	0	0.02	0	-0.06	0.06	0.03	-0.01	-0.02	0.07	**-1.16**	0.04	0.01	0.03	0.01	0	-0.19	0.06
Oranges	0.248	-0.02	-0.25	0.01	-0.01	0	0.01	-0.01	-0.01	-0.11	-0.07	0.15	**-1.09**	0.04	-0.08	0.12	0.03	0.08	-0.02
Peaches	0.13	0.05	0.1	-0.04	-0.08	-0.01	0.07	0.04	-0.02	-0.02	0.13	0.02	0.01	**-1**	0.08	0.01	0.01	-0.2	0.01
Pears	0.186	0	0.06	0.01	-0.01	-0.05	0.02	0.02	-0.01	-0.01	-0.09	0.06	-0.05	0.06	**-1.03**	0.02	0	0.02	0.00
Plums	0.217	0	0.03	0	-0.01	0	0.01	0	0	0.03	-0.02	0.01	0.02	0.01	0.01	**-1**	0	-0.06	0.01
Strawberries	0.238	-0.04	-0.54	0.11	0.04	-0.03	0.16	0.02	0.01	0.06	0	0.03	0.06	0.08	0.04	0.03	**-1.22**	0.1	-0.08
Tangerines	0.459	0.07	0.38	0.02	0.06	0.01	0.04	0.01	0.02	0.03	0.1	-0.45	0.09	-0.11	0.08	-0.16	0.07	**-2.05**	0.08
Watermelons	0.31	0.01	0.31	-0.01	-0.04	-0.06	0.02	-0.03	0	0	0.01	0.22	-0.01	0.05	0.02	0.06	-0.02	0.07	**-1.12**

Table 9: Unconditional Expenditure and Price Elasticities of Demand for Vegetables

		With Respect to Price of																			
Elasticity of Demand for	With Respect to Total Vegetable Expenditure	Artichokes	Asparagus	Broccoli	Cabbage	Carrots	Cauliflower	Celery	Cucumbers	Kale	Lettuce (Head)	Lettuce (Leaf)	Lettuce (Romaine)	Onions (Bulb)	Peppers, Bell	Peppers, Chile	Snap Beans	Spinach	Squash	Sweet Corn	Tomatoes
Artichokes	0.085	**-1.26**	0.06	-0.02	-0.03	0.05	-0.09	0.01	0.02	0.57	-0.01	0.07	0.03	0	-0.02	0.03	-0.05	-0.01	-0.02	0.06	-0.01
Asparagus	0.158	0.26	**-0.95**	-0.02	0.01	-0.01	-0.01	0.01	-0.02	0.1	0	0.05	-0.04	-0.02	0.01	0.03	-0.02	-0.02	-0.03	-0.03	0.01
Broccoli	0.145	-0.17	-0.04	**-0.95**	0	0	-0.21	-0.1	-0.01	0.4	0.02	0.05	0.11	-0.04	-0.02	0.01	-0.01	0.06	0	0	0.01
Cabbage	0.123	-0.1	0	0	**-1.05**	-0.07	-0.02	-0.07	0	0.06	-0.01	0.04	0.03	0	-0.02	0.03	0.09	-0.06	-0.01	0.09	-0.01
Carrots	0.227	0.54	0	0.04	-0.17	**-1.22**	0.01	-0.03	-0.1	-0.81	-0.35	0.13	0.02	-0.05	-0.04	0.09	0.24	0.67	0.01	0.25	-0.05
Cauliflower	0.228	-0.18	0	-0.05	0	0	**-1.11**	-0.01	-0.02	0.43	-0.02	0.04	0.04	0	-0.01	0.06	0.02	0.05	0.01	0	0.01
Celery	0.19	0.08	0.02	-0.05	-0.1	-0.02	-0.03	**-0.85**	0	0.11	0.08	-0.01	-0.02	-0.02	-0.04	0.09	-0.12	-0.03	0.01	0.05	0.01
Cucumbers	0.207	0.13	-0.01	0.01	0.02	-0.06	-0.05	0	**-1.02**	-0.03	-0.04	-0.08	-0.01	0	0.01	0.01	0.02	0.07	0.02	-0.05	0.01
Kale	0.078	0.17	0.01	0.01	0.01	-0.03	0.06	0	0	**-1.18**	0	-0.01	-0.02	0	-0.02	-0.01	0.04	-0.05	0	0	0
Lettuce (Head)	0.248	-0.01	0.02	0.04	0.01	-0.2	-0.05	0.11	-0.03	0.11	**-0.73**	0.01	-0.01	-0.04	0.01	0.13	-0.09	-0.01	0.03	-0.03	0
Lettuce (Leaf)	0.151	0.14	0.02	0.01	0.03	0.02	0.02	-0.01	-0.03	-0.06	-0.01	**-0.65**	0.04	0	-0.04	0.07	-0.01	0.02	-0.01	0	-0.03
Lettuce (Romaine)	0.178	0.14	-0.03	0.06	0.05	0	0.07	-0.02	-0.01	-0.22	-0.02	0.08	**-1.18**	-0.02	0	0.02	-0.08	0.18	0.01	-0.03	0.01
Onions (Bulb)	0.206	0.06	-0.04	-0.03	0.07	-0.08	-0.03	-0.05	0.01	0.13	-0.1	0.06	-0.04	**-0.72**	0.03	0.14	-0.09	-0.05	0.03	-0.15	-0.05
Peppers (Bell)	0.179	-0.18	0.02	-0.01	-0.05	-0.07	-0.07	-0.08	0.01	-0.49	-0.02	-0.18	0	0.01	**-1.02**	-0.09	0.1	-0.12	0	0.02	0.01
Peppers (Chile)	0.147	0.04	0.01	0	0.01	0.01	0.03	0.02	0	-0.04	0.02	0.04	0	0.01	-0.01	**-1.24**	0	-0.01	0	-0.02	-0.01
Snap Beans	0.045	-0.4	-0.08	-0.04	0.19	0.11	0.01	-0.24	-0.03	0.93	-0.19	-0.07	-0.2	-0.11	0.03	-0.04	**-0.7**	0.02	-0.07	0.13	-0.01
Spinach	0.161	0	-0.01	0.02	-0.04	0.15	0.05	-0.02	0.02	-0.37	-0.01	0.03	0.1	-0.01	-0.03	-0.02	0.02	**-2.19**	0	0.06	0.01
Squash	0.177	-0.09	-0.04	0.01	-0.01	-0.01	0.01	0.01	0.01	-0.01	0.01	-0.02	0.01	0	0	-0.01	-0.01	0.01	**-1**	0	-0.01
Sweet Corn	0.064	0.62	-0.13	-0.04	0.27	0.17	-0.11	0.05	-0.17	-0.02	-0.14	-0.04	-0.13	-0.19	-0.04	-0.2	0.19	0.24	-0.06	**-0.85**	-0.04
Tomatoes	0.167	-0.29	0.1	0.06	-0.02	-0.27	-0.01	0.02	0	-0.11	-0.12	-0.56	0.07	-0.18	0.01	-0.12	0.16	0.13	-0.1	0.04	**-0.96**

