Market and Welfare Effects on the U.S. Nationwide Sugar-sweetened Beverages Tax

by Yunkyung Lee and Konstantinos Giannakas

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Abstract: The sugar-sweetened beverage (SSB) tax has been considered a key weapon to discourage the consumption of sugary drinks. While a nationwide application of this policy has gained considerable support in recent years, it is not clear how the different interest groups involved will be affected by such policy. To determine the system-wide market and welfare impacts of a nationwide SSB tax, our study develops a theoretical framework that considers (a) the interaction of sugary drinks and their healthier substitutes (e.g., 100% fruit juice), (b) differences in consumer preferences, (c) differences in producer agronomic characteristics, and (d) imperfect competition among beverage firms. Analytical results show that the SSB tax reduces the demand for soda and soda firms' profits, while increasing fruit juice demand and fruit juice firms' profits. The magnitude of these changes is shown to depend on the degree of consumer heterogeneity and the producer efficiency level. The theoretical results on the economic impacts of the SSB tax through the simulation. Under a $0.01 per ounce tax, soda firms are shown to experience an 81.7% profit reduction, while fruit juice firms' profits increase by 52.9%. Soda consumers and those who switch from soda to other alternatives realize the greatest reduction in their welfare.

Keywords: sugar-sweetened beverages, soda taxes, beverage supply chain

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I. Introduction

The sugar-sweetened beverage (SSB) tax policy is considered a key weapon in the quest to discourage unhealthy beverage consumption. Berkeley, CA, and Philadelphia, PA, have been experiencing the effectiveness of the policy in reducing sugary drink consumption since these cities have enacted the SSB tax in 2015 and 2017, respectively (Lee et al., 2019; Seiler et al., 2019). When reduced consumption of sugary drinks can decrease the incidence of diabetes and other diseases, people who are at risk and those already ill can benefit from this policy (Escobar et al., 2013; Basu et al., 2014). Reducing the incidence of those diseases can also reduce government expenses for public health treatments, which were about $157 billion in 2018 (Cawley et al., 2019). The potential health benefits and tax revenues have made the SSB tax an increasingly appealing policy response to obesity and diabetes in the U.S.

Despite its potential benefits, the effectiveness and desirability of the SSB tax have been a controversial issue in the related literature. Cawley et al. (2019) argue that the impact of local SSB taxes on the consumption of sugary drinks is limited because the policy increases cross-border (outside-of-tax jurisdiction) shopping, and the pass-through effect is greater for retailers than for consumers. Wang (2015) also argues that it is unlikely for the policy to lead to a decrease in sugary drink consumption in the long term due to the inelastic nature of the demand for sugary drinks in the U.S. market. Such findings have been the basis for the argument that SSB tax policy reduces the welfare of both consumers and producers without any benefits.

Central to the debate on the desirability of the SSB tax are, of course, the market and welfare effects of this policy instrument. The determination of the system-wide market and welfare impacts of the SSB tax is the key objective of this paper. In particular, this study seeks to (1) determine the impact of the SSB tax on the market for sugary drinks and their higher quality substitutes (like 100% fruit juices) and the welfare of the interest groups involved (i.e., consumers, producers, and firms of sugary drinks and their substitute products), and (2) quantify the theoretical findings using actual data from the U.S. soda and 100% fruit juice (fruit juice, hereafter) markets, which represent SSB and non-SSB markets, respectively.

To determine the market and welfare effects of the SSB tax, the study develops a vertically- (or quality-) differentiated model that explicitly accounts for (a) differences in consumer preferences for sodas and fruit juices, (b) differences in producer agronomic characteristics, and (c) imperfect competition among soda and fruit juice firms. This multi-market framework is an adaptation of the Giannakas (2019) framework of heterogeneous agents and enables the disaggregation of the welfare impacts of the SSB tax as well as the determination of the cross-market effects of the policy that have largely been ignored by the relevant literature. Once developed, the theoretical model is (i) calibrated using price, production cost, and quantity data, and estimated market power of U.S. soda and fruit juice manufacturers between 2015 and 2018, and (ii) simulated to quantify the market and welfare impacts of a nationwide SSB tax on sugary drinks.

The rest of the article is organized as follows. In the next section, the model of heterogeneous consumers and producers and imperfectly competitive firms is developed to analyze their decisions, profits, and welfare before the introduction of the SSB tax. In the following section, we introduce the SSB tax policy in the soda market and analyze the market and welfare impacts on the different stakeholders. The simulation analysis and results are presented before the final section summarizes and concludes the paper.

II. Equilibrium Conditions before the Introduction of the SSB Tax

1. Consumer decisions

Consumers have a choice between three products: sugar-added beverages (soda), non-sugar-added beverages (fruit juice), and other beverages (water or milk based-beverages). As noted earlier, the analysis views soda and fruit juice as representatives of sugar-added and non-sugar-added beverages, respectively.

Soda, fruit juice, and other types of beverages are close but imperfect substitutes that are vertically differentiated – i.e., uniformly quality-ranked by consumers so that, if offered at the same price, all consumers would prefer the higher quality product (fruit juice, in our case). While consumers agree on the relative quality ranking of these beverages, they differ in their valuation of the perceived quality differences between these products (Sutton, 1986).

Let $\alpha \in [0, c]$ be the consumer differentiating attribute capturing the heterogeneity in consumer valuation of the different beverages. Assuming consumers spend a small share of their income in purchasing beverages, the consumer utility function can be written as

$U_s = U - P_s^c + \lambda\alpha$ if a unit of soda is consumed

$U_j = U - P_j^c + \mu\alpha$ if a unit of fruit juice is consumed

$U_o = U$ if a unit of other beverages is consumed (1)

where U_s, U_j, and U_o are the utilities associated with the unit consumption of soda, fruit juice, and other beverages, respectively; U is the base level of utility associated with beverage consumption; P_s^c and P_j^c are the consumer prices of soda and fruit juice, respectively; and λ and μ are preference parameters (or utility enhancement factors) associated with the consumption of soda and fruit juice, respectively. The quality difference between soda and fruit juice is captured by the assumption $\lambda < \mu$ with $(\mu - \lambda)\alpha$ capturing the difference in the valuation of fruit juice and soda of the consumer with differentiating attribute α – the greater is α, the stronger the consumer preference for high quality beverages. For simplicity and tractability, we assume that the utility associated with the consumption of other beverages, U_o, is equal to the base level of utility.

When all three options are available, the consumer with differentiating attribute α_o

$$\alpha_o: U_o = U_s \Rightarrow \alpha_o = \frac{p_s^c}{\lambda} \quad (2)$$

is indifferent between consuming a unit of soda and a unit of other beverages as the utility associated with the consumption of these beverages is the same. Similarly, the consumer with differentiating characteristic α_s where

$$\alpha_s: U_j = U_s \Rightarrow \alpha_s = \frac{p_j^c - p_s^c}{\mu - \lambda} \quad (3)$$

is indifferent between consuming a unit of soda and a unit of fruit juice. Consumers with $\alpha \in [0, \alpha_o)$ prefer other beverages, consumers with $\alpha \in (\alpha_o, \alpha_s)$ prefer soda, while consumers with $\alpha \in (\alpha_s, c]$ prefer the fruit juice.

Figure II.1.1 shows the utilities associated with the consumption of the different beverages and the consumer purchasing decisions when the three products coexist in the market. When consumers are uniformly distributed between the polar values of α, $c-\alpha_s$ captures the consumer demand for fruit juice, x_j, and $\alpha_s-\alpha_o$ determines the consumer demand for soda, x_s, which can be expressed mathematically as

$$x_s = \frac{p_j^c - p_s^c}{\mu - \lambda} - \frac{p_s^c}{\lambda} = \frac{\lambda p_j^c - \mu p_s^c}{\lambda(\mu - \lambda)} \quad (4)$$

$$x_j = c - \frac{p_j^c - p_s^c}{\mu - \lambda} = \frac{c(\mu - \lambda) + p_s^c - p_j^c}{\mu - \lambda} \quad (5)$$

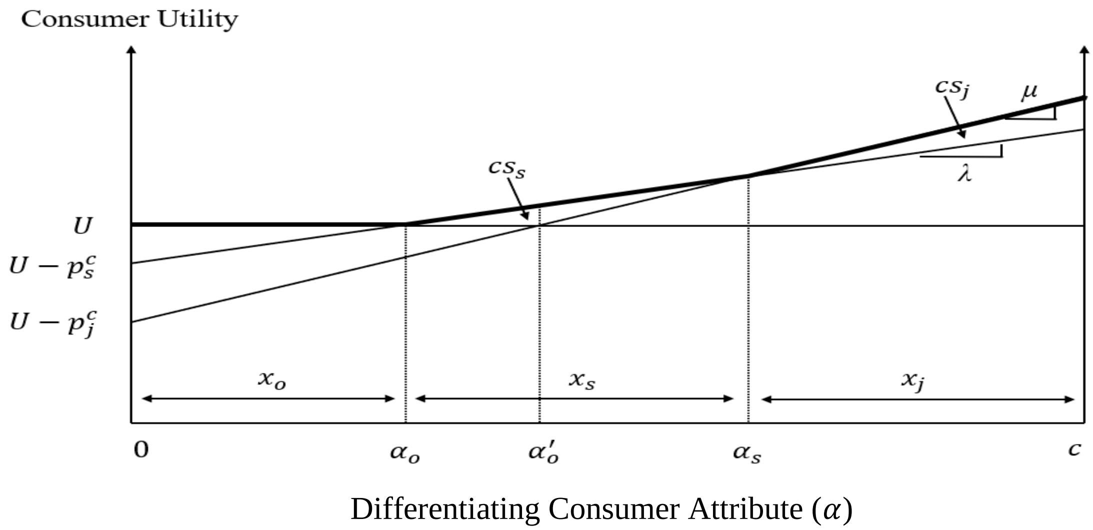


Figure II.1.1. Consumption decisions and welfare

Equations (4) and (5) indicate that the demand for soda (fruit juice) reduces with an increase in its price and/or a decrease (increase) in the strength of the consumer preference for quality μ-λ. If p_s^c were greater than p_j^c, the utility curve U_s would lie underneath U_j for all consumers and soda would be driven out of the beverage market. The demand for fruit juice would be

$$x_j = c - \alpha_o' = \frac{c\mu - p_j^c}{\mu} \quad \text{where } \alpha_o' \text{: } U_o = U_j \tag{6}$$

On the other hand, if the price premium for fruit juice $p_j^c - p_s^c$ outweighed the valuation of the quality difference between the two beverages $\mu - \lambda$ for all consumers, the utility curve U_j would lie underneath U_s for all consumers and it would be the fruit juice driven out of the market. In this case, the demand for soda would be

$$x_s = c - \alpha_o = \frac{c\lambda - p_s^c}{\lambda} \tag{7}$$

Figure II.1.2 graphs the inverse demands for soda (D_s) and fruit juice (D_j) for the case in which the two beverages co-exist in the market. The inverse consumer demands for soda and fruit juice are derived from equations (4) and (5) and are given by

$$p_s^c = \frac{\lambda}{\mu} p_j^c - \frac{\lambda}{\mu}(\mu - \lambda) x_s \tag{8}$$

$$p_j^c = c(\mu - \lambda) + p_s^c - (\mu - \lambda) x_j \tag{9}$$

Equations (8) and (9) capture the interdependence between the soda and fruit juice markets as the price and preference parameters associated with the consumption of a product are direct arguments in the demand for its substitute.

