What Are the Overall Implications of Rising Demand for Organic Fruits and Vegetables?
Evidence from Theory and Simulations

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Abstract

U.S. consumers currently eat less fruits and vegetables (FV) than recommended by dietary guidelines. Inadequate FV consumption exists alongside rapid growth in demand for organic FV. Since the viable production area of FV is finite, organic and conventional FV are linked in production while serving as substitutes in consumption. Rising purchases of organic FV may have important implications for prices and quantities consumed in the conventional FV market. In this paper, we analyze the implications of rising demand for organic produce when organic and conventional FV are linked in supply and demand. More specifically, we use a multi-market equilibrium displacement model to examine the impact of rising demand for organic produce on prices and total quantities consumed of conventional and organic FV under two scenarios: product differentiation (i.e., organic versus conventional produce) while assuming that consumers have identical preferences that can be represented by a single market demand function for each good; and product differentiation with segmented markets, which allows for two types of consumers with unique demand functions. Both scenarios were simulated with and without an offsetting shift in demand for conventional FV. Our simulation results indicate that the increasing demand for organic FV may result in decreased consumption of combined conventional and organic FV, and that the direction of changes in FV consumption may vary by consumer segment. Under the most realistic assumptions, when one segment of consumers increases its demand for organic FV, this segment’s overall consumption of organic plus conventional FV falls; the other segment’s overall consumption rises. We provide sensitivity analyses and discuss caveats and directions for future research.

Keywords: Fruit and vegetable consumption, conventional and organic, product differentiation, market segmentation, equilibrium displacement model

JEL: D11, D40, D50

1. Introduction
The United States Department of Agriculture (USDA) has long promoted healthy diets, including consumption of more fruits and vegetables (FV) (USDA CNPP, 2019). At the same time, USDA supports research on organic agriculture through Sustainable Agriculture Research & Education and other grant programs. The USDA Organic seal provides a reliable signal so that consumers can self-select to engage in the conventional or organic markets. Organic food sales increased from approximately $21 billion in 2009 to around $48 billion in 2018 (Organic Trade Association, 2019) and FV are the largest category of organic food, accounting for approximately 40% of sales in any given year (USDA-ERS, 2014). USDA also promotes farmers’ markets and local food consumption (USDA AMS, 2019), and subsidizes farmers’ market purchases for low-income consumers through the Food Insecurity Nutrition Incentive grant program. Although local foods are not always organic, they are closely associated in the minds of many consumers (Campbell et al., 2014). Given that the premium for organic products is typically greatest for produce (Carlson, 2016), programs that result in a positive demand shift for organic food may reduce overall consumption of healthy FV by individuals who do not consume a large quantity of organic FV. In other words, the goals of promoting nutrition while also promoting organic and local foods may be at odds with one another.

Demand in organic markets is the subject of a growing literature that encompasses topics like the response to changes in price (Lin et al., 2009; Kasteridis and Yen 2012; Okrent and Alston 2011; Ferrier et al., 2019) and the characteristics of primary consumers (Stevens-Garmon et al., 2007; Li et al., 2007; Dettmann and Dimitri, 2009; Dimitri and Dettmann, 2012; Smith, Huang, and Lin, 2009). Although earlier research shows an ambiguous relationship between income and purchases of organic FV (Stevens-Garmon et al., 2007; Li et al., 2007; Dettmann and Dimitri, 2009; Dimitri and Dettmann, 2012), recent work by Nelson et al. (2017) estimated that households with income greater than 500% of the poverty line were responsible for 56% of national spending on organic fruit in 2013. This same group accounted for
43% of spending on conventional fruit in 2013, despite making up only 34% of all households that bought fruit.

In this paper, we analyze the implications of rising demand for organic FV when organic and conventional FV are linked in demand. More specifically, we use a multi-market equilibrium displacement model\(^1\) (EDM) (Wohlgenant, 2011) to examine the impact of rising demand for organic produce on prices and quantities consumed of FV under two scenarios. First, we allow for product differentiation (i.e., organic versus conventional produce) but assume that consumers have identical preferences within a market that can be represented by a single market demand function for each good. Second, we maintain product differentiation but introduce market segmentation, i.e., we allow for two types of consumers with unique demand functions. Since a small share of consumers is responsible for the majority of purchases of organic FV (Dettmann and Dimitri, 2009; Stevens-Garmon et al., 2007, Nelson et al., 2017), we believe that segmentation is an appropriate characterization of the market for organic and conventional FV.

Understanding the differences between differentiation with and without market segmentation has not been at the forefront of concerns for agricultural economists, especially for raw commodities, due to the often-applied assumption of a homogeneous product (Sexton, 2013).\(^2\) While differentiation and market segmentation are typically associated with manufactured and processed foods, neither is frequently associated with raw agricultural commodities. However, agricultural producers, or perhaps manufacturers, are increasingly interested in segmenting markets by catering to heterogeneity in demand functions. Catering to heterogeneity in demand functions benefits consumers because the product will more closely satisfy a segment of consumers’ preferences, and benefits producers because demand should become more inelastic when preferences are better met (Chamberlin, 1965). While market segmentation is widely

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\(^1\) Multi-market equilibrium displacement models are commonly used in ex ante analysis of agricultural policy. They allow researchers and policy analysts to study effects of policy changes or shifts in supply or demand curves on both producer surplus and consumer surplus while allowing for substitution in production and consumption. They contrast with calculation of changes in consumer and producer welfare based on demand and supply curves for a single product—ignoring the possibility of substitution in either production or consumption. See, e.g., Croppenstedt et al. (2007) for a discussion.

\(^2\) Bonroy and Constantatos (2015) briefly discuss market segmentation and differentiation effects of labels and describe segmentation as the emergence of submarkets for quality.
practiced among sellers, we are only aware of two EDMs that incorporate multiple demand curves for the same (sets of) goods: Alston et al. (2009) and de Mouzon et al. (2012), which considered the effects of SNAP expansion and FV vouchers, respectively.\(^3\) Our paper innovates and contributes to the policy discussion by simulating the effects of a demand shock in the context of market segmentation, where demand curves are distinct not because of a welfare program, as in the previous literature, but because of underlying consumer preferences.

Under both scenarios, we simulate the effects on market equilibrium of a shock affecting relative demand for organic and conventional FV. This shock could be thought of as the result of an effective promotion campaign carried out by organic producers collectively (e.g., through the Organic Trade Association) or individually by large organic farms or manufacturers. It could also be thought of as the result of effective government programs to promote organic food,\(^4\) or even as the consequence of some hypothetical health scare surrounding conventional FV.\(^5\) We provide sensitivity analysis by varying the magnitude of a contemporaneous negative shift in demand for conventional FV and the expenditure shares of each segment of consumers in the markets for organic and conventional FV. To demonstrate a range of plausible outcomes, we simulate demand shifts that affect a single good at a time.

We show that the implications of a shock that affects relative demand for organic and conventional FV depend on whether consumers are assumed to have the same demand functions (i.e., there is product differentiation without segmentation) or different demand functions (i.e., product differentiation with segmentation).\(^6\) When consumers are modeled as having heterogeneous demand functions, a demand shock that results in increased demand for organic FV leads to price changes that in

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\(^3\) Rickard (2011) uses a similar model to simulate the effects of introducing wine into grocery stores, with one demand curve representing total demand and another to represent demand for wine in liquor stores.

\(^4\) The Organic Research, Promotion, and Information Order was proposed by USDA on January 17, 2017. The rulemaking proceeding was terminated in May 2018. See https://www.federalregister.gov/documents/2017/01/18/2017-00601/organic-research-promotion-and-information-order and https://www.regulations.gov/document?D=AMS_FRDOC_0001-1716.

\(^5\) Of course, there could also be demand shocks that stimulate demand for conventional products. As one example, recall the 2006 outbreak of \(E.\) coli in fresh spinach grown using organic methods (see Calvin, 2007).

\(^6\) Differentiation is the activity of a producer attempting to gain market share from consumers with the same demand functions, while market segmentation is the activity of reaching consumers who have different demand functions (Smith, 1956).
turn reduce overall consumption of FV, which carries negative health and nutrition implications. Furthermore, the segment of consumers who consume less FV, and less organic FV, are those whose overall consumption of FV decreases the most. Thus, any anticipatory analysis of organic promotion policies must appropriately account for consumer heterogeneity, i.e., market segmentation.

The rest of the paper is organized as follows. In section 2 we build a mathematical framework to demonstrate the difference between assuming product differentiation with and without market segmentation. Section 3 develops a numerical example by applying the mathematical framework to conventional and organic FV and uses comparative statics to determine the effects of assuming product differentiation without market segmentation versus with market segmentation. Our results are presented and discussed in section 4 and we end with a brief conclusion.