Table 10: Shifts in Equilibrium Prices, Quantities, and Welfare and Cost Pass-Through (Fruit)

Commodity	Expend. Shares	$d\ln Q$	$d\ln P$	CPT (Cons.)	$d\ln X$	$d\ln W$	$d\ln MI$	CPT (Farm)	Δ CS	Δ PS
1. Apples	19.7 %	-0.49 %	0.30 %	13.58 %	-0.49 %	1.22 %	-0.49 %	55.83 %	-0.30 %	-0.96 %
2. Apricots	0.2 %	-0.44 %	0.38 %	18.74 %	-0.44 %	1.17 %	-0.44 %	57.95 %	-0.38 %	-0.85 %
3. Avocados	4.6 %	-1.24 %	1.29 %	36.57 %	-1.24 %	1.82 %	-1.24 %	51.54 %	-1.28 %	-1.70 %
4. Bananas	15.2 %	-0.89 %	0.75 %	21.56 %	-0.89 %	2.27 %	-0.89 %	65.33 %	-0.74 %	-1.20 %
5. Cantaloupes	3.0 %	-0.26 %	0.22 %	15.20 %	-0.26 %	1.05 %	-0.26 %	74.28 %	-0.22 %	-0.36 %
6. Cherries	4.1 %	-0.54 %	0.49 %	18.17 %	-0.54 %	1.66 %	-0.54 %	61.64 %	-0.49 %	-1.03 %
7. Grapefruit	1.1 %	-0.28 %	0.21 %	12.23 %	-0.28 %	1.18 %	-0.28 %	68.32 %	-0.21 %	-0.54 %
8. Grapes	14.4 %	-0.42 %	0.45 %	22.05 %	-0.42 %	1.24 %	-0.42 %	60.34 %	-0.45 %	-0.82 %
9. Honeydew	0.5 %	-0.08 %	0.12 %	16.63 %	-0.08 %	0.59 %	-0.08 %	83.60 %	-0.12 %	-0.11 %
10. Mangos	1.1 %	-0.85 %	0.80 %	22.41 %	-0.85 %	2.42 %	-0.85 %	67.92 %	-0.80 %	-1.14 %
11. Nectarines	1.5 %	-0.08 %	0.21 %	16.91 %	-0.08 %	1.07 %	-0.08 %	86.94 %	-0.21 %	-0.16 %
12. Oranges	5.0%	-0.35 %	0.24 %	11.00 %	-0.35 %	1.48 %	-0.35 %	68.65 %	-0.24 %	-0.68 %
13. Peaches	4.7%	-0.39 %	0.50 %	21.56 %	-0.39 %	1.55 %	-0.39 %	67.60 %	-0.50 %	-0.74 %
14. Pears	2.9%	-0.47 %	0.46 %	15.34 %	-0.47 %	2.07 %	-0.47 %	69.61 %	-0.45 %	-0.90 %
15. Plums	1.2%	-0.42 %	0.43 %	18.49 %	-0.42 %	1.49 %	-0.42 %	64.65 %	-0.42 %	-0.81 %
16. Strawberries	11.7%	-0.31 %	0.33 %	24.91 %	-0.31 %	0.88 %	-0.31 %	67.04 %	-0.33 %	-0.43 %
17. Tangerines	3.5%	-0.05 %	0.17 %	12.33 %	-0.05 %	1.24 %	-0.05 %	92.85 %	-0.17 %	-0.10 %
18. Watermelons	5.5%	-0.81 %	0.89 %	33.56 %	-0.81 %	1.53 %	-0.81 %	57.92 %	-0.89 %	-1.11 %
Average		**-0.53** %	**0.49** %	**20.21** %	**-0.53** %	**1.46** %	**-0.53** %	**63.83**%	**-0.48**%	**-0.86**%