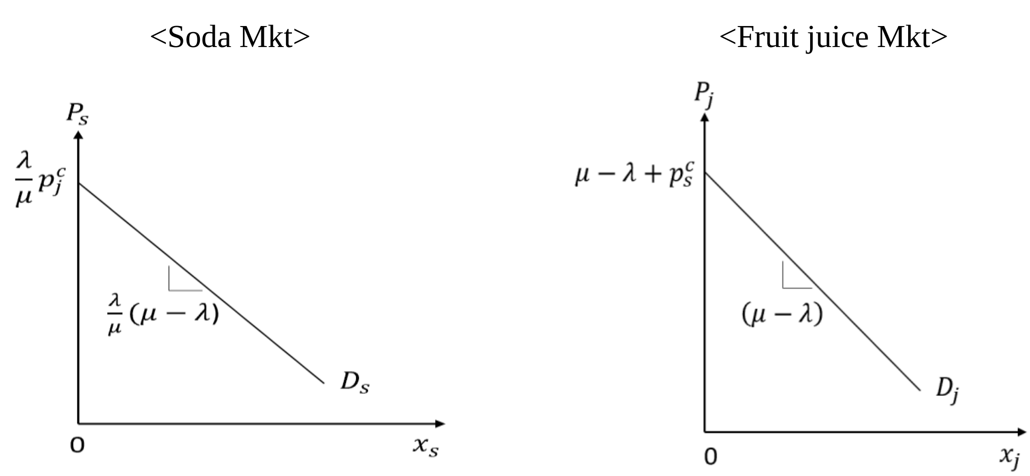


Figure II.1.2. Consumer demands for soda and fruit juice

Before concluding this section, it is important to note that, in addition to depicting consumer purchasing decisions, Figure II.1.1 also enables us to derive the welfare of different consumer groups when soda, fruit juice, and other beverages coexist in the market. The area under the effective bold kinked utility curve captures the welfare of soda consumers (U_s^*), the welfare of fruit juice consumers (U_j^*), and the welfare of other beverage consumers (U_o^*). This is because equation (1) directly captures the utility associated with the consumption of different beverages for the consumer with differentiating attribute α. Mathematically, U_s^*, U_j^* and U_o^* are given by

$$U_s^* = \int_{\alpha_o}^{\alpha_s} U_s d\alpha = Ux_s + \frac{1}{2}\lambda x_s^2 = \left[U + \frac{\lambda p_j^c - \mu p_s^c}{2(\mu-\lambda)}\right]\frac{\lambda p_j^c - \mu p_s^c}{\lambda(\mu-\lambda)} \tag{10}$$

$$\begin{aligned} U_j^* &= \int_{\alpha_s}^{c} U_j d\alpha = (U + \lambda x_s)x_j + \frac{1}{2}\mu x_j^2 \\ &= \left[U + \frac{c\mu(\mu-\lambda) + (2\lambda-\mu)p_j^c - 3\mu p_s^c}{2(\mu-\lambda)}\right]\frac{c(\mu-\lambda) - p_j^c + p_s^c}{\mu-\lambda} \end{aligned} \tag{11}$$

$$U_o^* = \int_0^{\alpha_o} U_o d\alpha = U\alpha_o = \frac{Up_s^c}{\lambda} \tag{12}$$

Aggregate consumer welfare is then given by the summation of equations (10)-(12), as

$$\begin{aligned} \mathrm{CW} &= \int_{\alpha_o}^{\alpha_s} U_s d\alpha + \int_{\alpha_s}^{c} U_j d\alpha + \int_0^{\alpha_o} U_o d\alpha = \\ &\left[U + \frac{\lambda p_j^c - \mu p_s^c}{2(\mu-\lambda)}\right]\frac{\lambda p_j^c - \mu p_s^c}{\lambda(\mu-\lambda)} + \left[U + \frac{c\mu(\mu-\lambda) + (2\lambda-\mu)p_j^c - 3\mu p_s^c}{2(\mu-\lambda)}\right]\frac{c(\mu-\lambda) - p_j^c + p_s^c}{\mu-\lambda} + \frac{Up_s^c}{\lambda} \end{aligned} \tag{13}$$

While equations (10)-(12) measure the total welfare of consumers of soda, fruit juice, and other beverages, Figure II.1.1 can also be used to derive the consumer surplus measures, normally derived from the demand curves in Figure II.1.2. Given consumer prices of soda and fruit juice (p_s^c and p_j^c, respectively), the surplus of each consumer group is determined by the benefit received from the beverage consumption relative to its best alternative. In this context, the consumer surplus of soda and fruit juice, CS_s and CS_j, respectively, can be derived as

$$CS_s = \int_{\alpha_o}^{\alpha_o'} (U_s - U) d\alpha + \int_{\alpha_o'}^{\alpha_s} (U_s - U_j) d\alpha = \frac{1}{2}\left(\frac{\lambda}{\mu} p_j^c - p_s^c\right) x_s = \frac{\left(\lambda p_j^c - \mu p_s^c\right)^2}{2\mu\lambda(\mu - \lambda)} \quad (14)$$

$$CS_j = \int_{\alpha_s}^{c} (U_j - U_s) d\alpha = \frac{1}{2}\left(p_s^c + c(\mu - \lambda) - p_j^c\right) x_j = \frac{\left(p_s^c + c(\mu - \lambda) - p_j^c\right)^2}{2(\mu - \lambda)} \quad (15)$$

2. Producer decisions

Our framework assumes that there are two types of producers: crop producers and fruit producers. Crop producers have the choice of producing corn, soybeans or an alternative crop. Corn and soybeans are typically produced in the Great Plains area of the U.S. and are substitutes for crop producers (Holt, 1992). Crop producers' planting decisions are jointly made based on the soybean-corn price ratio and the quality of land (e.g., nitrogen level). Due to these factors, supply decisions of corn and soybeans involve trade-offs with respect to acreage allocation: an increase in corn acreage leads to a reduction in soybean acreage, and vice versa (Ubilava, 2012). Corn production is "located" upstream the supply chain in the soda industry. About 3% of domestic corn is used for producing high-fructose corn syrup (HFCS) (USDA ERS, 2020), and over 70% of HFCS is used in beverage production (White and Nicklas, 2016).

Fruit producers choose whether to produce fruit that will be marketed as fresh fruit, processed fruit, or an alternative product (e.g., dried or canned fruit). Producers' net returns from producing processed fruit are different from producing alternative types of fruit due to the agronomic characteristics of land, management skill, input usage, technology adopted, and other factors. According to Singerman and Useche (2016), most citrus growers in Florida produce processed fruits, which cover 70% of U.S. domestic fruit juice supply. Due to high disease and pest pressure in Florida, there is a significant difference in the costs of producing processed and fresh citrus.

2.1. Crop producers

Crop producers have three different choices for crop production: soybeans, corn, and an alternative crop. Producers differ in the costs of producing the different crops (and, thus, in the net returns associated with the production of these crops) due to differences in their characteristics (e.g., age, education, experience, management skills), agronomic characteristics of land (e.g., land quality, location, weather), and the technology they use. Let $A \in [0, a]$ be the producers' differentiating attribute that captures their heterogeneity. Producers are distributed from the most efficient producer ($A = 0$) to the least efficient one ($A = a$) and their net returns function can be expressed as

$$
\begin{aligned}
NR_b &= P_b - w_b - \gamma A && \text{if a unit of soybeans is produced} \\
NR_c &= P_c - w_c - \delta A && \text{if a unit of corn is produced} \\
NR_{oc} &= 0 && \text{if a unit of the alternative crop is produced} \qquad (16)
\end{aligned}
$$

where P_b and P_c are the producer prices of soybeans and corn, respectively; w_b and w_c are the production costs for soybeans and corn, respectively, that are exogenous to producers; A is the producer's efficiency level; and γ and δ are non-negative cost enhancement factors associated with the production of soybeans and corn, respectively. For simplicity, the net returns from the production of the alternative crop are normalized to zero. To capture the higher cost of producing soybeans (USDA ERS, 2020), we assume $\gamma > \delta$, with $(\gamma - \delta)A$

capturing the difference in the idiosyncratic costs of producing soybeans and corn for the producer with differentiating characteristic A.

The producer with differentiating attribute A_b, where $A_b: NR_b = NR_c$, is indifferent between producing a unit of soybeans and a unit of corn. Similarly, the producer with differentiating attribute A_c, where $A_c: NR_{oc} = NR_c$, is indifferent between producing a unit of corn and a unit of the alternative crop, where

$$A_b = \frac{(p_b - p_c) + (w_c - w_b)}{\gamma - \delta} \tag{17}$$

$$A_c = \frac{p_c - w_c}{\delta} \tag{18}$$

As shown in Figure II.2.1, more efficient producers with differentiating attribute $A \in [0, A_b]$ find it optimal to grow soybeans, producers with $A \in (A_b, A_c]$ grow corn, while the least efficient producers with $A \in (A_c, a]$ grow the alternative crop.

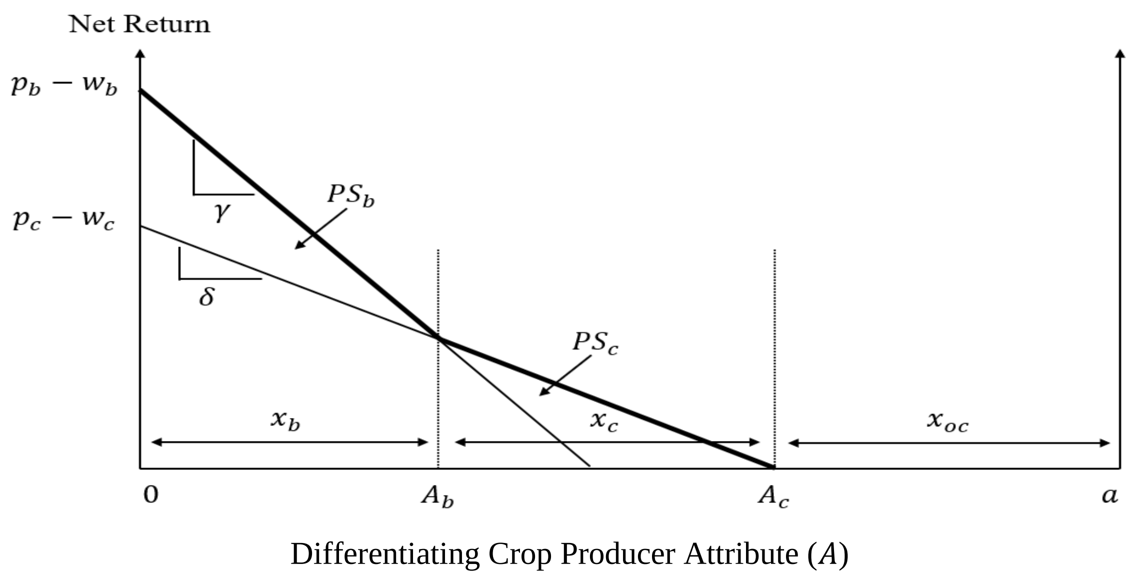


Figure II.2.1. Crop producer decisions and welfare

Assuming that producers are uniformly distributed between the polar values of A, A_b determines the supply of soybeans, x_b; and $A_c - A_b$ represents the supply of corn, x_c, which can be expressed as

$$x_b = \frac{(p_b - p_c) + (w_c - w_b)}{\gamma - \delta} \tag{19}$$

$$x_c = \frac{\gamma(p_c - w_c) - \delta(p_b - w_b)}{\delta(\gamma - \delta)} \tag{20}$$

Figure II.2.2 graphs the inverse supply curves for soybeans and corn in the price-quantity space when these crops co-exist in the market. Mathematically, the inverse supply curves for soybeans (p_b) and corn (p_c) can be written as

$$p_b = w_b + (p_c - w_c) + (\gamma - \delta)x_b \tag{21}$$

$$p_c = w_c + \frac{\delta}{\gamma}(p_b - w_b) + \frac{\delta(\gamma-\delta)}{\gamma}x_c \tag{22}$$

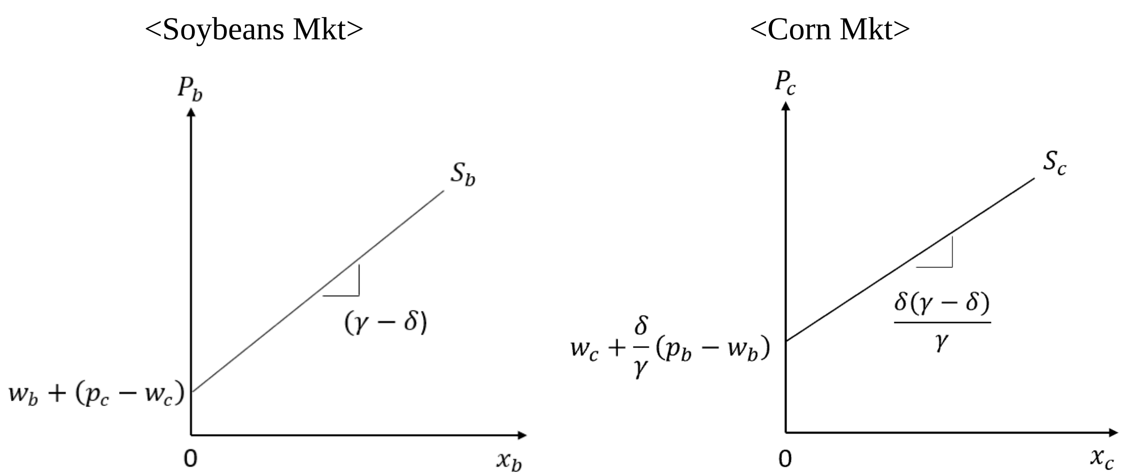


Figure II.2.2. Farm supplies of soybeans and corn

Note that, in addition to depicting farmers' production decisions, Figure II.2.1 can also be used to derive the welfare of the different crop producer groups considered here.