2. Theoretical model

2.1 Product differentiation with a single demand curve

To provide a complete mathematical framework demonstrating the differences between measuring the effects of a demand shift from product differentiation with and without market segmentation, we begin with differentiation without market segmentation. This is a standard approach for characterizing demand within an EDM (see Wohlgenant, 1989; Davis and Espinoza, 1998; Alston et al., 2007; Okrent and Alston, 2012; Zhang, 2021). As discussed by Zhao et al. (2000), differentiated products within a market are substitutes and fall within the same decision-making problem for all consumers.7

Consider a consumer with a given budget (m) who is participating in a differentiated market for good \( Q_i, i \in \{c, o\} \).8 The consumer’s indirect utility function is given by:

\[
(1) \quad v(p_c, p_o, m) = \max_{Q_c, Q_o} \{u(Q_c, Q_o): p_c Q_c + p_o Q_o \leq m\},
\]

where \( p_c \) and \( p_o \) are prices for \( Q_c \) and \( Q_o \), respectively. Now suppose that there is a positive shift in demand for product \( o \). The quantities demanded

7 Some of the derivation for the differentiated market closely follows Zhao et al. (2000), which examined the effect of promotion on grass- and grain-fed beef.
8 Later, the subscripts \( c \) and \( o \) will be used to denote conventional and organic, respectively.
and supplied and the market-clearing condition for the market with differentiation but not segmentation are represented by:

(2a) \( QD_c = qd_c(p_c, p_o, \Delta_c, \Delta_o) \),

(2b) \( QD_o = qd_o(p_c, p_o, \Delta_c, \Delta_o) \),

(2c) \( QS_c = qs_c(p_c, p_o) \),

(2d) \( QS_o = qs_o(p_c, p_o) \),

(2e) \( QD_c = QS_c \),

(2f) \( QD_o = QS_o \),

where \( QD_c \) and \( QD_o \) are quantities demanded, \( \Delta_c \) and \( \Delta_o \) are demand shifters, \( QS_c \) and \( QS_o \) are quantities supplied, and the last two equations are market-clearing quantity identities. Note that quantity demanded of each product is potentially affected by each demand shifter. Taking the logarithmic differentials of the quantity demanded and supplied equations above gives the following:

(3a) \( E QD_c = \eta_c(Ep_c + \Delta_c) + \eta_{co}(Ep_o + \Delta_o) \),

(3b) \( E QD_o = \eta_{oc}(Ep_c + \Delta_c) + \eta_o(Ep_o + \Delta_o) \),

(3c) \( E QS_c = \varepsilon_c(Ep_c) + \varepsilon_{co}(Ep_o) \),

(3d) \( E QS_o = \varepsilon_{oc}(Ep_c) + \varepsilon_o(Ep_o) \),

where \( E \) denotes relative changes (e.g., \( EQD = \frac{dQD}{QD} = d \ln (QD) \)), \( \eta_c, \eta_o, \eta_{co}, \) and \( \eta_{oc} \) are own- and cross-price elasticities of demand, \( \varepsilon_c, \varepsilon_o, \varepsilon_{co}, \) and \( \varepsilon_{oc} \) are own- and cross-price elasticities of supply. Using the market clearing conditions allows us to express relative changes in prices \( (Ep_c \) and \( Ep_o \) as follows:

\[
(4a) \ 
Ep_c = \frac{(\eta_{oc}\Delta_c + \eta_o\Delta_o)(\varepsilon_{co} - \eta_{co}) - (\eta_c\Delta_c + \eta_{co}\Delta_o)(\eta_o - \varepsilon_o)}{(\varepsilon_c - \eta_c)(\varepsilon_o - \eta_o) - (\eta_{oc} - \varepsilon_{oc})(\eta_{co} - \varepsilon_{co})},
\]

\[9\] See Appendix A.1 for a full derivation of the logarithmic differentials.
If the price elasticities are known, or can be reasonably assumed, solving the above equations allow us to calculate the relative changes in quantities demanded and supplied for the two differentiated products given some shift in demand.

2.2 Product differentiation with market segmentation

The previous model assumes consumers are homogeneous and fundamental to the concept of market segmentation is distinct demand functions that arise from demand heterogeneity (Dickson and Ginter, 1987). Thus, if the interest were estimating the effects of a demand shift occurring from promotion to a specific segment of consumers, or changes in tastes and preferences for a specific segment, separate demand functions would need to be considered for each market segment. The indirect utility functions for the segmented consumers are:

(5a) \[ v^1(p_c, p_o, m) = \max_{Q_c, Q_o} \{ u(Q^h_c, Q^h_o) : p_c Q^h_c + p_o Q^h_o \leq m \}, \]
(5b) \[ v^2(p_c, p_o, m) = \max_{Q_c, Q_o} \{ u(Q^l_c, Q^l_o) : p_c Q^l_c + p_o Q^l_o \leq m \}, \]

where the superscripts \( h \) (high organic demand) and \( l \) (low organic demand) represent consumer segments whose preferences are better satisfied by markets \( o \) and \( c \), respectively.

Now suppose that through promotion, or changes in tastes and preferences, a demand shift occurs for the products. The segmented market and quantities demanded and supplied for the products can be represented by:

(6a) \[ Q_{D^h_c} = q_d^h(p_c, p_o, \Delta_c, \Delta_o), \]
(6b) \[ Q_{D^l_c} = q_d^l(p_c, p_o), \]
(6c) \[ Q_{D^h_o} = q_d^h(p_c, p_o, \Delta_c, \Delta_o), \]

\(^{10}\) Some of the derivation for the segmented markets closely follows Alston et al. (2009), which examined the effect of proposed changes to the U.S. food stamp program on demand for healthy and unhealthy foods.
(6d) \( QD_o^l = qd_o^l(p_c, p_o) \),

(6e) \( QS_c = qs_c(p_c, p_o) \),

(6f) \( QS_o = qs_o(p_c, p_o) \),

(6g) \( QD_c = QD_c^1 + QD_c^2 \),

(6h) \( QD_o = QD_o^1 + QD_o^2 \),

(6i) \( QD_c = QS_c \),

(6j) \( QD_o = QS_o \).

The only differences between these equations and equations (2a) – (2f) are that there are now two segments of consumers, with only one of them (segment \( h \)) experiencing a demand shift. Taking the logarithmic differentials of the segmented markets and respective quantities demanded gives the following:

(7a) \( E\!QD_c^h = \eta_c^h(Ep_c + \Delta_c) + \eta_o^h(Ep_o + \Delta_o) \),

(7b) \( E\!QD_c^l = \eta_c^l(Ep_c) + \eta_o^l(Ep_o) \),

(7c) \( E\!QD_o^h = \eta_o^h(Ep_c + \Delta_c) + \eta_o^h(Ep_o + \Delta_o) \),

(7d) \( E\!QD_o^l = \eta_o^l(Ep_c) + \eta_o^l(Ep_o) \),

(7e) \( E\!QS_c = \varepsilon_c(Ep_c + \varepsilon_c(Ep_o) \),

(7f) \( E\!QS_o = \varepsilon_o(Ep_c + \varepsilon_o(Ep_o) \),

(7g) \( E\!QD_c = \phi E\!QD_c^h + (1 - \phi)E\!QD_c^l \),

(7h) \( E\!QD_o = \psi E\!QD_o^h + (1 - \psi)E\!QD_o^l \),

where \( \phi \) and \( \psi \) are consumption proportions for consumer segment \( h \) in markets \( c \) and \( o \), respectively.

Using the market clearing conditions allows the derivation of \( Ep_c \) and \( Ep_o \), which gives:

\[
(8a) Ep_c = \frac{(\psi \eta_o^h \Delta_c + \psi \eta_o^h \Delta_o) (\phi \eta_c^h \Delta_c + (1 - \phi) \eta_c^l \Delta_o) (\varepsilon_o + \psi \eta_o^h (1 - \psi) \eta_o^l)}{(\varepsilon_c - \psi \eta_o^h (1 - \phi) \eta_c^l)(\varepsilon_o - \psi \eta_o^h (1 - \psi) \eta_o^l) - (\psi \eta_o^h + (1 - \psi) \eta_o^l \Delta_c - \varepsilon_o \Delta_c + \eta_o^l \varepsilon_o)}.
\]
Notice that accounting for demand heterogeneity allows the incorporation of separate price elasticities for the two consumer segments. This is an important contribution because it has long been recognized that demand becomes less price elastic when a product satisfies a consumer’s requirement more precisely (Chamberlin, 1965), and market segmentation is a strategy of offering multiple varieties of a product in recognition of consumers’ heterogeneous preferences (Smith, 1956). Whether a market is better characterized by segmentation or differentiation has important implications for policymaking, and for simulating the effects of marketing and promotion programs or other demand shifts. Our model and simulation results illustrate the necessity of considering heterogeneous preferences in simulation exercises; the two-demand-curve model can easily be extended to reflect greater heterogeneity.

2.3 An illustration using comparative statics

Consider a change in tastes and preferences that increases demand for organic FV accompanied by a negative shift in demand for conventional FV. Figure 1 illustrates shifts in demand under the assumption of product differentiation, while the assumption of market segmentation is illustrated in Figure 2. Both Figures 1 and 2 both show a negative shift in demand for a conventional market ($\Delta_c$) and a positive shift in the organic market ($\Delta_o$). The new prices and quantities demanded in the conventional and organic markets caused by the demand shift are denoted by apostrophes.