Notes: $d\ln Z = \frac{dZ}{Z}$ for $Z = Q, P, X, W, MI$. Q and P represent output quantity and price, respectively. X is the quantity of farm inputs, W is the price of farm inputs, and MI is the quantity of marketing (non-farm) inputs. CPT = Cost Pass-Through.

Table 11: Shifts in Equilibrium Prices, Quantities, and Welfare and Cost Pass-Through (Vegetables)

Commodity	Expend. Shares	$d\ln Q$	$d\ln P$	CPT (Cons.)	$d\ln X$	$d\ln W$	$d\ln MI$	CPT (Farm)	Δ CS	Δ PS
1. Artichokes	0.73%	-0.07%	0.04%	10.93%	-0.12%	0.13%	-0.02%	34.92%	-0.04%	-0.23 %
2. Asparagus	3.29%	-0.01%	0.00%	NA%	0.00%	-0.01%	-0.01%	NA	0.00%	-0.01 %
3. Broccoli	6.23%	-0.07%	0.04%	8.91%	-0.16%	0.21%	0.02%	47.04%	-0.04%	-0.23 %
4. Cabbage	2.31%	-0.21%	0.20%	12.59%	-0.54%	0.83%	0.13%	51.99%	-0.20%	-0.76 %
5. Carrots	7.38%	-0.07%	0.10%	10.09%	-0.31%	0.54%	0.17%	55.33%	-0.10%	-0.43 %
6. Cauliflower	1.60%	-0.06%	0.06%	14.27%	-0.14%	0.23%	0.03%	52.47%	-0.06%	-0.20 %
7. Celery	3.68%	-0.06%	0.02%	5.22%	-0.16%	0.20%	0.03%	46.43%	-0.02%	-0.22 %
8. Cucumbers	4.28%	-0.14%	0.16%	7.68%	-0.68%	1.17%	0.40%	55.00%	-0.16%	-0.95 %
9. Kale	0.25%	0.01%	0.00%	NA	0.00%	0.01%	0.01%	NA	0.00%	0.01 %
10. Lettuce (Head)	4.21%	-0.04%	0.03%	9.01%	-0.12%	0.16%	0.03%	49.75%	-0.03%	-0.17 %
11. Lettuce (Leaf)	1.38%	0.00%	0.02%	6.23%	-0.11%	0.23%	0.11%	58.73%	-0.02%	-0.16 %
12. Lettuce (Romaine)	3.02%	-0.01%	0.02%	6.41%	-0.09%	0.18%	0.08%	56.88%	-0.02%	-0.13 %
13. Onions	9.43%	-0.33%	0.49%	28.68%	-0.57%	0.93%	-0.10%	53.78%	-0.49%	-0.79 %
14. Peppers (Bell)	7.63%	-0.18%	0.15%	11.95%	-0.45%	0.65%	0.09%	50.71%	-0.15%	-0.63 %
15. Peppers (Chile)	0.82%	-0.24%	0.20%	7.62%	-0.89%	1.40%	0.41%	53.22%	-0.20%	-1.22 %
16. Snap Beans	5.65%	-0.23%	0.24%	8.01%	-0.98%	1.63%	0.52%	54.49%	-0.24%	-1.35 %
17. Spinach	1.77%	-0.13%	0.06%	7.50%	-0.31%	0.40%	0.05%	47.37%	-0.06%	-0.44 %
18. Squash	3.94%	-0.29%	0.29%	11.55%	-0.85%	1.32%	0.27%	52.79%	-0.29%	-1.18 %
19. Sweet Corn	7.88%	-0.04%	-0.01%	NA%	-0.02%	-0.03%	-0.05%	NA	0.01%	-0.03 %
20. Tomatoes	24.54%	-0.26%	0.13%	12.27%	-0.44%	0.45%	-0.09%	42.29%	-0.13%	-0.62 %
Average		**-0.17 %**	**0.14 %**	**12.20 %**	**-0.39 %**	**0.56 %**	**0.05 %**	**49.38%**	**-0.14%**	**-0.55%**