Specifically, the area under the bold kinked net returns curve captures the welfare of soybean producers (NR_b^*) and the welfare of corn producers (NR_c^*), as equation (16) is a direct measure of the net returns associated with the production of the different crops. Mathematically, NR_b^* and NR_c^* can be expressed as

$$NR_b^* = \int_0^{A_b} NR_b dA = \left(p_b - w_b - \frac{1}{2}\gamma x_b\right) x_b = \frac{[(\gamma - 2\delta)(p_b - w_b) + \gamma(p_c - w_c)][(p_b - w_b) - (p_c - w_c)]}{2(\gamma - \delta)^2} \tag{23}$$

$$NR_c^* = \int_{A_b}^{A_c} NR_c dA = \frac{1}{2}(p_c - w_c - \delta x_b)x_c = \frac{[\gamma(p_c - w_c) - \delta(p_b - w_b)]^2}{2\delta(\gamma - \delta)^2} \tag{24}$$

Aggregate crop producer welfare is given by the summation of equations (23) and (24) as

$$CPW = \int_0^{A_b} NR_b dA + \int_{A_b}^{A_c} NR_c dA = \frac{[(\gamma - 2\delta)(p_b - w_b) + \gamma(p_c - w_c)][(p_b - w_b) - (p_c - w_c)]}{2(\gamma - \delta)^2} + \frac{[\gamma(p_c - w_c) - \delta(p_b - w_b)]^2}{2\delta(\gamma - \delta)^2} \tag{25}$$

While equations (23) and (24) measure the total net returns of soybean and corn producers, Figure II.2.1 can also be used to derive the producer surplus measures, derived normally from the supply curves in Figure II.2.2. The producer surplus is determined by the net returns received from the production of a crop relative to its best alternative. In this context, soybean producer surplus (PS_b) and corn producer surplus (PS_c) are given by

$$PS_b = \int_0^{A_b} (NR_b - NR_c) dA = \frac{1}{2}[(p_b - w_b) - (p_c - w_c)]x_b = \frac{[(p_b - w_b) - (p_c - w_c)]^2}{2(\gamma - \delta)} \tag{26}$$

$$PS_c = \int_{A_b}^{A_c} (NR_c - NR_b) dA = \frac{1}{2}\left[(p_c - w_c) - \frac{\delta}{\gamma}(p_b - w_b)\right] x_c$$
$$= \frac{[\gamma(p_c - w_c) - \delta(p_b - w_b)]^2}{2\gamma\delta(\gamma - \delta)} \quad (27)$$

2.2. Fruit producers

A similar approach is used to analyze the fruit producer decisions. In particular, fruit producers can produce fresh fruit, processed fruit, or other types of fruit and their choice depends on the net returns associated with the production of the different kinds of fruit. Processed fruits are used for fruit juice production, whereas other types of fruit are used for canned or dried fruit production. Let $B \in [0, b]$ be the fruit producers' differentiating attribute with $B = 0$ corresponding to the most efficient producer and $B = b$ to the least efficient one. Normalizing the net returns to the other kinds of fruit to zero, producers' net return function can be expressed as follows:

$$\begin{aligned} NR_f &= P_f - w_f - \varepsilon B && \text{if a unit of fresh fruit is produced} \\ NR_p &= P_p - w_p - \upsilon B && \text{if a unit of processed fruit is produced} \\ NR_{of} &= 0 && \text{if a unit of other types of fruit is produced} \end{aligned} \qquad (28)$$

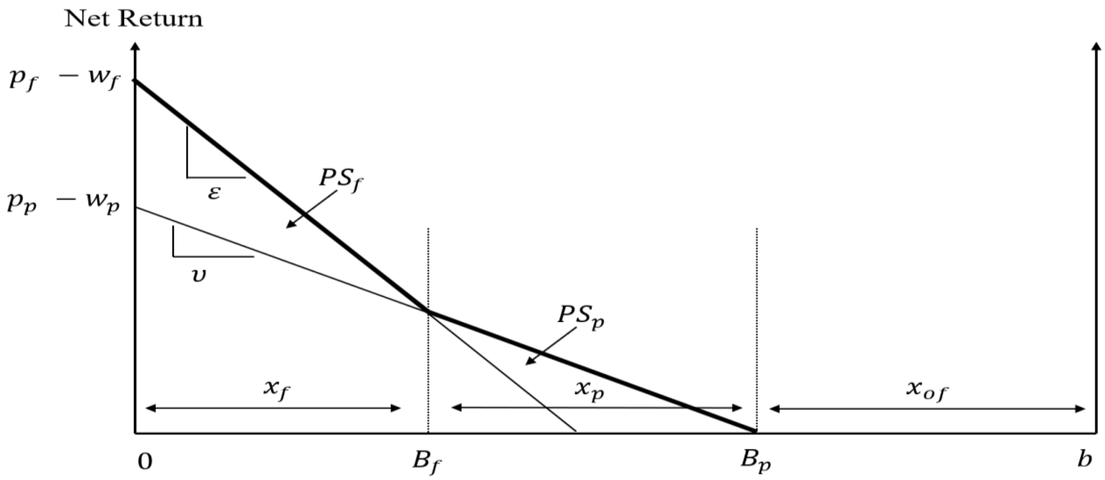
where P_f and P_p are the producer prices of fresh and processed fruit, respectively; w_f and w_p are the production costs for fresh and processed fruit, respectively, that are exogenous to fruit producers; B is the producer's efficiency level; and ε and υ are non-negative cost enhancement factors associated with the production of fresh and processed fruit, respectively. We assume that $\varepsilon > \upsilon$ with $(\varepsilon - \upsilon)B$ capturing the difference in the costs of producing fresh and processed fruit for the producer with differentiating attribute B.

Setting $NR_f = NR_p$, we can determine the producer with differentiating attribute B_f who is indifferent between producing a unit of fresh fruit and a unit of processed fruit. Similarly, using $NR_{of} = NR_p$, we can identify the producer with differentiating attribute B_p who is indifferent between producing processed fruit and other types of fruit where

$$B_f = \frac{(p_f - p_p) + (w_p - w_f)}{\varepsilon - \upsilon} \quad (29)$$

$$B_p = \frac{p_p - w_p}{\upsilon} \quad (30)$$

Figure **II.2.3** graphs the net returns associated with the different options and the fruit producers' decisions when the different products coexist in the market. More efficient producers with differentiating attribute $B \in [0, B_f]$ grow fresh fruit, producers with $B \in (B_f, B_p]$ grow processed fruit, while the least efficient producers with $B \in (B_p, b]$ grow alternative types of fruit.



Differentiating Fruit Producer Attribute (B)

Figure II.2.3. Fruit producer decisions and welfare

When the producers are uniformly distributed between the polar values of B, x_f $(= B_f)$ and x_p $(= B_p - B_f)$ give the supplies of fresh and processed fruit, respectively, where

$$x_f = \frac{(p_f - p_p) + (w_p - w_f)}{\varepsilon - \upsilon} \quad (31)$$

$$x_p = \frac{\varepsilon(p_p - w_p) - \upsilon(p_f - w_f)}{\upsilon(\varepsilon - \upsilon)} \quad (32)$$

From equations (31) and (32), we can derive the inverse supply functions for fresh and processed fruit. These inverse supplies are given by equations (33) and (34) and are graphed in Figure II.2.4 below.

$$p_f = p_p - w_p + w_f + (\varepsilon - \upsilon)x_f \quad (33)$$

$$p_p = w_p + \frac{\upsilon}{\varepsilon}(p_f - w_f) + \frac{\upsilon(\varepsilon - \upsilon)}{\varepsilon} x_p \quad (34)$$

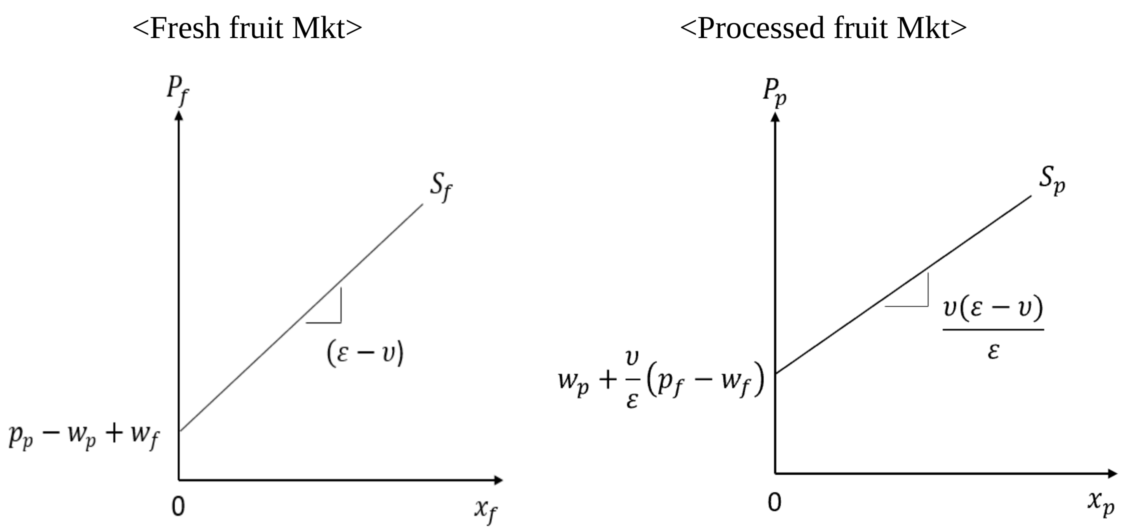


Figure II.2.4. Farm supplies of fresh fruit and processed fruit

Regarding the welfare of fruit producers, it is given by the area under the effective bold kinked net returns curve in Figure II.2.3. Specifically, the welfare of fresh fruit producers (NR_f^*) and the welfare of processed fruit producers (NR_p^*) are given by

$$NR_f^* = \int_0^{B_f} NR_f dB = \left(p_f - w_f - \frac{1}{2}\varepsilon x_f\right) x_f$$
$$= \frac{[(\varepsilon - 2\upsilon)(p_f - w_f) + \varepsilon(p_p - w_p)][(p_f - w_f) - (p_p - w_p)]}{2(\varepsilon - \upsilon)^2} \quad (35)$$

$$NR_p^* = \int_{B_f}^{B_p} NR_p dB = \frac{1}{2}\left(p_p - w_p - \upsilon x_f\right)x_p = \frac{\left[\varepsilon\left(p_p - w_p\right) - \upsilon(p_f - w_f)\right]^2}{2\upsilon(\varepsilon - \upsilon)^2} \qquad (36)$$

while aggregate fruit producer welfare is given by the summation of NR_f^* and NR_p^* as:

$$\begin{aligned} FPW &= \int_0^{B_f} NR_f dB + \int_{B_f}^{B_p} NR_p dB \\ &= \frac{\left[(\varepsilon - 2\upsilon)\left(p_f - w_f\right) + \varepsilon\left(p_p - w_p\right)\right]\left[\left(p_f - w_f\right) - \left(p_p - w_p\right)\right]}{2(\varepsilon - \upsilon)^2} \\ &+ \frac{\left[\varepsilon\left(p_p - w_p\right) - \upsilon(p_f - w_f)\right]^2}{2\upsilon(\varepsilon - \upsilon)^2} \end{aligned} \qquad (37)$$

Fresh and processed fruit producer surplus (PS_f and PS_p, respectively), derived normally from the supply curves in Figure II.2.4, can also be derived from Figure II.2.3 as

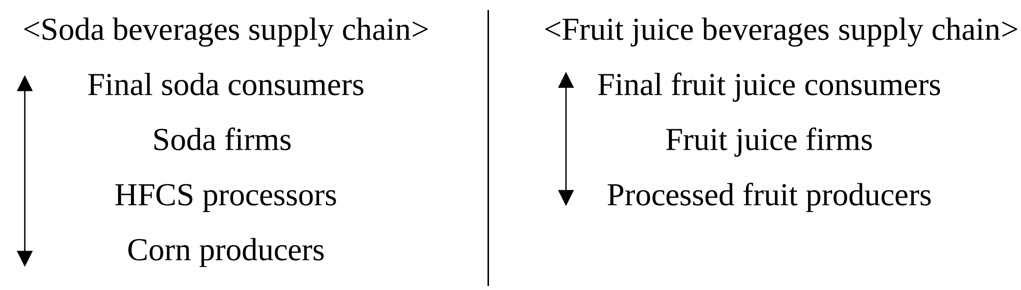
$$\begin{aligned} PS_f &= \int_0^{B_f} (NR_f - NR_p) dB = \frac{1}{2}\left[\left(p_f - w_f\right) - \left(p_p - w_p\right)\right]x_f \\ &= \frac{\left[\left(p_f - w_f\right) - \left(p_p - w_p\right)\right]^2}{2(\varepsilon - \upsilon)} \end{aligned} \qquad (38)$$

$$\begin{aligned} PS_p &= \int_{B_f}^{B_p} \left(NR_p - NR_f\right) dB = \frac{1}{2}\left[\left(p_p - w_p\right) - \frac{\upsilon}{\varepsilon}\left(p_f - w_f\right)\right]x_p \\ &= \frac{\left[\varepsilon\left(p_p - w_p\right) - \upsilon\left(p_f - w_f\right)\right]^2}{2\varepsilon\upsilon(\varepsilon - \upsilon)} \end{aligned} \qquad (39)$$

3. Firms decisions

Soda and fruit juice firms manufacture their beverages by using as major ingredients inputs supplied by the corn and processed fruit producers. High-fructose corn syrup (HFCS) processors process corn starch to corn syrup, and provide a link between corn producers and soda firms. Compared to processed fruits where over 90% are used for fruit juice production, only 10% of corn is used for soda production, while more than 70% of the HFCS is used in the beverage industry (White and Nicklas, 2016). Figure II.3.1 describes the key participants in the two supply channels.