Given the assumption that product differentiation was the mechanism that shifted demand in the conventional and organic markets (Figure 1) total quantity demanded could increase or decrease, depending on the price elasticities and magnitude of the shifts. Total quantity demanded for FV increases if the decrease in quantity demanded in the conventional market is less than the increase in quantity demanded in the organic market ($[QD'_c - QD_c] < [QD'_o - QD_o]$). But it is plausible that total quantity

\[
E p_o = \frac{(\varphi \eta^h_c + \varphi \eta^h_o) \Delta_c (\psi \eta^l_o + (1-\psi) \eta^l_o - \epsilon_o) + (\psi \eta^l_o + \psi \eta^l_o) \Delta_o (\epsilon_c - \varphi \eta^l_c - (1-\varphi) \eta^l_c)}{(\epsilon_o - \psi \eta^l - (1-\psi) \eta^l_o) (\epsilon_c - \varphi \eta^l - (1-\varphi) \eta^l_c) - (\varphi \eta^l_o + (1-\varphi) \eta^l_o - \epsilon_o) (\psi \eta^l_o + (1-\psi) \eta^l_o - \epsilon_o)}.
\]
demanded would decrease \((|QD'_c - QD_c| > |QD'_o - QD_o|)\) without an increase in expenditures on FV because prices of organic produce is relatively more expensive.

Conversely, market segmentation allows the examination of how quantities change among segments (Figure 2). If the shifts in the markets were due to heterogeneous demand functions, then changes in quantity demanded will vary among the segments of consumers. This prompts the question: could the change in demand from organic consumers (segment \(h\)) result in price shifts that increase consumption of FV by conventional consumers (segment \(l\))? Assuming market segmentation, the demand curve for segment \(l\) consumers in the conventional market is between \(QD'_c + QD'_c\) and \(QD'_c + QD'_c + \Delta_c\) (where \(\Delta_c < 0\)). The decrease in price \((p'_c - p_o)\) resulting from the shift in the conventional market \((\Delta_c)\) increases quantity demanded for segment \(l\) if \(QD'_c\) is greater than \(QD'_o\). The demand curve for which \(QD'_c\) equals \(QD'_c\) is shown in Figure 2. The overall change in FV purchases for segment \(h\) \(((QD'_o - QD'_o) - (QD'_c - QD'_c))\) is likely to decrease without an increase in expenditure, similar to the scenario under the assumption of differentiation.

3. Numerical simulation methodology

In this section, we present results from four sets of simulations of shocks that affect relative demand for organic and conventional FV. In the first and second set of simulations, we assume that consumers share a single demand function for organic varieties, and a single demand function for conventional varieties. In the third and fourth sets of simulations, we introduce additional complexity in the form of market segmentation: there are two groups of consumers, and each group has its own demand function for organic varieties and its own demand function for conventional varieties. In reality, consumer preferences are sufficiently heterogeneous that each consumer (or household) has their own unique demand functions. Our simulations will demonstrate the nuances that would be lost if researchers and policy analysts assume
that all consumers share a single demand function, as compared with two; addition of more demand functions would help improve the usefulness of these simulation analyses.

Within each set of simulations, we simulate shocks that affect demand for a single commodity at a time, focusing on nine commodities and two aggregate “other” commodities. For example, there may be a shock that increases demand for organic apples relative to conventional apples; or a shock that increases demand for organic tomatoes relative to conventional tomatoes. These shocks would not affect demand, price, or quantity sold of oranges or potatoes.\footnote{Demand shocks of this nature might include, for example, the annual publication of the Environmental Working Group’s (2020) “Dirty Dozen” list of FV with “more pesticides than other crops”; or knowledge that conventional romaine lettuce (but not organic) has had a recent contamination incident.} In doing so, we assume that preferences are weakly separable at the commodity level and that consumers make two-stage budget decisions (see Deaton and Muellbauer, 1980).\footnote{An alternative characterization of consumer decision making is that some consumers may have weak separability over all organics and make two-stage budget decisions among organic and conventional FV. In a slightly different context, Denver and Christensen (2014) show that 61% of Danish consumers who “almost always” buy organic food products tend to group hypothetical baskets of FV into (a) organic FV and (b) conventional FV, rather than (a) F and (b) V. However, the “almost always” group of consumers is tiny (11% of the sample) and 58% of all consumers group by F and V, rather than organic and conventional. We thank an anonymous referee for pointing out this possibility and the example.} While this is a strong assumption, own-price elasticity estimates vary considerably across studies, and we find that estimated cross-price elasticities for different FV commodities do not even have the same sign across studies about a third of the time. Rather than allowing these inconsistent demand estimates drive results for a complex simulation involving all commodities at once, we opt for the simpler but perhaps less realistic approach.

Under the no-segmentation model, we first simulate a shock that stimulates a 5% positive shift in demand for organic FV ($\Delta_o = 0.05$) with no effects on demand for conventional FV ($\Delta_c = 0$). Our second simulation involves a 5% positive shift in demand for organic FV ($\Delta_o = 0.05$) and a 5% negative shift in demand for conventional FV ($\Delta_c = -0.05$). Under the segmentation model, we first simulate a 5% positive shift in demand for organic FV ($\Delta_o = 0.05$) by segment $h$ consumers with no effects on the segment $h$ demand curve for conventional ($\Delta_c = 0$) and no effect on segment $l$ consumers’ demand curve for organic apples ($\Delta_o = 0.05$) with no effects on demand for conventional apples ($\Delta_c = 0$).
curves. We also demonstrate results for a shock in which $\Delta_o = -0.05$ and $\Delta_c = 0.05$. In both segmentation scenarios, only the demand curves of segment $h$ consumers are affected. Any of these demand responses is conceptually possible and we provide results from all four sets of simulations to demonstrate a range of possibilities.

The FV commodities we analyze are those for which relatively recent estimates of demand elasticities are available in the literature. We draw estimated price elasticities of demand (i.e., $\eta_c$, $\eta_o$, $\eta_{co}$, and $\eta_{oc}$) from Lin et al. (2009), Kasteridis and Yen (2012), Okrent and Alston (2011), Nelson et al. (2017) and Ferrier et al. (2019), with some stochastic variation. We randomly draw sets of plausible price elasticities for 10,000 runs of the simulation. Details on these parameters are given in appendix A.2. Household expenditures on each good (i.e., $S_c$ and $S_o$) are based on Lin et al. (2009) and Kasteridis and Yen (2012), with the organic expenditure shares tripled to reflect today’s market.\(^{13}\)

Price elasticities of supply are difficult to obtain for any good, much less for specialty crops that vary in production methods (see, e.g., de Mouzon et al., 2012; Bovay and Sumner, 2018). It is expected that the positive shift in organic demand will likely be followed by a positive shift in organic supply. However, sales of organic food have significantly outpaced organic farmland acreage (Organic Trade Association, 2019) which explains why there was a 106% increase in organic imports from 2011 to 2013 (ERS, 2016). Nevertheless, estimates of own- and cross-price elasticities of supply for organic FV do not currently exist; thus, we are forced to assume values. For most of our simulations, own-price elasticities of supply (i.e., $\varepsilon_c$ and $\varepsilon_o$) are assumed to follow the distribution $\sim N(1,0.25)$ (de Mouzon et al., 2012), meaning that when the price of a conventional (organic) good rises by 1 percent, the supply of the

\(^{13}\) Nielsen data suggest that organic accounted for 10.1% of total produce sales in 2018, according to https://www.freshplaza.com/article/9067905/us-organic-fresh-produce-sales-hit-5-6-billion-in-2018/. Lin et al. (2009), Kasteridis and Yen (2012), and Nelson et al. (2017) use expenditure shares implying that organic accounted for 3.5% of total produce sales during their study periods (2006 to 2013).
conventional (organic) good rises by 1 percent. Cross-price elasticities are assumed to be $\varepsilon_{co} = 0$ and $\varepsilon_{oc} \sim N(-0.5, 0.1)$, reflecting that conventional products cannot be marketed as organic but organic products may be marketed as conventional.

For the segmentation model, we assume that segment $h$ consumers purchase 56% of all organic products sold, and 43% of all conventional products sold, as reported by Nelson et al. (2017). Given that organic products make up 10% of total expenditures on FV in our simulation, segment $h$ consumers spend 13% of their FV budget on organic FV. Segment $l$ consumers, meanwhile, spend about 8% of their FV budget on organic FV.

4. Results: Prices and Quantities under Differentiation and Segmentation

Results of our simulations are shown in Tables 1 through 4 and in Figure 3. The numbers in these tables and figure represent median results from 10,000 runs of models simulating demand shocks that affect one good at a time. A key to understanding all the results is that organic and conventional varieties are substitutes in demand. Table 1 displays the market effects of a 5% positive shift in demand for organic FV commodities, assuming a single demand curve. Expenditure-weighted median organic consumption is simulated to increase by 3.0%, while the median price of organics rises by 2.9%. The expenditure-weighted average equilibrium prices and consumption of conventional FV are simulated to decrease by 0.4%, which is driven by substitution between conventional and organic. Given the market shares of organic and conventional FV, total consumption of FV remains roughly constant under this scenario.

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14 We vary the distribution of supply elasticities for one set of simulation results, maintaining the same relative values of the four supply elasticities and the relationships between the means and standard deviations, but allowing $\varepsilon_c = \varepsilon_o$ to vary from 0.01 to 10.