Notes: $d\ln Z = \frac{dZ}{Z}$ for $Z = Q, P, X, W, MI$. Q and P represent output quantity and price, respectively. X is the quantity of farm inputs, W is the price of farm inputs, and MI is the quantity of marketing (non-farm) inputs. CPT = Cost Pass-Through.

Table 12: Consumer and Producer Welfare Changes Under Alternative Elasticity of Supply Specifications (Fruit)

	Medium		Low		High	
Commodity	Δ CS	Δ PS	Δ CS	Δ PS	Δ CS	ΔPS
1. Apples	-0.30 %	-0.96 %	-0.12 %	-1.69 %	-0.36 %	-0.68 %
2. Apricots	-0.38 %	-0.85 %	-0.23 %	-1.30 %	-0.45 %	-0.63 %
3. Avocados	-1.28 %	-1.70 %	-0.94 %	-2.19 %	-1.50 %	-1.39 %
4. Bananas	-0.74 %	-1.20 %	-0.59 %	-1.66 %	-0.83 %	-0.93 %
5. Cantaloupes	-0.22 %	-0.36 %	-0.18 %	-0.52 %	-0.23 %	-0.28 %
6. Cherries	-0.49 %	-1.03 %	-0.32 %	-1.61 %	-0.57 %	-0.76 %
7. Grapefruit	-0.21 %	-0.54 %	-0.14 %	-0.91 %	-0.24 %	-0.39 %
8. Grapes	-0.45 %	-0.82 %	-0.27 %	-1.31 %	-0.54 %	-0.59 %
9. Honeydew	-0.12 %	-0.11 %	-0.10 %	-0.19 %	-0.12 %	-0.08 %
10. Mangos	-0.80 %	-1.14 %	-0.64 %	-1.63 %	-0.89 %	-0.87 %
11. Nectarines	-0.21 %	-0.16 %	-0.16 %	-0.39 %	-0.22 %	-0.09 %
12. Oranges	-0.24 %	-0.68 %	-0.16 %	-1.15 %	-0.27 %	-0.48 %
13. Peaches	-0.50 %	-0.74 %	-0.33 %	-1.27 %	-0.57 %	-0.52 %
14. Pears	-0.45 %	-0.90 %	-0.30 %	-1.59 %	-0.52 %	-0.62 %
15. Plums	-0.42 %	-0.81 %	-0.27 %	-1.34 %	-0.49 %	-0.58 %
16. Strawberries	-0.33 %	-0.43 %	-0.27 %	-0.59 %	-0.36 %	-0.34 %
17. Tangerines	-0.17 %	-0.10 %	-0.13 %	-0.35 %	-0.18 %	-0.02 %
18. Watermelons	-0.89 %	-1.11 %	-0.66 %	-1.51 %	-1.02 %	-0.88 %
Average	**-0.48**%	**-0.86** %	**-0.33** %	**-1.34** %	**-0.56** %	**-0.64** %

Table 13: Consumer and Producer Welfare Changes Under Alternative Elasticity of Supply Specifications (Vegetables)

	Medium		Low		High	
Commodity	Δ CS	Δ PS	Δ CS	Δ PS	Δ CS	ΔPS
1. Artichokes	-0.04%	-0.23%	-0.02%	-0.30%	-0.05%	-0.19%
2. Asparagus	0.00%	-0.01%	0.00%	-0.01%	0.00%	-0.01%
3. Broccoli	-0.04%	-0.23%	-0.03%	-0.29%	-0.05%	-0.19%
4. Cabbage	-0.20%	-0.76%	-0.15%	-0.98%	-0.23%	-0.62%
5. Carrots	-0.10%	-0.43%	-0.07%	-0.57%	-0.11%	-0.35%
6. Cauliflower	-0.06%	-0.20%	-0.05%	-0.26%	-0.07%	-0.17%
7. Celery	-0.02%	-0.22%	-0.02%	-0.28%	-0.03%	-0.19%
8. Cucumbers	-0.16%	-0.95%	-0.12%	-1.25%	-0.19%	-0.77%
9. Kale	0.00%	0.01%	0.00%	0.00%	0.00%	0.01%
10. Lettuce (Head)	-0.03%	-0.17%	-0.02%	-0.21%	-0.04%	-0.14%
11. Lettuce (Leaf)	-0.02%	-0.16%	-0.02%	-0.22%	-0.03%	-0.13%
12. Lettuce (Romaine)	-0.02%	-0.13%	-0.01%	-0.18%	-0.02%	-0.11%
13. Onions (Bulb)	-0.49%	-0.79%	-0.36%	-1.03%	-0.57%	-0.64%
14. Peppers (Bell)	-0.15%	-0.63%	-0.11%	-0.81%	-0.18%	-0.52%
15. Peppers (Chile)	-0.20%	-1.22%	-0.15%	-1.59%	-0.23%	-0.99%
16. Snap Beans	-0.24%	-1.35%	-0.18%	-1.77%	-0.28%	-1.09%
17. Spinach	-0.06%	-0.44%	-0.05%	-0.55%	-0.07%	-0.37%
18. Squash	-0.29%	-1.18%	-0.21%	-1.52%	-0.34%	-0.95%
19. Sweet Corn	0.01%	-0.03%	0.01%	-0.04%	0.01%	-0.03%
20. Tomatoes	-0.13%	-0.62%	-0.09%	-0.76%	-0.16%	-0.52%
Average	**-0.14%**	**-0.55%**	**-0.10%**	**-0.70%**	**-0.17%**	**-0.45%**