Figure II.3.1. Soda and fruit juice supply chains



In the U.S. beverage industry, the two key manufacturers are the Coca-Cola Company and PepsiCo, Inc., which cover about 70% and 66% of the soda and fruit juice markets, respectively. The Coca-Cola Company has seven different soft drink brands (Coca-Cola, Fanta, Sprite, Schweppes, Appletiser, Fresca, and Barq's), and two fruit juice brands (Minute Maid and Simply orange), while PepsiCo, Inc. has five brands of soda (Pepsi, Diet Pepsi, Zero Pepsi, Mountain Dew, and Bubbly) and two brands of fruit juice and smoothie (Tropicana and Naked). Although these two companies dominate both markets, the fruit juice market is less concentrated than the soda market because there are approximately more than ten fruit juice firms (e.g., V8, Florida's Natural, Uncle Matt's, and Ceres) and local wholesalers tend to produce fruit juice products.

3.1. Soda firms

The soda industry is divided into (a) *flavoring syrup and concentrate* manufacturing, and (b) *soft drink* manufacturing (Williams and Goldsworthy, 2011). Most soda products have a similar supply chain from flavoring syrup producer, to bottler, to distributer, to merchant, to the final consumer. Flavoring syrup manufacturers used mostly cane sugar for sweetening soda beverages before the 1990s. Since then, they have switched to the relatively cheaper HFCS, which is, nowadays, found in about 90% of soda products.

Corn producers supply corn to the HFCS processors, and those processors supply corn syrup to soda firms. HFCS is manufactured with (a) *corn* and (b) *other inputs* (e.g., inputs for wet milling process). Corn is processed to corn starch, and then it is combined with fungi to extract glucose and fructose, which become HFCS. Soda firms combine the *HFCS* with *other inputs* (e.g., carbonated water and coloring ingredients) to produce the final soda products.

Soda firms have oligopsonistic and oligopolistic market power that are exercised when procuring HFCS and when selling soda to the final consumers (Thomson et al., 1996; Evans et al., 2001; Dhar et al., 2005; White and Nicklas, 2016). As a result, soda firms maximize their profit by producing at a level determined by the equality of marginal outlays and marginal revenues. Soda firms can charge the maximum price consumers are willing to pay for this quantity, p_s^c, while they incur cost p_s^f, which is the summation of the prices of HFCS (p_h) and other inputs (p_{os}), i.e.,

$$p_s^f = p_h + p_{os} \tag{40}$$

For simplicity and without loss of generality, we assume that the supply of other inputs is perfectly elastic, and the price of those inputs is exogenous to soda manufacturers (i.e.,

$p_{os} = k$).

Under a fixed proportions technology, the equilibrium quantities of soda and two inputs are normalized to be equal

$$x_s = x_h = x_{os} \tag{41}$$

where x_h and x_{os} are the equilibrium quantities of HFCS and other inputs, respectively.

Regarding the price of HFCS, it is determined by the prices of corn and other inputs used in its production (*oh*), i.e.,

$$p_h = p_c + p_{oh} \tag{42}$$

We assume a perfectly elastic supply of other inputs (*oh*) and a price that is exogenous to HFCS manufacturers (i.e., $p_{oh} = h$).

Under a fixed proportions technology, the equilibrium quantities of HFCS and the two inputs are normalized to be equal, i.e.,

$$x_h = x_c = x_{oh} \tag{43}$$

where x_{oh} is the equilibrium quantity of other inputs (*oh*).

Based on the supply equation for corn (given by equation (22))

$$p_c = w_c + \frac{\delta}{\gamma}(p_b - w_b) + \frac{\delta(\gamma - \delta)}{\gamma} x_c$$

and equations (42) and (43), we can derive the supply of HFCS as

$$p_h = p_c + h = w_c + \frac{\delta}{\gamma}(p_b - w_b) + h + \frac{\delta(\gamma - \delta)}{\gamma} x_h \tag{44}$$

Similarly, using equations (40), (43) and (44), the supply of soda is given by

$$p_s^f = p_h + k = w_c + \frac{\delta}{\gamma}(p_b - w_b) + h + k + \frac{\delta(\gamma - \delta)}{\gamma} x_s \tag{45}$$

To capture the soda producers' market power when they procure the HFCS, we use the market power parameter θ_h^b, where b refers to buyers. This parameter, also referred to as conjectural variation elasticity, takes values between 0 to 1. When $\theta_h^b = 1$, it corresponds to a monopsony, whereas $\theta_h^b = 0$ corresponds to a perfectly competitive market structure. Given that soda firms have oligopsonistic market power (Thomson et al., 1996; Evans et al., 2001; White and Nicklas, 2016), the marginal outlay curve for HFCS is determined by the θ_h^b and equation (44), as

$$MO_h = w_c + \frac{\delta}{\gamma}(p_b - w_b) + h + \frac{\delta(\gamma-\delta)}{\gamma}(1 + \theta_h^b)x_h \qquad (46)$$

Accordingly, the marginal outlay can be depicted in the soda market as

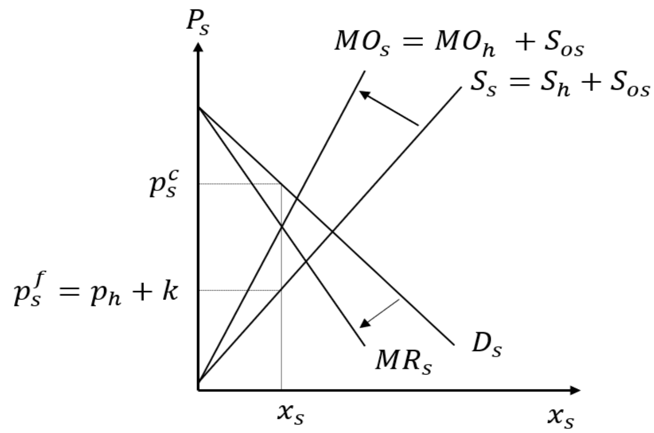
$$MO_s = MO_h + S_{os} = w_c + \frac{\delta}{\gamma}(p_b - w_b) + h + k + \frac{\delta(\gamma-\delta)}{\gamma}(1 + \theta_h^b)x_s \qquad (47)$$

Soda firms also have oligopolistic market power captured by the parameter $\theta_s^s \in [0,1]$ (White and Nicklas, 2016). Using the consumer demand for soda in equation (8), we can determine the marginal revenue curve for soda as follows

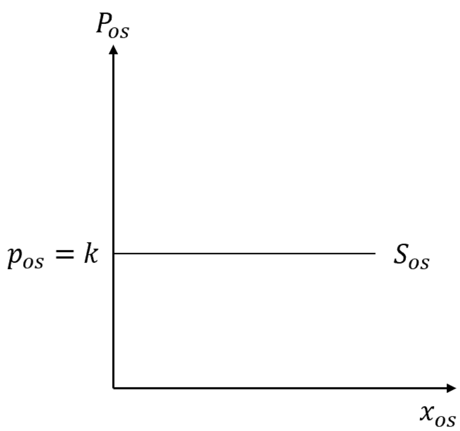
$$MR_s = \frac{\lambda}{\mu}p_j^c - \frac{\lambda}{\mu}(\mu - \lambda)(1 + \theta_s^s)x_s \qquad (48)$$

Finally, Figure II.3.2 graphs the equilibrium conditions in the soda supply channel.

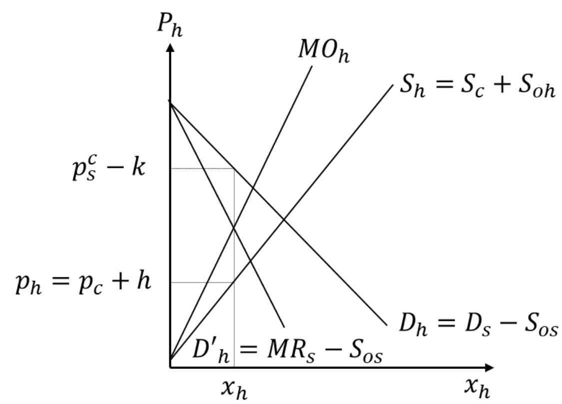
<Soda Firms> **Soda Mkt**



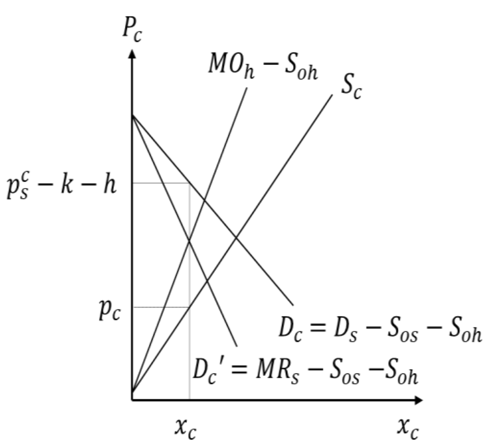
Inputs for soda: **(c) Other Inputs Mkt**



(d) HFCS Mkt



Inputs for HFCS: **(a) Corn Mkt**



(b) Other Inputs Mkt

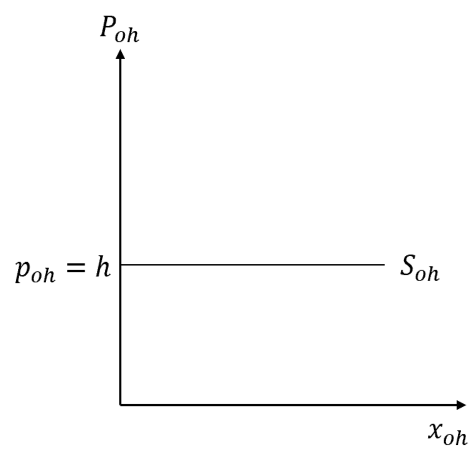


Figure II.3.2. Determination of soda firm, HFCS processor, and corn producer prices

3.2 Fruit juice firms

The Coca-Cola Company and PepsiCo, Inc. accounted for two thirds of the U.S. fruit juice market in 2019 and have both oligopolistic and oligopsonistic market power (Grigoryan et al., 2019). According to Luckstead et al. (2015), Florida fruit juice processors' estimated market power has increased from 0.11 to 0.45 between 1997 and 2010, while the number of processors decreased from 45 to 16 during the same period. The four major fruit juice processors' concentration ratio (CR4) has increased from 42.6% in 2000 to 69% in 2007, while the eight largest fruit juice processors accounted for 96% of the market (Guci and Brown, 2007).

Assuming that fruit juice beverages are produced with (e) *processed fruit* and (f) *other inputs* (e.g. packaging), the price relationship between the final product and the two inputs is given by

$$p_j^f = p_p + p_{oj} \tag{49}$$

where p_j^f is the cost of fruit juice firms and p_{oj} is the price of other inputs. We assume that the other inputs' supply curve is perfectly elastic, and the price of those inputs is exogenous to the fruit juice firms (i.e., $p_{oj} = m$).

Under a fixed proportions technology, we have

$$x_j = x_p = x_{oj} \tag{50}$$

where x_{oj} is the equilibrium quantity of other inputs used in fruit juice production.

Based on the equation (34), the supply equation for processed fruit is

$$p_p = w_p + \frac{\upsilon}{\varepsilon}\left(p_f - w_f\right) + \frac{\upsilon(\varepsilon - \upsilon)}{\varepsilon} x_p$$

Using the equation (49), the supply equation for fruit juice is given as

$$p_j^f = p_p + m = w_p + \frac{\upsilon}{\varepsilon}\left(p_f - w_f\right) + m + \frac{\upsilon(\varepsilon - \upsilon)}{\varepsilon} x_j \tag{51}$$

Given that fruit juice firms have oligopsonistic and oligopolistic market power, the marginal outlay and marginal revenue curve for fruit juice firms are

$$MO_j = w_p + \frac{\upsilon}{\varepsilon}\left(p_f - w_f\right) + m + \frac{\upsilon(\varepsilon - \upsilon)}{\varepsilon}(1 + \theta_p^b)x_j \tag{52}$$

$$MR_j = c(\mu - \lambda) + p_s^c - (\mu - \lambda)(1 + \theta_j^s)x_j \tag{53}$$

where θ_p^b captures fruit juice firm's oligopsonistic power, while θ_j^s captures these firms' oligopolistic market power. Figure II.3.3 graphs the equilibrium conditions in the fruit juice supply channel.