15 Of course, in the long run, producers of conventional FV could switch to producing organic FV. (Organic certification in the United States requires three years of growing using organic practices.) Our model is designed to reflect shorter-term changes in market equilibria. As Gardner (1979) discusses, cross-elasticities of supply are unlikely to be positive. Moreover, an organic grower who realizes that demand for conventional products has shifted out may at any time abandon organic practices, give up certification, and market her products as conventional. In the long run, then, we would expect that $\varepsilon_{oe} = \varepsilon_{eo} = -\varepsilon_{oo} = -\varepsilon_{cc}$. In the very short run, of course, supply is completely inelastic. So, in the medium-short run (i.e., the period relevant for any policy analysis), assuming that $\varepsilon_{oe} = -0.5\varepsilon_{oo} = -0.5\varepsilon_{cc}$ (halfway between the very short run and the long run) seems reasonable.

16 Please see Appendix Table A.1 for details on the parameters used in the expenditure-weighted average calculations.
A somewhat different and more nuanced picture emerges from the segmentation model, results of which are displayed in Table 2. The simulation presented in Table 2 follows assumptions identical to those used to generate Figure 2, where segment $h$ consumers are entirely responsible for the increased demand for organic FV. The demand shift causes prices of organic FV to rise by about 1.7%, on average, while the prices of conventional FV fall by about 0.1%, due to organic and conventional FV being substitutes in both consumption and production. Segment $h$ individuals, who consume 56% of organic products and 43% of conventional products (based on Nelson et al., 2017), and who are responsible for the demand shift, are simulated to consume about 5.3% more organic FV and 1.1% less conventional, after the shift occurs. Segment $l$ individuals are simulated to consume about 2.8% less organic FV and about 0.6% more conventional FV, a result that is driven by the price changes. Since conventional FV make up the majority of segment $l$ consumption, segment $l$ consumes 0.3% more FV overall after the shock; because of the shift toward consuming more of the higher-priced organic products, segment $h$ consumes 0.2% less FV overall after the shock. Thus, if we assume segmentation—which as discussed above seems to be more plausible given the large share of organic consumption by a small group of consumers—we find that a shock that increases relative demand for organic FV generates gains in FV consumption for the large segment of consumers who buy relatively less organic FV. In contrast, the consumers who are responsible for most organic purchases pay more for their FV and consume less.

Tables 3 and 4 show results for simulations with 5% increases in demand for organics and 5% decreases in demand for conventional. Again, all changes in demand in the segmentation model are driven by segment $h$ consumers. Results are similar to those in Tables 1 and 2 but are of greater magnitude. In particular, the negative effects on prices and consumption of conventional FV are amplified. Under the no-segregation model (Table 3), overall consumption of FV falls by 2.0%, a result driven by the shift away from the conventional FV that make up the majority of consumption. Under the segmentation model (Table 4), we find that despite a 1.9% increase in consumption of organic FV, the segment $h$
consumers who buy the majority of organic FV end up consuming 3.0% less total FV. At the same time, while consumption of conventional FV falls by 1.0%, the segment \( l \) consumers who buy the majority of conventional FV increase their overall consumption of FV by 1.0%.

In Table 5, we show that the qualitative results of our simulations under the assumption of segmentation are robust to a range of assumptions about the own-price elasticities of supply. The signs of all of the expenditure-weighted averages in Tables 2 and 4 are unchanged if using any mean value of \( \varepsilon_c = \varepsilon_o \) ranging from 0.5 to 10 (while maintaining the relationship between the own- and cross-price elasticities and the ratios of the standard deviations to the means). Furthermore, the expenditure-weighted effects on consumption of segment \( h \) and segment \( l \) maintain the same signs for \( \varepsilon_c = \varepsilon_o \) with a mean value as low as 0.01.

Our results, especially when considered as a range of scenarios with increasingly severe shocks, demonstrate the importance of price effects in determining consumption choices even when one segment of consumers shares a preference for another product such as organic FV. Across each of the scenarios modeled using segmentation, the negative effects of a shock that increases the relative preference of segment \( h \) consumers for organic products leads to a decrease in overall consumption of FV among segment \( h \) consumers, and an increase in overall consumption of FV among segment \( l \) consumers. This result holds unless segment \( h \)’s share of consumption of organic products (\( \psi \)) is very high, or segment \( h \)’s share of consumption of conventional products (\( \phi \)) is very low, or both. In Figure 3, we explore the sensitivity of our results to consumption shares \( \phi \) and \( \psi \).\(^{17}\) Panel A shows that under a shock that increases segment \( h \) consumers’ demand for organic FV by 5%, overall FV consumption by segment \( h \)

\(^{17}\) Note that we only provide results for the cases where \( \psi \geq \phi \); otherwise, we could not describe segment \( h \) consumers as having a strong preference for organic. The most recent available data (from 2013) show that more wealthy households make about 56% of all organic fruit expenditures (\( \psi \)) and 43% of all conventional fruit expenditures (\( \phi \)).
increases only if $\phi < 0.68\psi - 0.28\psi^2$. Under the same shock, overall FV consumption by segment $l$ increases, no matter the value of $\phi$ and $\psi$. Relative to Nelson et al. (2017) data for 2013, segment $h$’s consumption share of organic FV would have to increase substantially, and its consumption share of conventional FV would have to decrease substantially, for the signs of the results in Tables 2 and 4 to change. For example, under the scenario with no negative demand shift facing conventional FV, if $(\psi, \phi) = (0.66, 0.32)$, rather than $(0.56, 0.43)$ as in the main scenario represented in Table 2, the overall FV consumption of segment $l$ would increase by about 0.4% and the overall FV consumption of segment $h$ would increase by 0.02%. In the scenario represented by panel B, the shocks increase overall consumption of segment $h$ only when the value of $\phi$ is very small—that is, when the consumers with a strong preference for organic FV consume less than 8% of all conventional FV.

Note that none of our simulation models involves substitution in production or consumption between commodities. Instead, for the sake of clearer illustrations, we simulate demand shocks and price and consumption shifts that involve a single good at a time. These can also be thought of as case studies for demand shocks affecting all FV at once. As discussed, inconsistent estimates of cross-commodity price elasticities of demand mean that a simulation involving shocks that affect multiple commodities differentially would yield little meaningful insight.

5. Conclusions

Assuming organic FV are substitutes for conventional, a positive shift in demand for organic FV may affect the prices of conventional FV, in turn resulting in improved or worsened dietary outcomes for consumers who rarely or never buy organic FV. The USDA Organic seal theoretically increased utility for consumers who preferred organic food but did not previously have a reliable signal of production
characteristics (Zago and Pick 2004). However, it is not clear what the welfare effects were for consumers who do not prefer organic food.

Our paper builds on the existing literature on the economics of organic food by studying the consequences of rising demand for organic FV using a multi-market model. By explicitly accounting for linkages between conventional and organic FV markets, our findings shed light on the potential consequences of efforts to raise organic FV demand that would be obscured in a single-market approach. Although our focus is on the links between organic and conventional FV markets, we contribute to the literature on multi-market EDMs more generally.

Simulation results indicate that the increasing demand for organic FV may lead to decreasing consumption of FV overall, and that changes FV intake vary by consumer segment. When we assume consumers are homogeneous and expenditure is fixed, a 5% increase in demand for organic FV leads to more consumption of organic produce just as we would expect, but the gains are more than offset by falling consumption of conventional produce. If we assume demand for conventional FV holds steady, overall consumption remains at about the same level. If we assume that rising organic FV demand is accompanied by an equal negative shift in demand for conventional produce, overall FV consumption drops by 2.0%. (Reported percentage changes are medians of results generated by considering several different sets of price elasticities taken from the literature.)

We next move on to our segmented market scenario and assume that one consumer segment accounts for the majority of organic FV purchases, as empirical evidence suggests. We also assume that this segment is entirely responsible for the 5% increase in organic FV demand. For this segment, overall consumption of FV falls as the decrease in conventional FV consumption more than offsets greater demand for organic FV. When there is a 5% increase in demand for organic FV with no effect on demand for conventional FV, total FV consumption among high-volume consumers of organic produce falls by 0.2%, and total FV consumption among low-volume consumers of organic produce rises by 0.3%, a
consequence of a price rise affecting both types of FV. When there is a 5% drop in conventional demand in addition to the 5% increase in demand for organic, overall FV consumption drops by 3.0% among the consumer segment responsible for most organic purchases. But for the consumer segment that purchases relatively little organic produce, overall consumption of FV increases by 1.0% when there is a corresponding 5% downward shift in conventional FV demand.

Using multi-market EDMs that allow for product differentiation with and without market segmentation, we estimated the implications of rising demand for organic FV for consumption of all FV. In the differentiation-only model, the price of conventional FV falls while the price of organic FV rises. Similarly, the price of conventional FV falls while the price of organic FV rises in the differentiation with segmentation model; however, the price rise for organic FV is much more muted than in the differentiation model. The change in consumption of each product is more muted than in the differentiation-only model. It is important to note that these results are particularly sensitive to the relative prices of organic and conventional FV, since consumers have elastic demand for FV, and particularly for organic FV.