Table 14: Shifts in Equilibrium Prices, Quantities, and Welfare and Cost Pass-Through Associated with Commodity Groups Unilaterally Implementing FSMA Regulations (Fruit)

Commodity	Expend. Shares	$d\ln Q$	$d\ln P$	CPT (Cons.)	$d\ln X$	$d\ln W$	$d\ln MI$	CPT (Farm)	Δ CS	Δ PS
1. Apples	19.7%	-0.35%	0.37%	16.87%	-0.35%	1.51%	-0.35%	69.4%	-0.37%	-0.67%
2. Apricots	0.2%	-0.44%	0.37%	18.54%	-0.44%	1.16%	-0.44%	57.3%	-0.37%	-0.86%
3. Avocadoes	4.6%	-1.29%	1.25%	35.33%	-1.29%	1.76%	-1.29%	49.8%	-1.24%	-1.76%
4. Bananas	15.2%	-0.78%	0.80%	23.01%	-0.78%	2.42%	-0.78%	69.7%	-0.80%	-1.05%
5. Cantaloupes	3.0%	-0.24%	0.22%	15.64%	-0.24%	1.09%	-0.24%	76.4%	-0.22%	-0.33%
6. Cherries	4.1%	-0.63%	0.44%	16.21%	-0.63%	1.48%	-0.63%	55.0%	-0.44%	-1.21%
7. Grapefruit	1.1%	-0.27%	0.21%	12.50%	-0.27%	1.20%	-0.27%	69.8%	-0.21%	-0.52%
8. Grapes	14.4%	-0.45%	0.43%	20.96%	-0.45%	1.18%	-0.45%	57.3%	-0.43%	-0.88%
9. Honeydew	0.5%	-0.10%	0.11%	15.72%	-0.10%	0.55%	-0.10%	79.0%	-0.11%	-0.15%
10. Mangoes	1.1%	-0.87%	0.79%	22.07%	-0.87%	2.39%	-0.87%	66.9%	-0.78%	-1.18%
11. Nectarines	1.5%	-0.19%	0.17%	13.59%	-0.19%	0.86%	-0.19%	69.9%	-0.17%	-0.37%
12. Oranges	5.0%	-0.28%	0.26%	12.04%	-0.28%	1.62%	-0.28%	75.1%	-0.26%	-0.54%
13. Peaches	4.7%	-0.45%	0.46%	19.87%	-0.45%	1.43%	-0.45%	62.3%	-0.46%	-0.87%
14. Pears	2.9%	-0.47%	0.46%	15.40%	-0.47%	2.08%	-0.47%	69.9%	-0.46%	-0.89%
15. Plums	1.2%	-0.42%	0.42%	18.42%	-0.42%	1.48%	-0.42%	64.4%	-0.42%	-0.82%
16. Strawberries	11.7%	-0.36%	0.30%	22.76%	-0.36%	0.80%	-0.36%	61.3%	-0.30%	-0.51%
17. Tangerines	3.5%	-0.23%	0.12%	8.73%	-0.23%	0.88%	-0.23%	65.8%	-0.12%	-0.46%
18. Watermelons	5.5%	-0.90%	0.81%	30.56%	-0.90%	1.40%	-0.90%	52.7%	-0.81%	-1.25%
Average		**-0.51%**	**0.49%**	**20.17%**	**-0.51%**	**1.50%**	**-0.51%**	**64.34%**	**-0.49%**	**-0.83%**

Notes: $d\ln Z = \frac{dZ}{Z}$ for $Z = Q, P, X, W, MI$. Q and P represent output quantity and price, respectively. X is the quantity of farm inputs, W is the price of farm inputs, and MI is the quantity of marketing (non-farm) inputs. CPT = Cost Pass-Through.