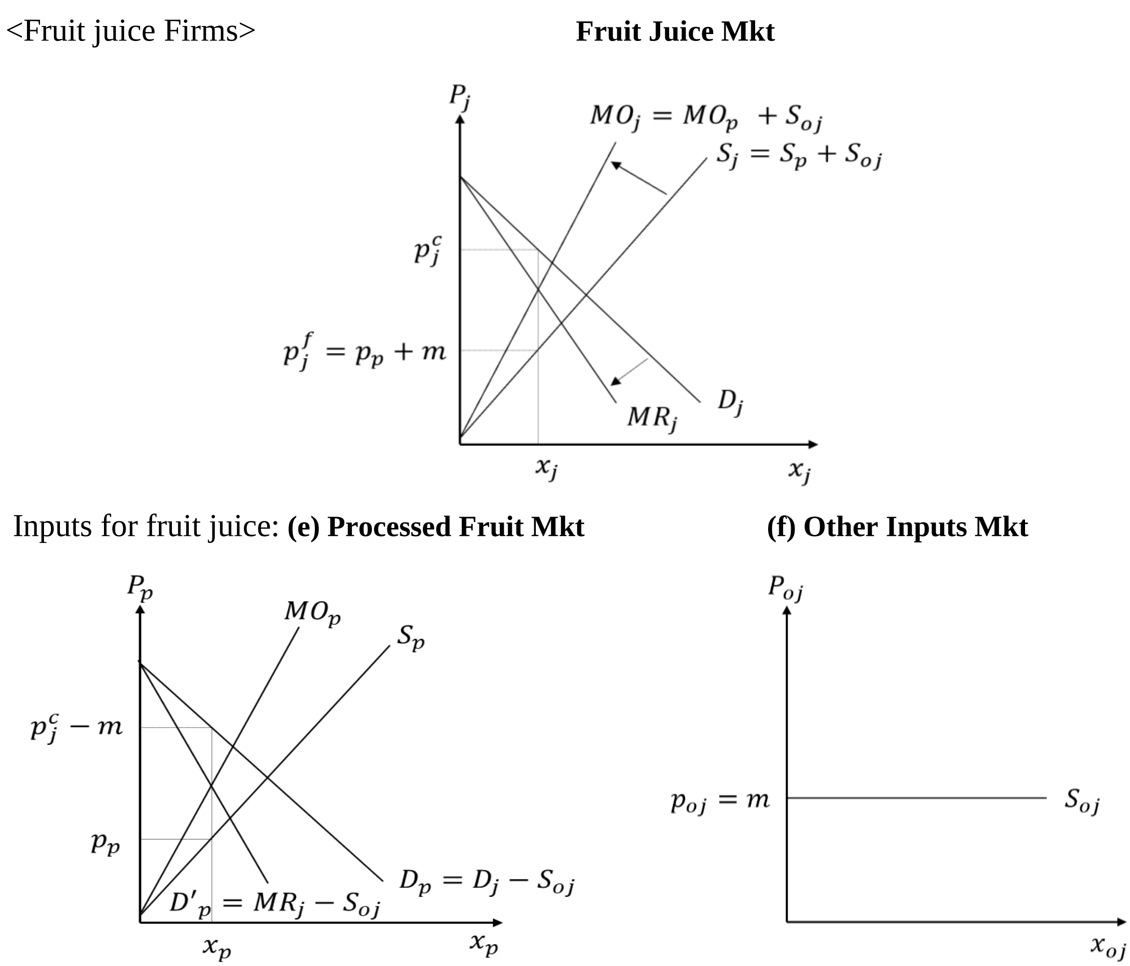


Figure II.3.3. Determination of fruit juice firm and processed fruit producer prices

4. Market equilibrium before the SSB tax

Figures II.3.2 and II.3.3 depict the market equilibria in the soda and fruit juice supply chains before the introduction of the SSB tax. Based on the optimality condition $MO_s = MR_s$, the equilibrium quantity of soda is

$$x_s^e = \frac{\gamma\lambda P_j^c - \gamma\mu(w_c + h + k) - \mu\delta(p_b - w_b)}{\delta\mu(\gamma - \delta)\left(1 + \theta_h^b\right) + \lambda\gamma(\mu - \lambda)(1 + \theta_s^s)} \tag{54}$$

and it depends positively on the consumer price of fruit juice (P_j^c) and the production cost of soybeans (w_b), and negatively on the marginal costs of other inputs (h and k), the production cost of corn (w_c), the cost enhancement factors (δ and μ), the price of soybeans (p_b), and the market power of soda firms in procuring HFCS and selling soda (θ_h^b and θ_s^s).

The equilibrium quantity of fruit juice is determined by the equality $MO_j = MR_j$ and is given by

$$x_j^e = \frac{\varepsilon\left[c(\mu - \lambda) + P_s^c - w_p - m\right] - \upsilon\left(p_f - w_f\right)}{\upsilon(\varepsilon - \upsilon)\left(1 + \theta_p^b\right) + \varepsilon(\mu - \lambda)(1 + \theta_j^s)} \tag{55}$$

This quantity depends positively on the consumer price of soda (P_s^c) and the production cost of fresh fruit (w_f), and negatively on the production cost of processed fruit (w_p), the marginal cost of other inputs (m), the price of fresh fruit (p_f), and the market power of fruit juice firms in buying processed fruit and selling fruit juice products (θ_p^b and θ_j^s).

Using equations (8) and (54), we can derive the equilibrium consumer price of soda as

$$p_s^{ce} = \frac{\lambda}{\mu} p_j^c - \frac{\lambda}{\mu}(\mu - \lambda)\left[\frac{\gamma\lambda P_j^c - \gamma\mu(w_c + h + k) - \mu\delta(p_b - w_b)}{\delta\mu(\gamma - \delta)\left(1 + \theta_s^b\right) + \lambda\gamma(\mu - \lambda)(1 + \theta_s^s)}\right] \tag{56}$$

This price depends positively on the producer price of soybeans, the production cost of corn, and the market power of soda firms, and negatively on the soybean production cost and the marginal costs of other inputs.

Similarly, using equations (9) and (55), the equilibrium consumer price of fruit juice is

$$p_j^{ce} = c(\mu-\lambda) + p_s^c - (\mu-\lambda)\left\{\frac{\varepsilon[c(\mu-\lambda)+P_s^c-w_p-m]-\upsilon\left(p_f-w_f\right)}{\upsilon(\varepsilon-\upsilon)\left(1+\theta_p^b\right)+\varepsilon(\mu-\lambda)(1+\theta_j^s)}\right\} \tag{57}$$

and it depends positively on the cost of processed fruit production, the marginal cost of other inputs (m), the price of processed fruit and the market power of fruit juice firms, and negatively on the cost of fresh fruit production.

The equilibrium cost of soda firms is derived by using equations (45) and (54). This cost represents the firms' expenses for buying other inputs and HFCS (p_h), where the price of HFCS is given by the summation of corn (p_c) and other inputs cost.

$$p_s^{fe} = w_c + \frac{\delta}{\gamma}(p_b - w_b) + h + k + \frac{\delta(\gamma-\delta)}{\gamma}\left[\frac{\gamma\lambda P_j^c-\gamma\mu(w_c+h+k)-\mu\delta(p_b-w_b)}{\delta\mu(\gamma-\delta)\left(1+\theta_s^b\right)+\lambda\gamma(\mu-\lambda)(1+\theta_s^s)}\right] \tag{58}$$

The equilibrium cost of producing soda products depends positively on the consumer price of fruit juice[3], and negatively on the market power of soda firms.

Using equation (51) and (55), the equilibrium cost of the fruit juice firms is

$$p_j^{fe} = w_p + \frac{\upsilon}{\varepsilon}\left(p_f - w_f\right) + m + \frac{\upsilon(\varepsilon-\upsilon)}{\varepsilon}\left\{\frac{\varepsilon[c(\mu-\lambda)+P_s^c-w_p-m]-\upsilon\left(p_f-w_f\right)}{\upsilon(\varepsilon-\upsilon)\left(1+\theta_p^b\right)+\varepsilon(\mu-\lambda)(1+\theta_j^s)}\right\} \tag{59}$$

[3] The greater consumer price of juice increases the demand for and equilibrium quantity of soda, and it also raises the equilibrium cost for soda firms.

which expresses the amount firms need to pay for procuring processed fruit and other inputs (m), and it depends positively on the consumer price of soda[4], and negatively on the market power of fruit juice firms.

The equilibrium processor price of HFCS (p_h^e, equations (40) and (58)), the equilibrium producer price of corn (p_c^e, equations (42) and (58)), and the equilibrium producer price of processed fruit (p_p^e, equations (34) and (59)) are, then, given by

$$p_h^e = p_s^{fe} - k = w_c + \frac{\delta}{\gamma}(p_b - w_b) + h + \frac{\delta(\gamma-\delta)}{\gamma}\left[\frac{\gamma\lambda P_j^c - \gamma\mu(w_c+h+k) - \mu\delta(p_b-w_b)}{\delta\mu(\gamma-\delta)\left(1+\theta_s^b\right)+\lambda\gamma(\mu-\lambda)(1+\theta_s^s)}\right] \quad (60)$$

$$p_c^e = p_s^{fe} - k - h = w_c + \frac{\delta}{\gamma}(p_b - w_b) + \frac{\delta(\gamma-\delta)}{\gamma}\left[\frac{\gamma\lambda P_j^c - \gamma\mu(w_c+h+k) - \mu\delta(p_b-w_b)}{\delta\mu(\gamma-\delta)\left(1+\theta_s^b\right)+\lambda\gamma(\mu-\lambda)(1+\theta_s^s)}\right] \quad (61)$$

$$p_p^e = p_j^{fe} - m = w_p + \frac{v}{\varepsilon}\left(p_f - w_f\right) + \frac{v(\varepsilon-v)}{\varepsilon}\left\{\frac{\varepsilon[c(\mu-\lambda)+P_s^c-w_p-m]-v\left(p_f-w_f\right)}{v(\varepsilon-v)\left(1+\theta_p^b\right)+\varepsilon(\mu-\lambda)(1+\theta_j^s)}\right\} \quad (62)$$

Based on the equilibrium consumer prices and firms' costs, the soda and fruit juice firms' profits, π_s and π_j, respectively, are given by

$$\begin{aligned}\pi_s &= \left(p_s^{ce} - p_s^{fe}\right)x_s^e \\ &= \left[\frac{\lambda}{\mu}p_j^c - w_c - \frac{\delta}{\gamma}(p_b - w_b) - h - k\right]\left[\frac{\gamma\lambda P_j^c - \gamma\mu(w_c+h+k) - \mu\delta(p_b-w_b)}{\delta\mu(\gamma-\delta)\left(1+\theta_s^b\right)+\lambda\gamma(\mu-\lambda)\left(1+\theta_s^s\right)}\right] \\ &\quad + \left[\frac{\lambda}{\mu}(\lambda-\mu) - \frac{\delta(\gamma-\delta)}{\gamma}\right]\left[\frac{\gamma\lambda P_j^c - \gamma\mu(w_c+h+k) - \mu\delta(p_b-w_b)}{\delta\mu(\gamma-\delta)\left(1+\theta_s^b\right)+\lambda\gamma(\mu-\lambda)(1+\theta_s^s)}\right]^2\end{aligned} \quad (63)$$

$$\begin{aligned}\pi_j &= \left(p_j^{ce} - p_j^{fe}\right)x_j^e \\ &= \left[c(\mu-\lambda) + p_s^c - w_p - \frac{v}{\varepsilon}\left(p_f - w_f\right) - m\right]\left\{\frac{\varepsilon[c(\mu-\lambda)+P_s^c-w_p-m]-v\left(p_f-w_f\right)}{v(\varepsilon-v)\left(1+\theta_p^b\right)+\varepsilon(\mu-\lambda)(1+\theta_j^s)}\right\} \\ &\quad + \left[(\lambda-\mu) - \frac{v(\varepsilon-v)}{\varepsilon}\right]\left\{\frac{\varepsilon[c(\mu-\lambda)+P_s^c-w_p-m]-v\left(p_f-w_f\right)}{v(\varepsilon-v)\left(1+\theta_p^b\right)+\varepsilon(\mu-\lambda)(1+\theta_j^s)}\right\}^2\end{aligned} \quad (64)$$

[4] When the consumer price of soda goes up, the equilibrium quantity of juice increases, which results in increased equilibrium cost for fruit juice firms.

III. Equilibrium Conditions after the Introduction of the SSB Tax

1. Introduction of the SSB tax

After the implementation of the SSB tax, soda beverage distributers are required to pay a unit tax amount of *t*. The unit tax *t* is equal to the price difference between the price paid by soda consumers and the price actually received by the soda firms. Graphically, the introduction of SSB tax shifts the demand curve D_s to D_s^t, where D_s is the consumer demand for soda mapping the maximum consumer willingness to pay for purchasing soda products without tax, and D_s^t is the demand curve that soda firms face which maps the maximum price they can receive for different quantities of their products in the presence of the tax.