Our contribution to the multi-market EDM literature illustrates how promotional programs may have competing goals that result in unintended consequences. While our theoretical model and numerical simulation suggest that organic promotion policies may not appropriately account for consumer heterogeneity, we do not suggest that organic-promotion programs should be abandoned in order to increase consumption of FV (and other healthy foods). Instead, we emphasize the importance of considering the distribution of costs and benefits as a part of program evaluation, especially as they relate to substitution decisions by consumers. This is necessary as substitution effects may result in lower consumption of FV.

Future research could focus on measuring both demand by market segments and explaining whether the recent growth in consumption of organic FV has been driven by growth in demand or
reduction in the price premium for organic foods relative to conventional foods, for certain commodities (see Jaenicke and Carlson, 2015; Carlson and Jaenicke, 2016). Moreover, have high-volume organic consumers been responsible for any positive shift in organic demand? Or has growth in demand for organics come from consumers who previously did not purchase organic FV, or who did not purchase FV at all? What do better-calibrated demand estimates suggest about the effects of increased organic demand on overall FV consumption? Answering these questions will further elucidate the nuanced implications of product differentiation and market segmentation.

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Figure 1. Changes in Prices and Quantities in the Conventional and Organic Markets assuming Product Differentiation and No Market Segmentation

Figure 2. Changes in Prices and Quantities in the Conventional and Organic Markets assuming Product Differentiation with Market Segmentation
Panel A: 5% Increase in Demand for Organic

Panel B: 5% Increase in Demand for Organic and 5% Decrease in Demand for Conventional

Figure 3. Sensitivity Analysis: Changes in Total Consumption of Fruits and Vegetables, by Segment, Depending upon Segment’s Consumers’ Shares of Expenditures on Organic and Conventional Products ($\psi$ and $\phi$).

Table 1. Median Changes in Price and Consumption assuming Product Differentiation and No Market Segmentation: 5% Positive Shift in Demand for Organic Products

| Product | Change in Price | Change in Consumption | Change in Total Consumption |
|---------|-----------------|-----------------------|----------------------------|
| Apples  | -0.10%          | 3.02%                 | -0.10%                     | 2.90%                     | 0.25%                       |
| Good              | Base Year 2020 | Expenditure-Weighted Changes | Base Year 2023 |
|-------------------|----------------|-----------------------------|----------------|
| Bananas           | -1.70%         | 2.32%                       | -1.67%         |
| Grapes            | -0.26%         | 2.31%                       | -0.25%         |
| Oranges           | -0.10%         | 2.55%                       | -0.10%         |
| Strawberries      | -0.03%         | 2.42%                       | -0.03%         |
| Other Fruits      | -0.23%         | 3.04%                       | -0.22%         |
| Carrots           | -0.15%         | 2.94%                       | -0.15%         |
| Onions            | -0.09%         | 3.11%                       | -0.09%         |
| Potatoes          | -0.12%         | 3.43%                       | -0.12%         |
| Tomatoes          | -0.02%         | 3.01%                       | -0.02%         |
| Other Vegetables  | -0.84%         | 2.99%                       | -0.82%         |
| Expenditure-Weighted Averages | -0.42% | 2.93%                       | -0.42%         |

Notes: Each row represents results for a demand shock affecting one good at a time. The estimates reported here are medians of 10,000 runs of the model. Expenditure-weighted changes are based on expenditure shares from Lin et al. (2009) and Kasteridis and Yen (2012), adjusted to reflect contemporary expenditure patterns.
Table 2. Median Changes in Price and Consumption assuming Product Differentiation with Market Segmentation: 5% Positive Shift in Demand for Organic Products

| Product      | Change in Price | Change in Conventional Consumption | Change in Organic Consumption | Change in Total Consumption |
|--------------|-----------------|-------------------------------------|------------------------------|----------------------------|
|              | Conventional    | Organic                             | Segment h                     | Segment l                  | Conventional     | Organic | Segment h | Segment l |
| Apples       | -0.02%          | 1.70%                               | -0.31% 0.19%                 | 5.31% -2.85%               | -0.02% 1.61%    | 0.52%   | 0.09%     |
| Bananas      | -0.42%          | 1.45%                               | -3.64% 2.01%                 | 4.72% -2.17%               | -0.42% 1.56%    | -2.40%  | 1.55%     |
| Grapes       | -0.08%          | 1.31%                               | -0.50% 0.25%                 | 3.52% -1.31%               | -0.08% 1.30%    | 0.09%   | 0.09%     |
| Oranges      | -0.03%          | 1.43%                               | -0.23% 0.12%                 | 3.95% -1.66%               | -0.03% 1.37%    | 0.39%   | -0.04%    |
| Strawberries | -0.01%          | 1.36%                               | -0.07% 0.03%                 | 3.56% -1.38%               | -0.01% 1.30%    | 0.47%   | -0.10%    |
| Other Fruits | -0.05%          | 1.72%                               | -0.70% 0.45%                 | 5.50% -2.96%               | -0.05% 1.65%    | 0.21%   | 0.13%     |
| Carrots      | -0.04%          | 1.66%                               | -0.37% 0.22%                 | 5.05% -2.60%               | -0.04% 1.58%    | 0.43%   | -0.04%    |
| Onions       | -0.02%          | 1.75%                               | -0.26% 0.16%                 | 5.64% -3.17%               | -0.02% 1.66%    | 0.61%   | -0.15%    |
| Potatoes     | -0.02%          | 1.93%                               | -0.43% 0.30%                 | 7.19% -4.71%               | -0.02% 1.83%    | 0.69%   | -0.16%    |
| Tomatoes     | -0.01%          | 1.69%                               | -0.06% 0.04%                 | 5.21% -2.77%               | -0.01% 1.59%    | 0.71%   | -0.22%    |
| Other Vegetables | -0.17%      | 1.73%                               | -2.16% 1.34%                 | 4.76% -3.18%               | -0.17% 1.70%    | -0.97%  | 0.88%     |
| Expenditure-Weighted Averages | -0.10% | 1.67%                               | -1.06% 0.64%                 | 5.34% -2.85%               | -0.09% 1.62%    | -0.24%  | 0.35%     |

Notes: Each row represents results for a demand shock affecting one good at a time. The estimates reported here are medians of 10,000 runs of the model. Expenditure-weighted changes are based on expenditure shares from Lin et al. (2009) and Kasteridis and Yen (2012), adjusted to reflect contemporary expenditure patterns. Expenditure shares for segments h and l are based on Nelson et al. (2017).

Table 3. Median Changes in Price and Consumption assuming Product Differentiation and No Market Segmentation: 5% Positive Shift in Demand for Organic Products and 5% Negative Shift in Demand for Conventional Products

| Product     | Change in Price | Change in Consumption | Change in Total Consumption |
|-------------|-----------------|-----------------------|----------------------------|
|             | Conventional    | Organic               | Conventional | Organic |
| Apples      | -0.02%          | 1.70%                 | -0.31% 0.19% | 5.31% -2.85% |
| Bananas     | -0.42%          | 1.45%                 | -3.64% 2.01% | 4.72% -2.17% |
| Grapes      | -0.08%          | 1.31%                 | -0.50% 0.25% | 3.52% -1.31% |
| Oranges     | -0.03%          | 1.43%                 | -0.23% 0.12% | 3.95% -1.66% |
| Strawberries | -0.01%         | 1.36%                 | -0.07% 0.03% | 3.56% -1.38% |
| Other Fruits | -0.05%         | 1.72%                 | -0.70% 0.45% | 5.50% -2.96% |
| Carrots     | -0.04%          | 1.66%                 | -0.37% 0.22% | 5.05% -2.60% |
| Onions      | -0.02%          | 1.75%                 | -0.26% 0.16% | 5.64% -3.17% |
| Potatoes    | -0.02%          | 1.93%                 | -0.43% 0.30% | 7.19% -4.71% |
| Tomatoes    | -0.01%          | 1.69%                 | -0.06% 0.04% | 5.21% -2.77% |
| Other Vegetables | -0.17%     | 1.73%                 | -2.16% 1.34% | 4.76% -3.18% |
| Expenditure-Weighted Averages | -0.10% | 1.67%                 | -1.06% 0.64% | 5.34% -2.85% |

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Table 4. Median Changes in Price and Consumption assuming Product Differentiation with Market Segmentation: 5% Positive Shift in Demand for Organic Products and 5% Negative Shift in Demand for Conventional Products

| Product   | Change in Price | Change in Conventional Consumption | Change in Organic Consumption | Change in Total Consumption |
|-----------|-----------------|------------------------------------|------------------------------|-----------------------------|
|           | Convention      | Organic                            | Segment b                    | Segment l                   | Convention | Organic | Segment b | Segment l |
| Apples    | -1.08%          | 1.51%                              | -3.77%                       | 1.08%                       | 5.74%      | -2.57%  | -1.05%    | 1.96%     |
| Bananas   | -1.47%          | 1.42%                              | -4.90%                       | 2.73%                       | 5.68%      | -2.35%  | -1.42%    | 2.03%     |
| Grapes    | -0.88%          | 1.16%                              | -2.73%                       | 0.63%                       | 3.88%      | -1.20%  | -0.84%    | 1.55%     |