Table 15: Shifts in Equilibrium Prices, Quantities, and Welfare and Cost Pass-Through Associated with Commodity Groups Unilaterally Implementing FSMA Regulations (Vegetables)

Commodity	Expend. Shares	$d \ln Q$	$d \ln P$	CPT (Cons.)	$d \ln X$	$d \ln W$	$d \ln MI$	CPT (Farm)	Δ CS	Δ PS
1. Artichokes	0.73%	-0.06%	0.05%	12.50%	-0.11%	0.14%	0.00%	40.0%	-0.05%	-0.22%
2. Asparagus	3.29%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0%	0.00%	-0.00%
3. Broccoli	6.23%	-0.04%	0.04%	10.10%	-0.14%	0.23%	0.06%	53.3%	-0.04%	-0.21%
4. Cabbage	2.31%	-0.21%	0.20%	12.55%	-0.55%	0.82%	0.13%	51.8%	-0.20%	-0.76%
5. Carrots	7.38%	-0.11%	0.09%	9.47%	-0.33%	0.50%	0.12%	51.9%	-0.09%	-0.47%
6. Cauliflower	1.60%	-0.06%	0.06%	13.70%	-0.15%	0.22%	0.02%	50.4%	-0.06%	-0.21%
7. Celery	3.68%	-0.02%	0.03%	6.19%	-0.13%	0.23%	0.09%	55.1%	-0.03%	-0.19%
8. Cucumbers	4.28%	-0.16%	0.16%	7.56%	-0.70%	1.15%	0.37%	54.1%	-0.16%	-0.97%
9. Kale	0.25%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0%	0.00%	-0.00%
10. Lettuce (Head)	4.21%	-0.02%	0.03%	9.98%	-0.10%	0.18%	0.06%	55.1%	-0.03%	-0.15%
11. Lettuce (Leaf)	1.38%	-0.01%	0.02%	5.95%	-0.12%	0.22%	0.09%	56.1%	-0.02%	-0.17%
12. Lettuce (Romaine)	3.02%	-0.02%	0.02%	6.02%	-0.10%	0.17%	0.06%	53.5%	-0.02%	-0.14%
13. Onions	9.43%	-0.34%	0.49%	28.34%	-0.57%	0.91%	-0.11%	53.1%	-0.49%	-0.80%
14. Peppers (Bell)	7.63%	-0.16%	0.16%	12.28%	-0.44%	0.67%	0.12%	52.1%	-0.16%	-0.62%
15. Peppers (Chile)	0.82%	-0.25%	0.20%	7.59%	-0.89%	1.39%	0.40%	53.0%	-0.20%	-1.23%
16. Snap Beans	5.65%	-0.17%	0.25%	8.30%	-0.94%	1.69%	0.61%	56.5%	-0.25%	-1.36%
17. Spinach	1.77%	-0.14%	0.06%	7.43%	-0.31%	0.39%	0.04%	46.9%	-0.06%	-0.44%
18. Squash	3.94%	-0.29%	0.29%	11.58%	-0.85%	1.32%	0.27%	52.9%	-0.29%	-1.12%
19. Sweet Corn	7.88%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0%	0.00%	0.00%
20. Tomatoes	24.54%	-0.15%	0.16%	15.01%	-0.37%	0.55%	0.06%	51.7%	-0.16%	-0.52%
Average		**-0.13%**	**0.15%**	**13.07%**	**-0.36%**	**0.57%**	**0.10%**	**52.74%**	**-0.15%**	**-0.50%**

Notes: $d \ln Z = \frac{dZ}{Z}$ for $Z = Q, P, X, W, MI$. Q and P represent output quantity and price, respectively. X is the quantity of farm inputs, W is the price of farm inputs, and MI is the quantity of marketing (non-farm) inputs. CPT = Cost Pass-Through.

Appendix A. Derivation of Equilibrium Displacement Model

To derive the equilibrium displacement model, we take the total derivative for each of equations (1) through (6) and then rearrange terms to organize the equations in terms of elasticities $(\eta, \varepsilon, \sigma)$, budget shares (ω) and log changes in variables (noting that $\frac{dX}{X} = d\ln X$, $\frac{dP}{P} = d\ln P$, and so on). Equation (1) becomes:

$$
\begin{aligned}
dQ &= \sum_{k=1}^{N} \frac{\partial Q_n^D}{\partial P_k} dP_n + \frac{\partial Q_n^D}{\partial A_N} \\
d\ln Q &= \sum_{k=1}^{N} \frac{\partial Q_n^D}{\partial P_k} \frac{P_n}{Q_n^D} d\ln P_n + \frac{\partial Q_n^D}{\partial A_N} \frac{A_N}{Q_n^D} \\
d\ln Q &= \sum_{k=1}^{N} \eta_{nk} d\ln P_n + \alpha_N.
\end{aligned}
$$