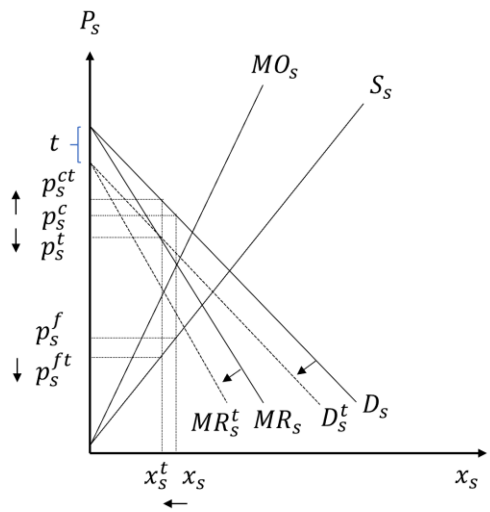


Figure III.1.1. The introduction of the SSB tax in the soda market

As shown in Figure III.1.1, the introduction of the tax reduces the equilibrium quantity of soda from x_s to x_s^t, increases the consumer price from p_s^c to p_s^{ct}, and reduces the price that soda firms receive from p_s^c to p_s^t, and the costs of these firms from p_s^f to p_s^{ft}. As a result, soda consumers and firms lose, while taxpayers benefit from the tax revenue under the policy.

The impacts of the SSB tax are not limited to soda consumers and firms; the tax affects all different vertically and diagonally related markets. Based on the cross-market relationships identified in the previous section, the rest of this section discusses the system-wide market and welfare effects of the SSB tax.

2. System-wide market and welfare effects of the SSB tax

To analyze the system-wide market and welfare effects of the SSB tax, we utilize the heterogenous agent framework developed in Section II. The use of this framework enables us to (i) determine the direct impacts of the SSB tax on consumers, firms, and producers and (ii) capture indirect and feedback effects of the tax and further explore the interactions between the soda and fruit juice markets. In this section, we focus on the impact of the tax on input and output markets in the soda and fruit juice supply chains, and determine its effects on the welfare of consumers, firms, and producers.

2.1. Consumers

The direct impact of the SSB tax on consumers stems from the increased consumer price of soda, which reduces the utility associated with the consumption of this product. This utility change decreases the soda demand while increasing the demand for its substitutes. As Figure III.2.1 shows, an increase in p_s^c causes a downward parallel shift of U_s, which reduces the demand for soda from x_s to x_s^t, and increases the demand of fruit juice and other beverages from x_j to x_j^t and from x_o to x_o^t, respectively. This is because previous soda consumers with differentiating attributes $\alpha \in (\alpha_s^t, \alpha_s]$ and $\alpha \in (\alpha_o, \alpha_o^t]$ switch from soda to fruit juice and other beverages, respectively.

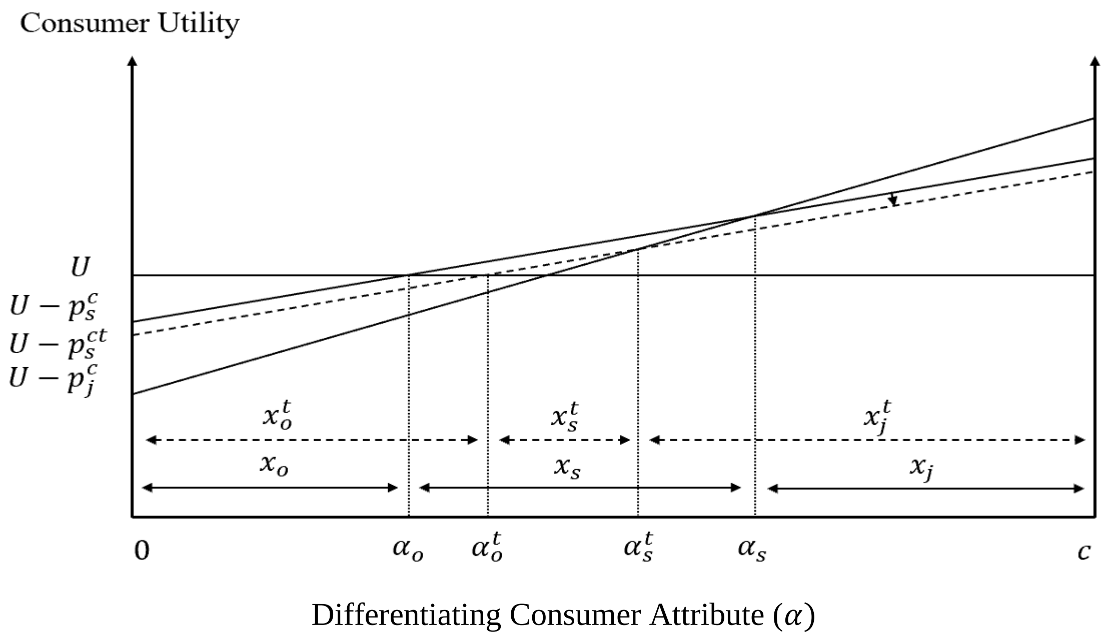


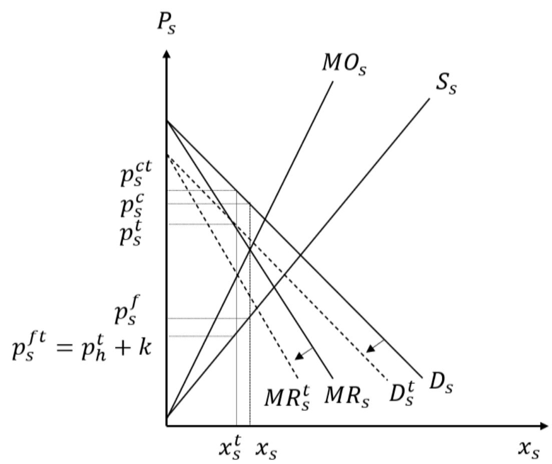
Figure III.2.1. Direct effects of the SSB tax on consumption decisions and welfare

2.2. Soda firms and crop producers

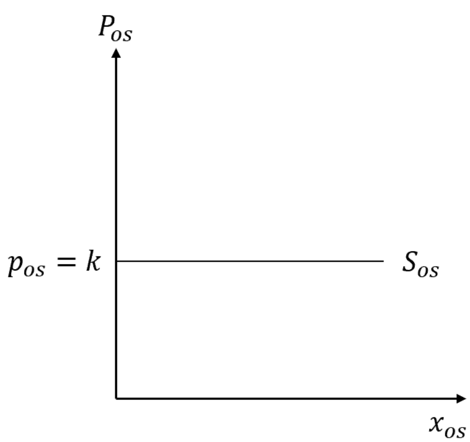
The introduction of the SSB tax reduces the soda firms' cost from p_s^f to p_s^{ft}, where p_s^{ft} is the cost of purchasing HFCS and other inputs for soda production (*os*). As shown in Figure III.2.2, the downward shift of the demand and marginal revenue curves for soda (i) decreases the price of HFCS from p_h to p_h^t, and (ii) reduces the price of corn from p_c to p_c^t, while (iii) leaving the prices of other inputs for soda (*os*) and HFCS (*oh*) unaffected.

The reduced producer price of corn, p_c, causes a downward parallel shift of the net returns curve for the corn producers and the switching of corn producers with differentiating attributes $A \in (A_b, A_b^t]$ and $A \in (A_c^t, A_c]$ to soybeans and other crops, respectively (see Figure III.2.3).

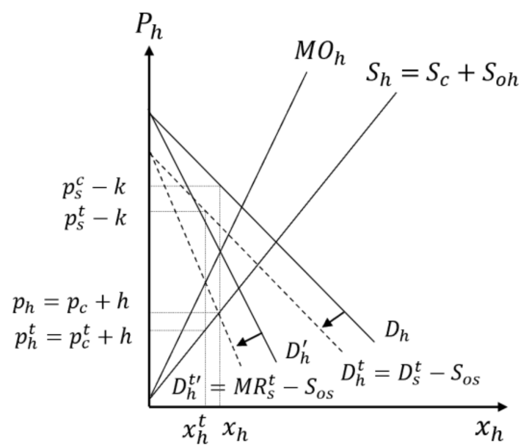
<Soda Firms> **Soda Mkt**



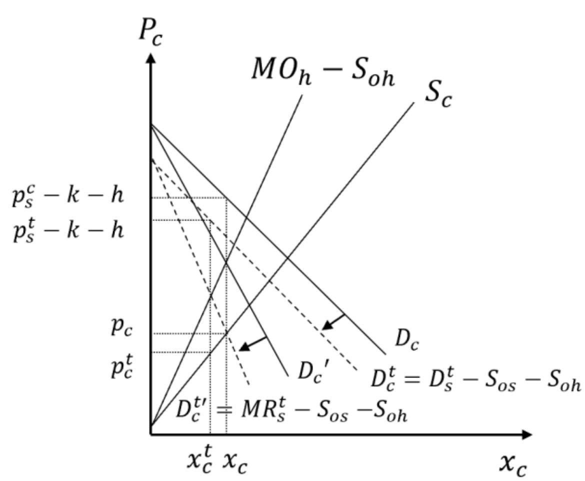
Inputs for soda: **(c) Other Inputs Mkt**



(d) HFCS Mkt



Inputs for HFCS: **(a) Corn Mkt**



(b) Other Inputs Mkt

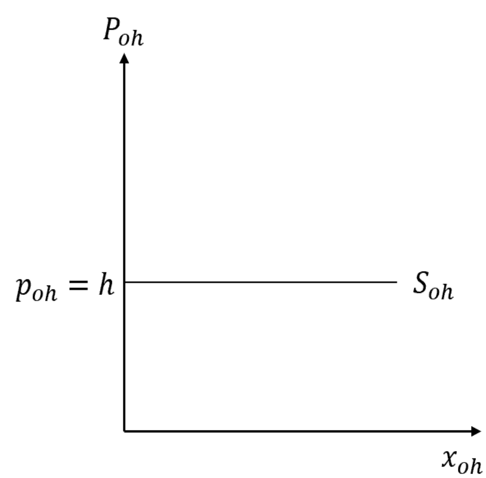


Figure III.2.2. Direct effects of the SSB tax on the soda supply chain

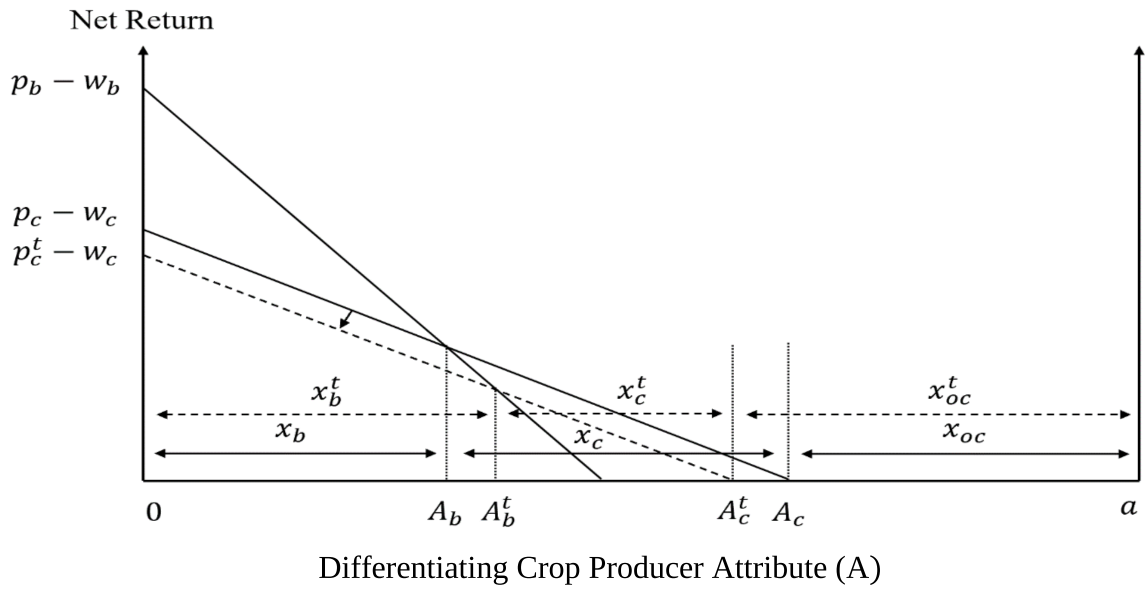


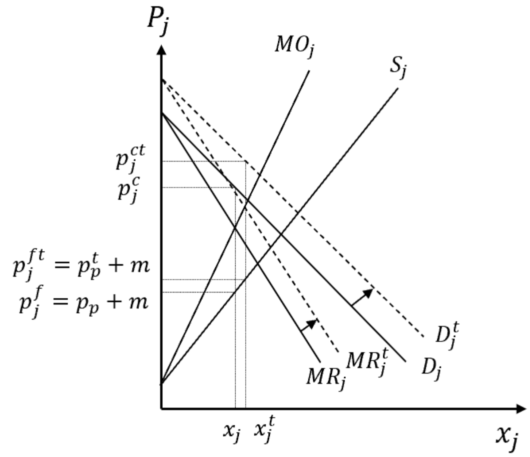
Figure III.2.3. Direct effects of the SSB tax on crop producer decisions and welfare

2.3. Fruit juice firms and fruit producers

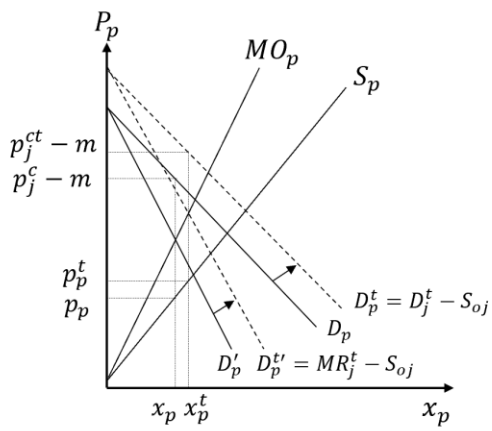
The change in the consumer price of soda in the presence of the tax has a direct impact on the fruit juice market. In particular, the increase in the soda price causes soda consumers to switch to alternative beverages, and increased the demand for fruit juice. Graphically, the change in fruit juice demand (from D_j to D_j^t) increases the consumer fruit juice price from p_j^c to p_j^{ct}, firms' cost from p_j^f to p_j^{ft}, and the processed fruit price from p_p to p_p^t in Figure III.2.4.