Notes: Each row represents results for a demand shock affecting one good at a time. The estimates reported here are medians of 10,000 runs of the model. Expenditure weighted changes are based on expenditure shares from Lin et al. (2009) and Kasteridis and Yen (2012), adjusted to reflect contemporary expenditure patterns.
### Table 5. Median Changes in Expenditure-Weighted Price and Consumption assuming Product Differentiation with Market Segmentation: Various assumptions about shifts and elasticities of supply

| Shift | $\varepsilon_{oo} = \frac{-2\varepsilon_{cc}}{\varepsilon_{cc}}$ | Change in Price | Change in conv. Consumption | Change in org. Consumption | Change in total consumption | $\varepsilon_{oo} = \frac{-2\varepsilon_{cc}}{\varepsilon_{cc}}$ |
|-------|------------------|-----------------|-----------------------------|--------------------------|-------------------------|------------------|
|       |                  | Conventional     | Organ ic only                | Segment $b$               | Segment $l$              | Conventional     | Organ ic only                | Segment $b$               | Segment $l$              |
| 0.01  | Organic only     | 0.28%           | 2.80%                       | 0.96%                    | 0.73%                   | 3.66%           | 4.59%                       | 0.003%                   | 0.03%                    | -0.37%                   | 0.28%                    |
| 0.01  | Both             | -1.83%          | -2.81%                      | -3.18%                   | 2.37%                   | 3.77%           | -4.72%                      | -0.02%                   | 0.04%                    | -2.29%                   | 1.80%                    |
| 0.5   | Organic only     | -0.01%          | 2.11%                       | -0.97%                   | 0.73%                   | 4.69%           | -3.56%                      | -0.004%                  | 0.99%                    | -0.25%                   | 0.37%                    |
| 0.5   | Both             | -1.37%          | 1.99%                       | -3.91%                   | 1.71%                   | 5.06%           | -3.43%                      | -0.66%                   | 1.25%                    | -2.76%                   | 1.30%                    |
| 1     | Organic only     | -0.10%          | 1.67%                       | -1.06%                   | 0.64%                   | 5.34%           | -2.85%                      | -0.09%                   | 1.62%                    | -0.24%                   | 0.35%                    |
| 1     | Both             | -1.08%          | 1.52%                       | -4.29%                   | 1.33%                   | 5.78%           | -2.65%                      | -1.04%                   | 1.95%                    | -2.99%                   | 1.02%                    |
| 5     | Organic only     | -0.09%          | 0.62%                       | -1.42%                   | 0.28%                   | 7.12%           | -1.08%                      | -0.45%                   | 3.42%                    | -0.32%                   | 0.17%                    |
| 5     | Both             | -0.39%          | 0.53%                       | -5.08%                   | 0.49%                   | 7.51%           | -0.92%                      | -1.90%                   | 3.71%                    | -3.47%                   | 0.38%                    |
| 10    | Organic only     | -0.06%          | 0.35%                       | -1.54%                   | 0.16%                   | 7.62%           | -0.60%                      | -0.57%                   | 3.97%                    | -0.36%                   | 0.10%                    |
|   | Both | -0.21% | 0.29% | -5.30% | 0.28% | 7.96% | -0.50% | -2.11% | 4.20% | -3.60% | 0.21% |
|---|------|--------|-------|--------|-------|-------|--------|--------|-------|--------|-------|

*Notes:* The estimates reported here are expenditure-weighted average effects for shocks affecting one commodity at a time, and are medians of 10,000 runs of the model. Expenditure-weighted changes are based on expenditure shares from Lin et al. (2009) and Kasteridis and Yen (2012), adjusted to reflect contemporary expenditure patterns. Expenditure shares for segments $h$ and $l$ are based on Nelson et al. (2017). While the mean own-price elasticities of supply vary across rows of this table, the relationships between the own- and cross-price elasticities of supply, and the mean and standard deviations, are the same in each row and as in tables 2 and 4.
Appendix

A.1. Derivation of equilibrium price equations.

Here we demonstrate the derivation of equilibrium price equations (4a), (4b), (8a), and (8b).

A.1.1. Product differentiation with a single demand curve

Beginning with equations (3a) through (3d):

(3a) \( EQD_c = \eta_c(Ep_c + \Delta_c) + \eta_{co}(Ep_o + \Delta_o) \),

(3b) \( EQD_o = \eta_{oc}(Ep_c + \Delta_c) + \eta_o(Ep_o + \Delta_o) \),

(3c) \( EQS_c = \epsilon_c(Ep_c) + \epsilon_{co}(Ep_o) \),

(3d) \( EQS_o = \epsilon_{oc}(Ep_c) + \epsilon_o(Ep_o) \),

and the market-clearing condition for conventional (i.e., \( EQD_c = EQS_c \)):

\[
\eta_c(Ep_c + \Delta_c) + \eta_{co}(Ep_o + \Delta_o) = \epsilon_c(Ep_c) + \epsilon_{co}(Ep_o) \Rightarrow
\]

\[
Ep_o(\eta_{co} - \epsilon_{co}) + \eta_c\Delta_c + \eta_{co}\Delta_o = Ep_c(\epsilon_c - \eta_c) \Rightarrow
\]

\[
Ep_c = \frac{Ep_o(\eta_{co} - \epsilon_{co}) + \eta_c\Delta_c + \eta_{co}\Delta_o}{(\epsilon_c - \eta_c)}.
\]

By symmetry:

\[
Ep_o = \frac{Ep_c(\eta_{oc} - \epsilon_{oc}) + \eta_{oc}\Delta_c + \eta_o\Delta_o}{(\epsilon_o - \eta_o)}.
\]

Now plug \( Ep_o \) into \( Ep_c \):

\[
Ep_c = \left(\frac{Ep_c(\eta_{oc} - \epsilon_{oc}) + \eta_{oc}\Delta_c + \eta_o\Delta_o}{(\epsilon_o - \eta_o)}\right)(\eta_{co} - \epsilon_{co}) + \eta_c\Delta_c + \eta_{co}\Delta_o \Rightarrow
\]

\[
Ep_c(\epsilon_c - \eta_c)(\epsilon_o - \eta_o) = (Ep_c(\eta_{oc} - \epsilon_{oc}) + \eta_{oc}\Delta_c + \eta_o\Delta_o)(\eta_{co} - \epsilon_{co}) + (\eta_c\Delta_c + \eta_{co}\Delta_o)(\epsilon_o - \eta_o) \Rightarrow
\]

\[
Ep_c(\epsilon_c - \eta_c)(\epsilon_o - \eta_o) - Ep_c(\eta_{oc} - \epsilon_{oc})(\eta_{co} - \epsilon_{co}) = (\eta_{oc}\Delta_c + \eta_o\Delta_o)(\eta_{co} - \epsilon_{co}) + (\eta_c\Delta_c + \eta_{co}\Delta_o)(\epsilon_o - \eta_o) \Rightarrow
\]
(4a) \( E_{p_c} = \frac{(\eta_{oc}\Delta_c + \eta_o\Delta_o) (\varepsilon_{co} - \eta_{co}) - (\eta_c\Delta_c + \eta_{co}\Delta_o) (\eta_o - \varepsilon_o)}{(\varepsilon_c - \eta_c)(\varepsilon_o - \eta_o) - (\eta_{oc} - \varepsilon_{oc})(\eta_{co} - \varepsilon_{co})}. \)

Plug \( E_{p_c} \) into \( E_{p_o} \):

\[
E_{p_o} = \frac{\left(\frac{E_{p_o}(\eta_{co} - \varepsilon_{co}) + \eta_c\Delta_c + \eta_{co}\Delta_o}{(\varepsilon_c - \eta_c)(\varepsilon_o - \eta_o)}\right) (\eta_{oc} - \varepsilon_{oc}) + \eta_{oc}\Delta_c + \eta_o\Delta_o}{(\varepsilon_o - \eta_o)}
\]

\( E_{p_o} (\varepsilon_o - \eta_o)(\varepsilon_c - \eta_c) = (E_{p_o}(\eta_{co} - \varepsilon_{co}) + \eta_c\Delta_c + \eta_{co}\Delta_o)(\eta_{oc} - \varepsilon_{oc}) + (\eta_{oc}\Delta_c + \eta_o\Delta_o)(\varepsilon_c - \eta_c) \Rightarrow
\]

\( E_{p_o} (\varepsilon_o - \eta_o)(\varepsilon_c - \eta_c) = (E_{p_o}(\eta_{co} - \varepsilon_{co}) + \eta_{oc}\Delta_c + \eta_o\Delta_o)(\eta_{oc} - \varepsilon_{oc}) + (\eta_{oc}\Delta_c + \eta_o\Delta_o)(\varepsilon_c - \eta_c) \Rightarrow
\]

(4b) \( E_{p_o} = \frac{(\eta_c\Delta_c + \eta_{co}\Delta_o)(\varepsilon_{oc} - \eta_{oc}) - (\eta_{oc}\Delta_c + \eta_o\Delta_o)(\eta_c - \varepsilon_c)}{(\varepsilon_o - \eta_o)(\varepsilon_c - \eta_c) - (\eta_{co} - \varepsilon_{co})(\eta_{oc} - \varepsilon_{oc})}. \)