Equation (2) becomes:

$$
\begin{aligned}
d\ln P_n &= \frac{\partial c_n}{\partial W_n} \frac{W_n}{P_n} d\ln W_n + \frac{\partial c_n}{\partial PMI} \frac{PMI}{P_n} d\ln PMI \\
d\ln P_n &= \frac{X_n W_n}{Q_n P_n} d\ln W_n + \frac{MI_n PMI}{Q_n P_n} d\ln PMI \\
d\ln P_n &= s_n d\ln W_n + (1 - s_n) d\ln PMI.
\end{aligned}
$$

Equation (3) becomes:

$$
\begin{aligned}
dX_n &= \frac{\partial g_n}{\partial W_n} dW_n + \frac{\partial g_n}{PMI} dPMI + dQ_n \\
d\ln X_n &= \frac{\partial g_n}{\partial W_n} \frac{W_n}{X_n} d\ln W_n + \frac{\partial g_n}{\partial PMI} \frac{PMI}{X_n} d\ln PMI + \frac{Q_n}{X_n} d\ln Q_n \\
d\ln X_n &= \gamma_n d\ln W_n + \frac{\partial g_n}{\partial PMI} \frac{PMI}{X_n} d\ln PMI + d\ln Q \\
d\ln X_n &= s_n \gamma_n d\ln W_n + (1 - s_n)\gamma_n d\ln PMI + d\ln Q.
\end{aligned}
$$

Equation (4) becomes:

$$\begin{aligned}
dX_n &= \frac{\partial X_n^S}{\partial W_n} dW_n + \frac{\partial X_n^S}{\partial B_n} dB_n \\
d\ln X_n &= \frac{\partial X_n^S}{\partial W_n} d\ln W_n + \frac{\partial X_n^S}{\partial B_n}\frac{B_n}{X_n} d\ln B_n \\
d\ln X_n &= \varepsilon_n d\ln W_n + \beta_n.
\end{aligned}$$

Equation (5) becomes:

$$\begin{aligned}
dMI_n^D &= \frac{\partial g_n}{\partial W_n} dW_n + \frac{\partial g_n}{\partial PMI} dPMI + dQ_n \\
d\ln X_n &= \frac{\partial g_n}{\partial W_n}\frac{W_n}{X_n} d\ln W_n + \frac{\partial g_n}{\partial PMI}\frac{PMI}{X_n} d\ln PMI + \frac{Q_n}{X_n} d\ln Q_n \\
d\ln MI_n &= s_n \nu_n^* d\ln W_n + (1 - s_n)\nu_n^* d\ln PMI + d\ln Q.
\end{aligned}$$

Equation (6) becomes:

$$\begin{aligned}
dMI &= \frac{\partial MI^S}{\partial PMI} dPMI \\
d\ln MI &= \frac{\partial MI^S}{\partial PMI}\frac{PMI}{MI} d\ln PMI \\
d\ln MI &= \varepsilon_{MI} d\ln PMI.
\end{aligned}$$

If the supply of marketing inputs is perfectly elastic, then $\varepsilon_{MI} = \infty$ and $\frac{1}{\varepsilon_{MI}} = 0$. These substitutions allow the last equation to be dropped as $d\ln PMI = 0$ and the other equations to be simplified to:

$$\begin{aligned} d\ln Q_N - \nu_N d\ln P_N &= \alpha_N \\ d\ln P_N - s_N d\ln W_N &= 0 \\ d\ln X_N - \gamma_N d\ln W_N - d\ln Q_N &= 0 \\ d\ln X_N - \varepsilon_N d\ln W_N &= \varepsilon_N \beta_N \\ \gamma_N d\ln W_n + d\ln Q_N - d\ln MI_N &= 0. \end{aligned}$$

The variables γ_N and γ_{MI} can be solved as a function of s_N and $\sigma_{N,MI}$. Note that q_i is produced with two inputs x_n and MI. Following equation (2) and suppressing subscripts, let the unit cost of $q = c(w, pmi)$ where w and pmi are the prices of the respective inputs. Following Sato and Koizumi (1973), we define the elasticity of substitution as:

$$\begin{aligned} \sigma_{w,mi} &= \frac{cc_{w,mi}}{c_w \times c_{mi}} \\ &= \frac{cc_{w,mi}}{c_w \times c_{mi}} \\ &= \frac{c_{w,mi}}{c_w}\frac{c}{c_{mi}}, \end{aligned}$$

where

$$\begin{aligned} c_{w,mi} &= \frac{\partial c^2}{\partial w \partial mi} \\ x = c_x &= \frac{\partial c}{\partial w} \\ mi = c_{mi} &= \frac{\partial c}{\partial pmi}. \end{aligned}$$

.