Figure III.2.5 shows that the increased processed fruit price p_p causes an upward parallel shift of the net returns curve associated with the processed fruit production, and the switching of fresh fruit and other types of fruit producers with differentiating attribute $B \in (B_f^t, B_f]$ and $B \in (B_p, B_p^t]$ to the production of processed fruit.

<Fruit juice Firms> **Fruit Juice Mkt**



Inputs for fruit juice: **(e) Processed Fruit Mkt** **(f) Other Inputs Mkt**



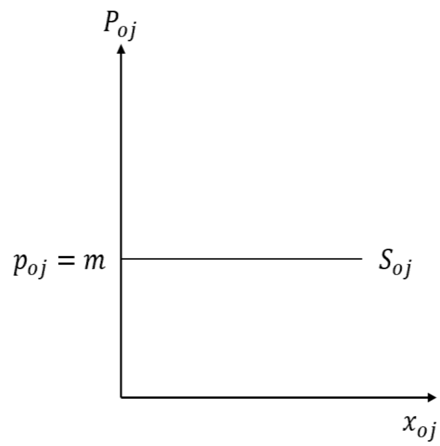


Figure III.2.4. Direct effects of the SSB tax on fruit juice supply chain

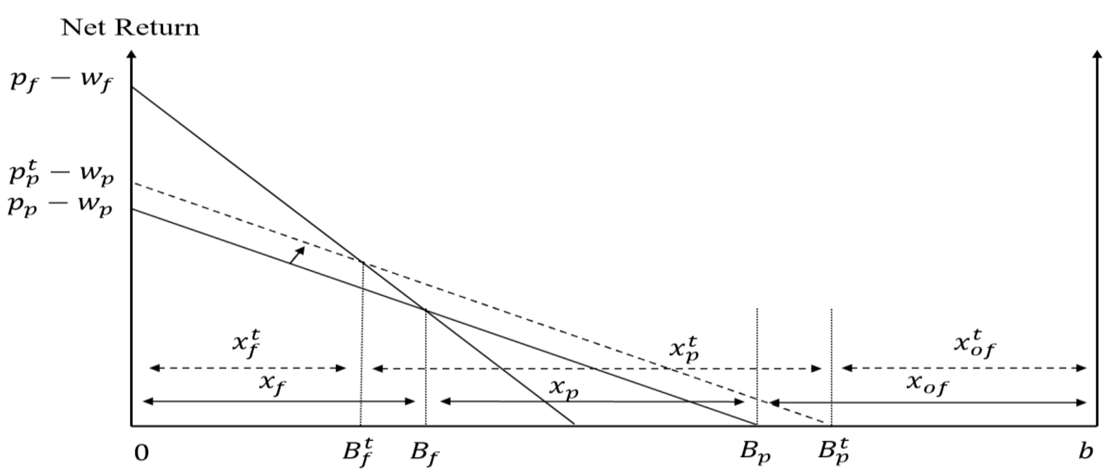
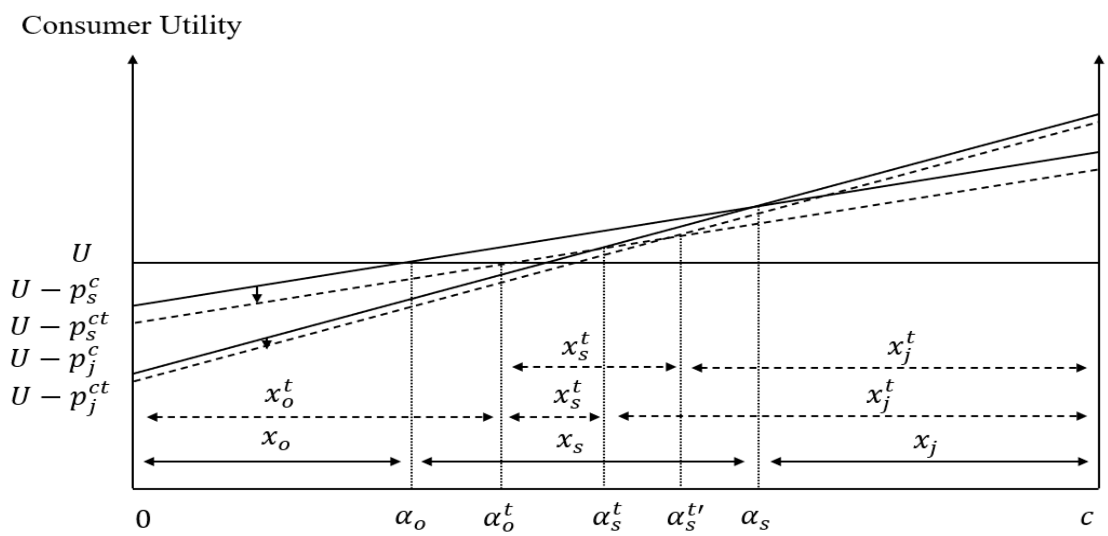


Figure III.2.5. Direct effects of the SSB tax on fruit producer decisions and welfare

2.4. Market and welfare effects of the SSB tax

The direct impacts of the SSB tax on consumers, firms, and producers discussed in the previous section are (i) the increased p_s^c causes an upward parallel shift of the demand for fruit juice, D_j (equation (5) and Figure III.2.1), and (ii) the increased D_j causes p_j^c and p_j^f to increase (equations (9), (51) and Figure III.2.4). The increased consumer price of fruit juice, p_j^c, reduces the utility associated with the fruit juice consumption and the number of consumers switching from soda to fruit juice. Figure III.2.6 shows that consumers with $\alpha \in (\alpha_o^t, \alpha_s^t]$ who consume soda before and after the SSB tax lose the most, followed by consumers with $\alpha \in (\alpha_o, \alpha_o^t]$, $\alpha \in (\alpha_s^t, \alpha_s^{t\prime}]$ and $\alpha \in (\alpha_s^{t\prime}, \alpha_s]$, who switch from soda to other substitutes, and fruit juice consumers with $\alpha \in (\alpha_s, c]$. Total consumers loss from the tax is given by

$$L_c = \int_{\alpha_o}^{\alpha_o^t}(U_s - U)d\alpha + \int_{\alpha_o^t}^{\alpha_s^{t\prime}}(U_s - U_s^t)d\alpha + \int_{\alpha_s^{t\prime}}^{\alpha_s}\left(U_s - U_j^t\right)d\alpha + \int_{\alpha_s}^{c}\left(U_j - U_j^t\right)d\alpha \qquad (65)$$



Differentiating Consumer Attribute (α)

Figure III.2.6. Total effects of the SSB tax on consumption decisions and welfare

Soda firms lose profits due to the reduced demand they face after the SSB tax introduction, whereas fruit juice firms gain due to the increased demand for fruit juice. The change in profits of soda and fruit juice firms (shown in Figures III.2.2 and III.2.4, respectively) are given by

$$\Delta\pi_s = (p_s^c - p_s^t)x_s + \left(p_s^t - p_s^f\right)(x_s - x_s^t) - \left(p_s^f - p_s^{ft}\right)x_s^t < 0 \qquad (66)$$

$$\Delta\pi_j = \left(p_j^{ct} - p_j^c\right)x_j^t + \left(p_j^c - p_j^{ft}\right)\left(x_j^t - x_j\right) - \left(p_j^{ft} - p_j^f\right)x_j > 0 \qquad (67)$$

Total crop and fruit producers' losses and gains from the SSB tax are depicted in Figures III.2.3 and III.2.5, respectively. Crop producers who produce corn and those who switch from corn to the substitutes lose after the introduction of the policy, whereas fruit producers who switch from substitutes to the processed fruit and those who continue to produce processed fruit gain after the policy is implemented. The magnitude of the loss or gain is determined by the producer differentiating attribute/efficiency in crop or fruit production. Total crop producers' losses and fruit producers' gains are given by

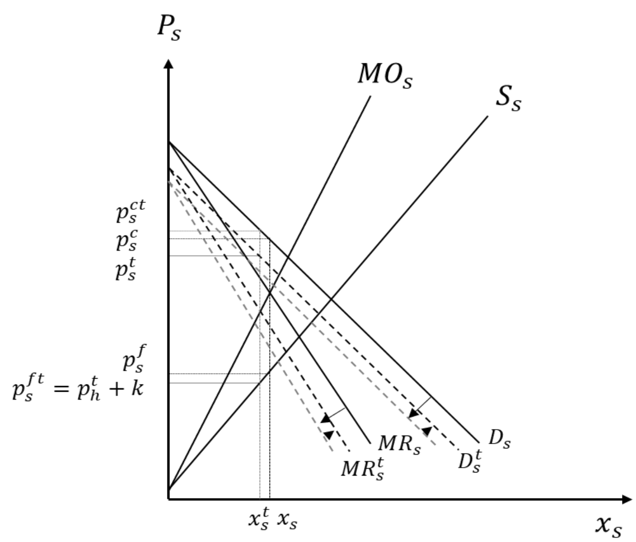
$$L_{cp} = \int_{A_b}^{A_b^t} (U_c - U_b)dA + \int_{A_b^t}^{A_c^t} (U_c - U_c^t)dA + \int_{A_c^t}^{A_c} U_c dA < 0 \qquad (68)$$

$$G_p = \int_{B_f^t}^{B_f} \left(U_p^t - U_f\right)dB + \int_{B_f}^{B_p} \left(U_p^t - U_p\right)dB + \int_{B_p}^{B_p^t} U_p^t dB > 0 \qquad (69)$$

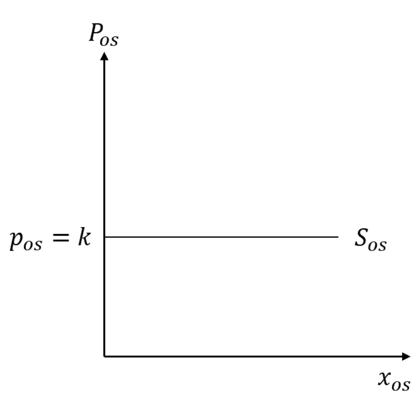
In addition to the direct effects of the SSB tax, the changes in p_s^c and p_j^c have feedback effects on the soda and fruit juice supply chains that reduce the magnitude of the impacts of the SSB tax on the different markets. The increased p_j^c after the introduction of the tax, for instance, increases the demand for soda, which lessens the impact of the SSB tax on the soda market. The total effects of the SSB tax on the soda and fruit juice supply chains are depicted in Figures III.2.7-III.2.9, with the grey lines capturing the directs effects of the SSB tax and the black dotted lines showing the total impacts after a feedback effects of the tax are considered.

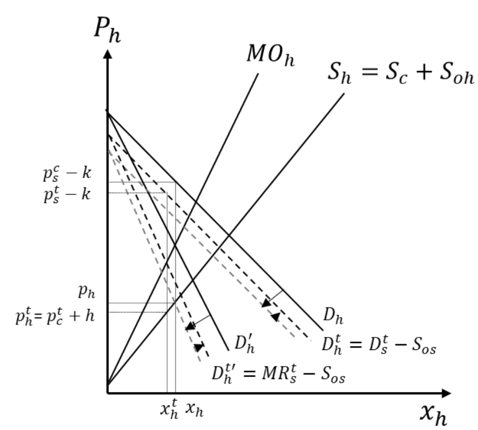
Similarly, the profits of fruit juice firms and the surplus of processed fruit producers increase after the SSB tax is introduced. However, the feedback effects reduce the magnitude of these gains. This is because the magnitude of an increased demand for fruit juice is decreased as the price of fruit juice is increased and the soda price drops.