A.1.2. Product differentiation with market segmentation

Beginning with equations (7a) through (7h):

(7a) \( EQD^h_c = \eta^h_c (E_{p_c} + \Delta_c) + \eta^h_{co} (E_{p_o} + \Delta_o), \)

(7b) \( EQD^l_c = \eta^l_c (E_{p_c}) + \eta^l_{co} (E_{p_o}), \)

(7c) \( EQD^h_o = \eta^h_{oc} (E_{p_c} + \Delta_c) + \eta^h_o (E_{p_o} + \Delta_o), \)

(7d) \( EQD^l_o = \eta^l_{oc} (E_{p_c}) + \eta^l_o (E_{p_o}), \)

(7e) \( EQS_c = \varepsilon_c(E_{p_c}) + \varepsilon_{co}(E_{p_o}), \)

(7f) \( EQS_o = \varepsilon_{oc}(E_{p_c}) + \varepsilon_o(E_{p_o}), \)

(7g) \( EQD_c = \phi EQD^h_c + (1 - \phi)EQD^l_c, \)

(7h) \( EQD_o = \psi EQD^h_o + (1 - \psi)EQD^l_o, \)

the market-clearing condition for conventional (i.e., \( EQD_c = EQS_c \)):

\( EQD^h_c + (1 - \phi)EQD^l_c = \varepsilon_c(E_{p_c}) + \varepsilon_{co}(E_{p_o}) \Rightarrow \)
\[ \varphi[\eta_c^h(Ep_c + \Delta_c) + \eta_{co}^h(Ep_o + \Delta_o)] + (1 - \varphi)[\eta_c^i(Ep_c) + \eta_{co}^i(Ep_o)] = \varepsilon_c(Ep_c) + \varepsilon_{co}(Ep_o) \Rightarrow \]

\[ Ep_o(\varphi\eta_{co}^h + (1 - \varphi)\eta_{co}^i - \varepsilon_{co}) + \varphi\eta_c^h\Delta_c + \varphi\eta_{co}^h\Delta_o = Ep_c(\varepsilon_c - \varphi\eta_c^h - (1 - \varphi)\eta_c^i) \Rightarrow \]

\[ Ep_c = \frac{Ep_o(\varphi\eta_{co}^h + (1 - \varphi)\eta_{co}^i - \varepsilon_{co}) + \varphi\eta_c^h\Delta_c + \varphi\eta_{co}^h\Delta_o}{(\varepsilon_c - \varphi\eta_c^h - (1 - \varphi)\eta_c^i)} \]

and the market-clearing condition for organic (i.e., \( EQD_o = EQS_o \)):

\[ \psi EQD_o^h + (1 - \psi) EQD_o^i = \varepsilon_{oc}(Ep_c) + \varepsilon_o(Ep_o) \Rightarrow \]

\[ \psi[\eta_{oc}^h(Ep_c + \Delta_c) + \eta_o^h(Ep_o + \Delta_o)] + (1 - \psi)[\eta_{oc}^i(Ep_c) + \eta_o^i(Ep_o)] = \varepsilon_{oc}(Ep_c) + \varepsilon_o(Ep_o) \Rightarrow \]

\[ Ep_c(\psi\eta_{oc}^h + (1 - \psi)\eta_{oc}^i - \varepsilon_{oc}) + \psi\eta_{oc}^h\Delta_c + \psi\eta_o^h\Delta_o = Ep_o(\varepsilon_o - \psi\eta_o^h - (1 - \psi)\eta_o^i) \Rightarrow \]

\[ Ep_o = \frac{Ep_c(\psi\eta_{oc}^h + (1 - \psi)\eta_{oc}^i - \varepsilon_{oc}) + \psi\eta_{oc}^h\Delta_c + \psi\eta_o^h\Delta_o}{(\varepsilon_o - \psi\eta_o^h - (1 - \psi)\eta_o^i)} . \]

Now plug \( Ep_o \) into \( Ep_c \):

\[ Ep_c = \frac{(Ep_o(\psi\eta_{oc}^h + (1 - \psi)\eta_{oc}^i - \varepsilon_{oc}) + \psi\eta_{oc}^h\Delta_c + \psi\eta_o^h\Delta_o)(\varphi\eta_{co}^h + (1 - \varphi)\eta_{co}^i - \varepsilon_{co}) + \varphi\eta_c^h\Delta_c + \varphi\eta_{co}^h\Delta_o}{(\varepsilon_c - \varphi\eta_c^h - (1 - \varphi)\eta_c^i)} \Rightarrow \]

\[ Ep_c(\varepsilon_c - \varphi\eta_c^h - (1 - \varphi)\eta_c^i)(\varepsilon_o - \psi\eta_o^h - (1 - \psi)\eta_o^i) \]

\[ = (Ep_c(\psi\eta_{oc}^h + (1 - \psi)\eta_{oc}^i - \varepsilon_{oc}) + \psi\eta_{oc}^h\Delta_c + \psi\eta_o^h\Delta_o)(\varphi\eta_{co}^h + (1 - \varphi)\eta_{co}^i - \varepsilon_{co}) + \varphi\eta_c^h\Delta_c + \varphi\eta_{co}^h\Delta_o \]

\[ + \varphi\eta_c^h\Delta_c(\varepsilon_o - \psi\eta_o^h - (1 - \psi)\eta_o^i) + \varphi\eta_{co}^h\Delta_o(\varepsilon_o - \psi\eta_o^h - (1 - \psi)\eta_o^i) \Rightarrow \]

\[ Ep_c(\varepsilon_c - \varphi\eta_c^h - (1 - \varphi)\eta_c^i)(\varepsilon_o - \psi\eta_o^h - (1 - \psi)\eta_o^i) \]

\[ - Ep_o(\psi\eta_{oc}^h + (1 - \psi)\eta_{oc}^i - \varepsilon_{oc})(\varphi\eta_{co}^h + (1 - \varphi)\eta_{co}^i - \varepsilon_{co}) \]

\[ = (\psi\eta_{oc}^h\Delta_c + \psi\eta_o^h\Delta_o)(\varphi\eta_{co}^h + (1 - \varphi)\eta_{co}^i - \varepsilon_{co}) + (\varphi\eta_c^h\Delta_c + \varphi\eta_{co}^h\Delta_o)(\varepsilon_o - \psi\eta_o^h - (1 - \psi)\eta_o^i) \Rightarrow \]
A.2. Details about parameters used in simulations.

Our main sources for price elasticities of demand for organic and conventional FV (including cross-price elasticities for the same good) are Lin et al (2009; henceforth LYHS) and Kasteridis and Yen (2012; henceforth KY). LYHS estimate price elasticities for five organic and conventional fresh fruits, plus an aggregate “other fruits”; KY estimate price elasticities for four organic and five conventional fresh vegetables, plus an aggregate “other vegetables”. We use these estimates as a starting point. There are some major concerns about each of the suites of price elasticities. For example, one would it is natural to reason that organic apples are substitutes for conventional apples, yet Lin et al. (2009) estimate \( \eta_{ao} \) and \( \eta_{oa} \) for apples, neither with statistical significance at even the .10 level. Moreover, many of the

\[
(8a) E_{pc} = \frac{(\psi \eta_{oc} + (1-\varphi)\eta_{co} - \varepsilon_{co}) + (\varphi \eta_{oc} \Delta_c + \psi \eta_{co} \Delta_o)(\varepsilon_{oc} - \psi \eta_{oc} - (1-\varphi)\eta_{o})}{(\varepsilon_{co} - \varphi \eta_{co} - (1-\varphi)\eta_{c})(\varepsilon_{oa} - \varphi \eta_{oa} - (1-\varphi)\eta_{o})}.
\]