Note that the Hicksian cross-price elasticities of demand for input x are:

$$\begin{aligned}\gamma_{mi} &= \frac{\partial c_w}{\partial pmi}\frac{pmi}{c_w}\\ &= \frac{\partial c^2}{\partial w \partial mi}\frac{pmi}{c_w}\\ &= \frac{\partial c^2}{\partial w \partial mi}\frac{mi}{c_w}\\ &= \frac{c_{w,mi}}{c_w}mi.\end{aligned}$$

Therefore,

$$\begin{aligned}\sigma_{w,mi} &= \frac{c_{w,mi}}{c_w}\frac{c}{c_{mi}}\\ &= \gamma_{mi}\frac{c}{c_{mi}}\\ &= \frac{1}{1-s_x}\gamma_{mi}\\ \gamma_{mi} &= (1-s_x)\sigma_{w,mi}.\end{aligned}$$

To solve for γ_n, note that:

$$c = xc_w + (mi)c_{mi}$$

and that:

$$\partial c = x\frac{\partial c_w}{\partial w} + (mi)\frac{\partial c_{mi}}{\partial w} = 0.$$

Since $\frac{\partial c_{mi}}{\partial x} = \frac{\partial c^2}{\partial w \partial mi} = \frac{\partial c_w}{\partial pmi}$, multiply by $\frac{1}{w}$ and simplify to get:

$$\gamma_n + \gamma_{mi} = 0$$

so that:

$$\gamma_n = -(1 - s_x)\sigma_{w,mi}.$$

Appendix B. Relationship between of Comprehensive and Unilateral Enactment

Denote Z_{Full} as the effects on P, Q, W, X, and MI from the Produce Safety Rule when all non-exempted commodities incur their respective costs, denoted D_{Full}, associated with the produce safety rules. Reorder the rows of A, Z, and D so that:

$$A = \begin{bmatrix} I_N & -\eta^N & 0_N & 0_N & 0_N \\ 0_N & I_N & 0_N & -s_N & 0_N \\ -I_N & 0_N & I_N & (I_N - s_N)\sigma_n & 0_N \\ -I_N & 0_N & 0_N & (I_N - s_N)\sigma_{MI} & I_N \\ 0_N & 0_N & I_N & -\varepsilon_N & 0_N \end{bmatrix}$$

$$Z = \begin{bmatrix} dlQ_N & dlP_N & dlX_N & dlMI_N & dlW_N \end{bmatrix}'$$

$$D = \begin{bmatrix} 0 & 0 & 0 & 0 & \varepsilon_N \beta_N \end{bmatrix}'.$$

Let $S = N \times k$. Partion the matrices A and D as follows:

$$A = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}$$

$$D = \begin{bmatrix} D_{11} \\ D_{21} \end{bmatrix},$$

where the dimensions of A_{11} and D_{11} are $[(S - N) \times (S - N)]$ and $[(S - N) \times 1]$.

Note that inverse of A^{-1} is:

$$A^{-1} = \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix}$$

where

$$
\begin{aligned}
B_{11} &= \left(A_{11} - A_{12}A_{22}^{-1}A_{21}\right)^{-1} \\
B_{12} &= -\left(A_{11} - A_{12}A_{22}^{-1}A_{21}\right)^{-1} A_{12}A_{22}^{-1} \\
B_{21} &= -\left(A_{22} - A_{21}A_{11}^{-1}A_{12}\right)^{-1} A_{21}A_{11}^{-1} \\
B_{22} &= \left(A_{22} - A_{21}A_{11}^{-1}A_{12}\right)^{-1}
\end{aligned}
$$

so that:

$$
Z = \begin{bmatrix} B_{11}D_1 - B_{12}D_2 \\ B_{21}D_1 - B_{22}D_2 \end{bmatrix},
$$

where the dimensions of $B_{11}D_1 - B_{12}D_2$ are $[(S-N) \times 1]$ and the dimensions of $B_{21}D_1 - B_{22}D_2$ are $[N \times 1]$. If producers of the N^{th} good unilaterally undertake the producer safety rules, then $D_1 = 0$.

Note that the value of an exemption of the N^{th} good is described by the Z values where $D_2 = 0$ so that

$$
Z_{D_2=0} = \begin{bmatrix} B_{11}D_1 \\ B_{21}D_1 \end{bmatrix}
.
$$

Similarly, the value of comprehensive enactment of the N^{th} good is the difference between the Z values under full enactment and the Z values when $D_1 = 0$. The values when $D_1 = 0$

are:

$$Z_{D_1=0} = \begin{bmatrix} -B_{12}D_2 \\ -B_{22}D_2 \end{bmatrix}$$

This shows that the total effect for the N^{th} producer is sum of the direct effect of the cost (through D_2) and the indirect effect of the increase in costs for other producers (through D_1).