Plug \( E_{pc} \) into \( E_{po} \):

\[
E_{po} = \frac{(E_{pc}(\varphi \eta_{co} + (1-\varphi)\eta_{co} - \varepsilon_{co}) + \varphi \eta_{oc} \Delta_c + \psi \eta_{co} \Delta_o)(\psi \eta_{oc} + (1-\varphi)\eta_{o} - \varepsilon_{oc}) + \psi \eta_{oc} \Delta_c + \varphi \eta_{co} \Delta_o)}{(\varepsilon_{co} - \varphi \eta_{co} - (1-\varphi)\eta_{c})(\varepsilon_{oa} - \varphi \eta_{oa} - (1-\varphi)\eta_{o})} \Rightarrow
\]

\[
E_{po}(\varepsilon_{o} - \psi \eta_{o} - (1-\varphi)\eta_{o})(\varepsilon_{c} - \varphi \eta_{c} - (1-\varphi)\eta_{c})
\]

\[
= (E_{po}(\varphi \eta_{co} + (1-\varphi)\eta_{co} - \varepsilon_{co}) + \varphi \eta_{oc} \Delta_c + \psi \eta_{co} \Delta_o)(\psi \eta_{oc} + (1-\varphi)\eta_{o} - \varepsilon_{oc}) + \psi \eta_{oc} \Delta_c(\varepsilon_{c} - \varphi \eta_{c} - (1-\varphi)\eta_{c}) + \psi \eta_{oc} \Delta_o(\varepsilon_{c} - \varphi \eta_{c} - (1-\varphi)\eta_{c}) \Rightarrow
\]

\[
E_{po}(\varepsilon_{o} - \psi \eta_{o} - (1-\varphi)\eta_{o})(\varepsilon_{c} - \varphi \eta_{c} - (1-\varphi)\eta_{c})
\]

\[
= (\varphi \eta_{co} + (1-\varphi)\eta_{co} - \varepsilon_{co})(\psi \eta_{oc} + (1-\varphi)\eta_{o} - \varepsilon_{oc}) + (\psi \eta_{oc} \Delta_c + \varphi \eta_{co} \Delta_o)(\varepsilon_{c} - \varphi \eta_{c} - (1-\varphi)\eta_{c}) \Rightarrow
\]

\[
(8b) E_{po} = \frac{(\varphi \eta_{co} + (1-\varphi)\eta_{co} - \varepsilon_{co})(\psi \eta_{oc} + (1-\varphi)\eta_{o} - \varepsilon_{oc}) + (\psi \eta_{oc} \Delta_c + \varphi \eta_{co} \Delta_o)(\varepsilon_{c} - \varphi \eta_{c} - (1-\varphi)\eta_{c})}{(\varepsilon_{o} - \psi \eta_{o} - (1-\varphi)\eta_{o})(\varepsilon_{c} - \varphi \eta_{c} - (1-\varphi)\eta_{c})}.
\]
cross-price elasticities have inconsistent signs across studies. So, instead of incorporating the estimates from LYHS and KY directly into our model, we draw on information about the relative values of $\eta_{cc}$, $\eta_{co}$, $\eta_{oc}$, and $\eta_{oo}$ for each good and complement these estimates of price elasticities for organic and conventional FV with updated estimates of price elasticities for each organic fruit (based on Nelson et al. (2017; henceforth NFTA) or non-quality-differentiated FV (based on Okrent and Alston, 2011 (OA) and Ferrier, Zhen, and Bovay, 2019 (FZB)). Note that OA provide estimates of demand for fresh FV, while FZB provide estimates of demand for aggregate fresh–frozen goods, for each fruit or vegetable. We randomly draw sets of plausible price elasticities for 10,000 runs of the simulation; median results are reported in Tables 1–5.

To be specific, the sets of plausible price elasticities were generated as follows. LYHS provides elasticity estimates for organic and conventional apples, bananas, grapes, oranges, strawberries, and “other fruit”. KY provides elasticity estimates for organic and conventional carrots, onions, potatoes, tomatoes, and “other vegetables”, plus estimates for conventional peppers (which we do not use). OA provides elasticity estimates for four of the nine commodities and both aggregates, plus “citrus”. FZB provides elasticity estimates for eight of the nine commodities. Both OA and FZB aggregate conventional and organic varieties of each good. NFTA provides nine sets of elasticity estimates (three different estimation approaches; three different income classes) for three organic fruit commodities.\footnote{22 of the 27 price elasticities estimated by NFTA for these three commodities are negative. We exclude the non-negative estimates.} We compute the cross-study ratios of own-price elasticity estimates for each good: $\eta_{cc}^{FZB} / \eta_{cc}^{KY}$ and $\eta_{oo}^{NFTA} / \eta_{oo}^{LYHS}$, for example.\footnote{For the sake of these ratios, we assume that the estimates by OA and FZB are for conventional FV. We compute the ratio $\eta_{cc}^{OA} / \eta_{cc}^{LYHS}$ using citrus (OA) and oranges (LYHS).} We also compute the ratios of organic- to conventional-own-price elasticities within the LYHS and KY studies: $\eta_{oo}^{LYHS} / \eta_{cc}^{LYHS}$, for example..
We use these ratios to generate new sets of plausible price elasticities for each good. It is easiest to explain the generation process using a specific example, as follows. LYHS estimate the own-price elasticity for conventional bananas to be \(-0.70\). Across all fruit commodities, there are 5 values of \(\frac{\eta_{cc}^{OZB}}{\eta_{cc}^{LYHS}}\) and 4 values of \(\frac{\eta_{cc}^{OA}}{\eta_{cc}^{LYHS}}\) available: 0.47, 0.53, 1.77, 2.06, 3.24; 0.72, 1.17, 1.20, 1.98. We randomly draw from the LYHS estimate and the price elasticities obtained by multiplying the LYHS estimate by these ratios, weighting each study equally. So, we assign the elasticity \(\eta_{cc}\) for bananas as \(-0.70\) with 1/3 probability; \(-0.33 = -0.7 \times 0.47\), \(-0.37 = -0.7 \times 0.53\), \(1.24 = -0.7 \times 1.77\), \(-1.44 = -0.7 \times 2.06\), \(-2.27 = -0.7 \times 3.24\) with 1/15 probability each; and \(-0.51 = -0.7 \times 0.72\); \(-0.82 = -0.7 \times 1.17\); \(-0.84 = -0.7 \times 1.20\); and \(-1.39 = -0.7 \times 1.98\) with 1/12 probability each.

We use equivalent processes to generate sets of plausible elasticity estimates for each own-price elasticity. Cross-price elasticities \(\eta_{co}\) and \(\eta_{oe}\) are taken directly from LYHS and KY, since OA, FZB, and NFTA do not provide any such estimates.

| Table A.1. Model Parameters for Organic and Conventional Fruits and Vegetables: Baseline Specification |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| **Product** | **Uncompensated Elasticities** | **Mean Expenditure** | **Source** |
| | | **Conventional** | **Organic** |
| **η_{cc}** | **η_{co}** | **η_{oc}** | **η_{oo}** | **Mean Expenditure ($/year)** | **Mean Expenditure ($/year)** |
| Apples | -0.83 | 0.1 | 0.03 | -1.06 | 19.34 | 0.78 | Lin et al. (2009) |
| Bananas | -0.70 | 1.43 | 0.23 | -3.19 | 16.59 | 0.50 | Lin et al. (2009) |
| Grapes | -0.49 | 0.15 | 0.05 | -3.54 | 14.70 | 0.21 | Lin et al. (2009) |
| Oranges | -0.57 | 0.07 | 0.03 | -0.92 | 10.42 | 0.16 | Lin et al. (2009) |
| Strawberries | -0.50 | -0.06 | -0.02 | -0.36 | 12.31 | 0.24 | Lin et al. (2009) |
| Other Fruits | -0.85 | 0.23 | 0.04 | -0.01 | 47.21 | 1.20 | Lin et al. (2009) |
| Carrots | -0.77 | 0.12 | 0.07 | -1.85 | 7.57 | 1.04 | Kasteridis and Yen (2012) |
| Onions | -0.89 | 0.08 | 0.05 | -1.90 | 8.80 | 0.21 | Kasteridis and Yen (2012) |
| Potatoes | -1.20 | 0.15 | 0.08 | -2.77 | 15.19 | 0.27 | Kasteridis and Yen (2012) |
### Table A.2. Uncompensated Own-Price Elasticities for Organic and Conventional Fruits and Vegetables

| Product       | Based on Okrent and Alston (2011) | Based on Ferrier et al. (2019) | Based on Nelson et al. (2017) |
|---------------|-----------------------------------|--------------------------------|--------------------------------|
| Apples        | -0.60                             | -0.39                          | -0.02 to -2.41 (7)             |
| Bananas       | -0.82                             | -0.37                          |                                |
| Grapes        | N.A.                              | -1.01                          |                                |
| Oranges/Citrus| -1.13                             | -1.01                          | -0.12 to -0.81 (6)             |
| Strawberries  | N.A.                              | -1.62                          | -0.02 to -7.33 (9)             |
| Other Fruits  | -1.02                             | N.A.                           |                                |
| Carrots       | N.A.                              | -1.10                          |                                |
| Onions        | N.A.                              | -0.35                          |                                |
| Potatoes      | -0.48                             | N.A.                           |                                |
| Tomatoes      | -0.51                             | -0.44                          |                                |
| Other Vegetables | -0.81                             | N.A.                           |                                |

**Notes:** N.A. indicates that estimates are not available. Okrent and Alston (2011) and Ferrier et al. (2019) estimate elasticities for fruit and vegetable commodities, aggregating organic and conventional. Nelson et al. (2017) use three different approaches to estimate elasticities for organic fruits, at three different income levels. We present the range of estimates from Nelson et al. (2017) and the number of (valid, i.e., negative) own-price elasticities estimated for each good in parentheses.

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### A.2. Code for replication.

The analysis in this paper was done in Matlab R2020b (update 4) using the following .m files:

1) `MBM_QOpen_simulation_noseg.m` is used to generate tables 1 and 3.

2) `MBM_QOpen_simulation_seg.m` is used to generate tables 2 and 4.
3) `MBM_QOpen_simulation_seg_epsilon.m` is used to generate table 5; see instructions at line 133 and line 703.

4) `MBM_QOpen_simulation_phipsi_1` is used to generate figure 3, panel A.

5) `MBM_QOpen_simulation_phipsi_3` is used to generate figure 3, panel B.