<Soda Firms> **Soda Mkt**



Inputs for soda: **(c) Other Inputs Mkt** **(d) HFCS Mkt**





Inputs for HFCS: **(a) Corn Mkt** **(b) Other Inputs Mkt**

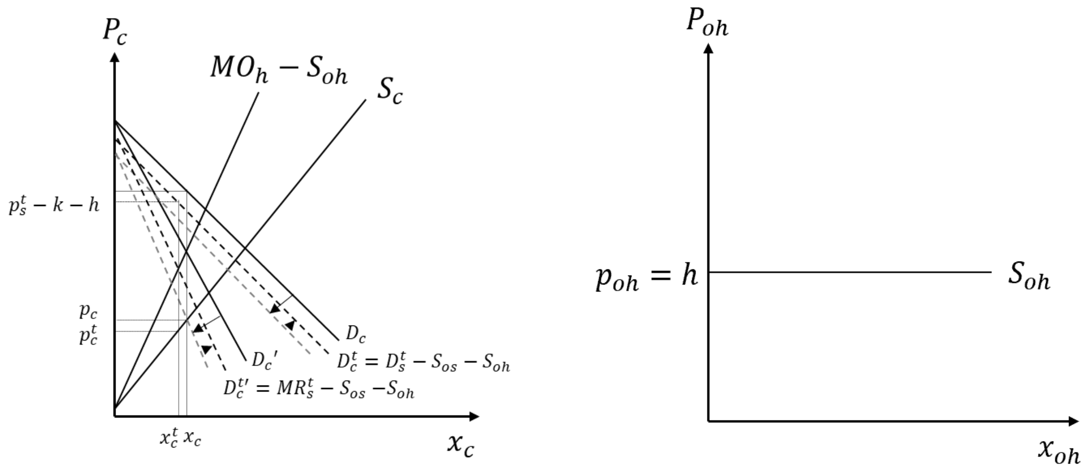


Figure III.2.7. Total impacts of the SSB tax on the soda supply chain

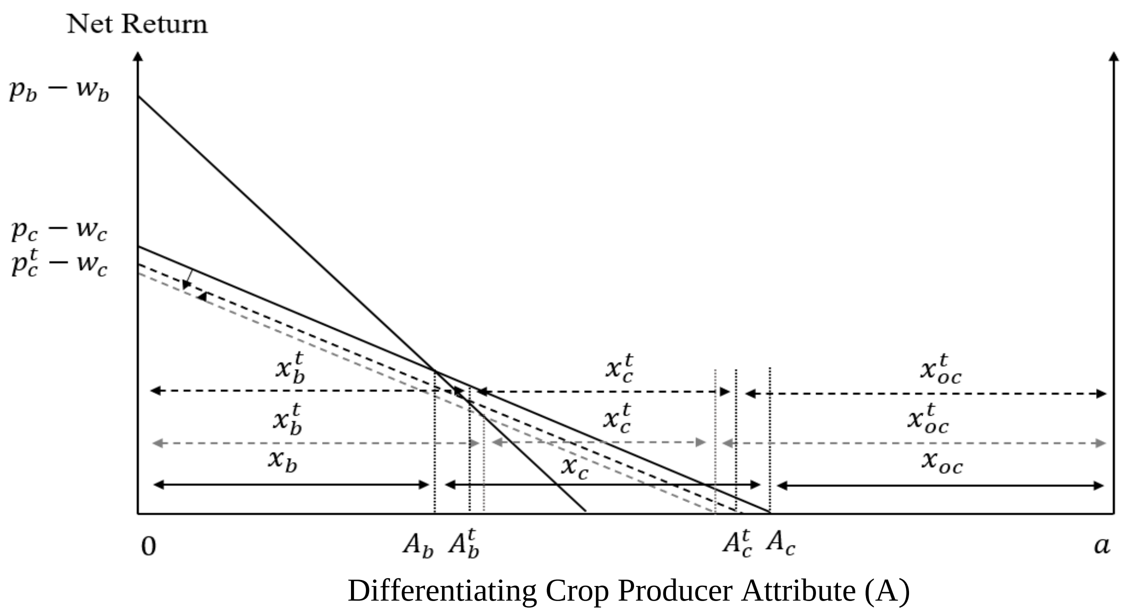
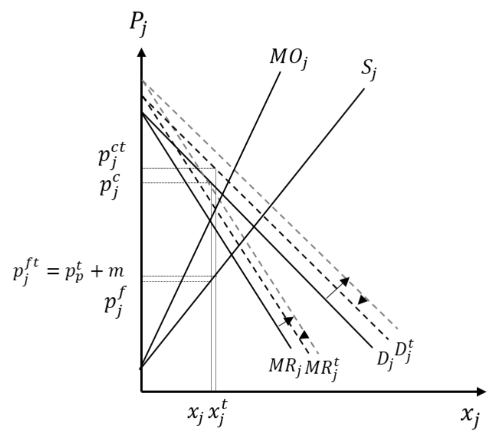
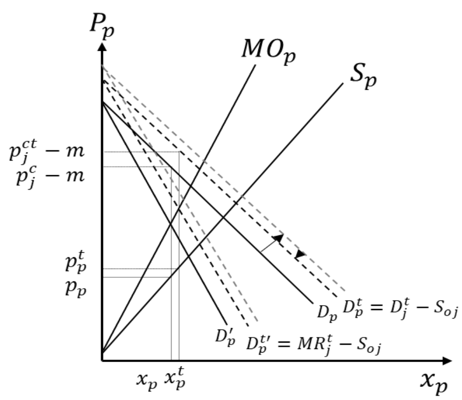


Figure III.2.8. Total impacts of the SSB tax on crop producers

<Fruit juice Firms> **Fruit Juice Mkt**



Inputs for fruit juice: **(e) Processed Fruit Mkt** **(f) Other Inputs Mkt**



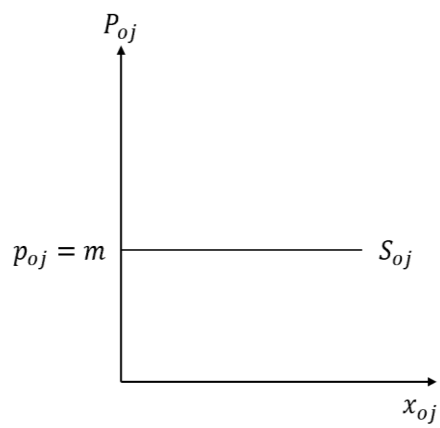


Figure III.2.9. Total impacts of the SSB tax on the fruit juice supply chain

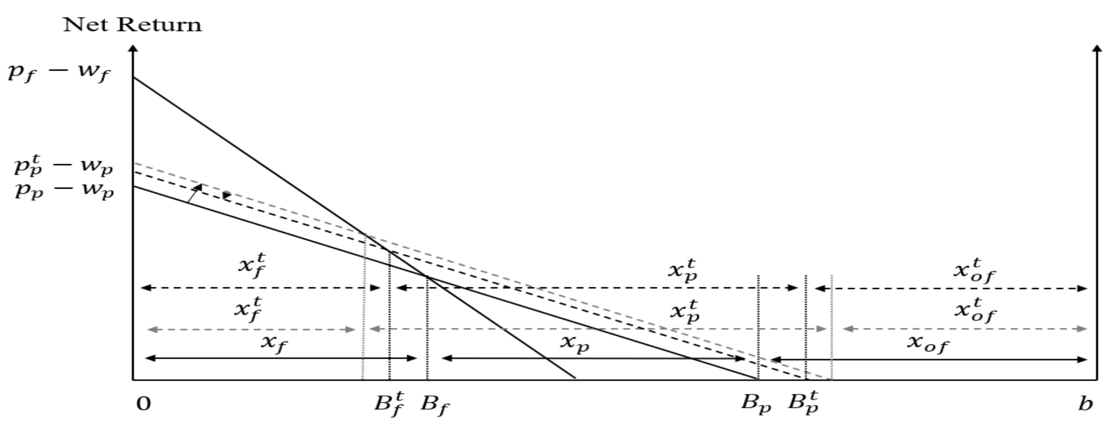


Figure III.2.10. Total impact of the SSB tax on fruit producers

3. Equilibrium conditions after the introduction of the SSB tax

The equilibrium conditions in the soda supply chain in the presence of the SSB tax are derived as follows. After the SSB tax is imposed in the soda market, the demand and marginal revenue curves shift downward by the amount of tax t. Using equations (8) and (48), soda firms' demand and marginal revenue curves after the tax are

$$D_s^t: \quad p_s^c = \frac{\lambda}{\mu} p_j^c - t - \frac{\lambda}{\mu}(\mu - \lambda) x_s \tag{70}$$

$$MR_s^t = \frac{\lambda}{\mu} p_j^c - t - \frac{\lambda}{\mu}(\mu - \lambda)(1 + \theta_s^s) x_s \tag{71}$$

Based on the optimality condition $MO_s = MR_s^t$, the equilibrium quantity of soda after the introduction of SSB tax is

$$x_s^t = \frac{\gamma\lambda P_j^{ct} - \mu\gamma t - \gamma\mu(w_c + h + k) - \mu\delta(p_b - w_b)}{\delta\mu(\gamma - \delta)\left(1 + \theta_h^b\right) + \lambda\gamma(\mu - \lambda)(1 + \theta_s^s)} \tag{72}$$

We can derive the post-tax equilibrium consumer price of soda and soda firms' price as

$$p_s^{ct} = \frac{\lambda}{\mu} p_j^{ct} - \frac{\lambda}{\mu}(\mu - \lambda)\left[\frac{\gamma\lambda P_j^{ct} - \mu\gamma t - \gamma\mu(w_c + h + k) - \mu\delta(p_b - w_b)}{\delta\mu(\gamma - \delta)\left(1 + \theta_h^b\right) + \lambda\gamma(\mu - \lambda)(1 + \theta_s^s)}\right] \tag{73}$$

$$p_s^t = \frac{\lambda}{\mu} p_j^{ct} - t - \frac{\lambda}{\mu}(\mu - \lambda)\left[\frac{\gamma\lambda P_j^{ct} - \mu\gamma t - \gamma\mu(w_c + h + k) - \mu\delta(p_b - w_b)}{\delta\mu(\gamma - \delta)\left(1 + \theta_h^b\right) + \lambda\gamma(\mu - \lambda)(1 + \theta_s^s)}\right] \tag{74}$$

The post-tax equilibrium cost of soda firms is

$$p_s^{ft} = w_c + \frac{\delta}{\gamma}(p_b - w_b) + h + k + \frac{\delta(\gamma - \delta)}{\gamma}\left[\frac{\gamma\lambda P_j^{ct} - \mu\gamma t - \gamma\mu(w_c + h + k) - \mu\delta(p_b - w_b)}{\delta\mu(\gamma - \delta)\left(1 + \theta_h^b\right) + \lambda\gamma(\mu - \lambda)(1 + \theta_s^s)}\right] \tag{75}$$

The post-tax equilibrium producer prices of HFCS and corn are derived based on the equation (75) as

$$p_h^t = w_c + \frac{\delta}{\gamma}(p_b - w_b) + h + \frac{\delta(\gamma-\delta)}{\gamma}\left[\frac{\gamma\lambda P_j^{ct} - \mu\gamma t - \gamma\mu(w_c+h+k) - \mu\delta(p_b - w_b)}{\delta\mu(\gamma-\delta)\left(1+\theta_h^b\right)+\lambda\gamma(\mu-\lambda)(1+\theta_s^s)}\right] \quad (76)$$

$$p_c^t = w_c + \frac{\delta}{\gamma}(p_b - w_b) + \frac{\delta(\gamma-\delta)}{\gamma}\left[\frac{\gamma\lambda P_j^{ct} - \mu\gamma t - \gamma\mu(w_c+h+k) - \mu\delta(p_b - w_b)}{\delta\mu(\gamma-\delta)\left(1+\theta_h^b\right)+\lambda\gamma(\mu-\lambda)(1+\theta_s^s)}\right] \quad (77)$$

The equilibrium conditions in the fruit juice supply chain under the SSB tax are

$$x_j^t = \frac{\varepsilon\left[c(\mu-\lambda)+P_s^{ct}-w_p-m\right]-\upsilon\left(p_f-w_f\right)}{\upsilon(\varepsilon-\upsilon)\left(1+\theta_p^b\right)+\varepsilon(\mu-\lambda)(1+\theta_j^s)} \quad (78)$$

$$p_j^{ct} = c(\mu-\lambda) + p_s^{ct} - (\mu-\lambda)\left\{\frac{\varepsilon\left[c(\mu-\lambda)+P_s^{ct}-w_p-m\right]-\upsilon\left(p_f-w_f\right)}{\upsilon(\varepsilon-\upsilon)\left(1+\theta_p^b\right)+\varepsilon(\mu-\lambda)(1+\theta_j^s)}\right\} \quad (79)$$

$$p_j^{ft} = w_p + \frac{\upsilon}{\varepsilon}\left(p_f - w_f\right) + m + \frac{\upsilon(\varepsilon-\upsilon)}{\varepsilon}\left\{\frac{\varepsilon\left[c(\mu-\lambda)+P_s^{ct}-w_p-m\right]-\upsilon\left(p_f-w_f\right)}{\upsilon(\varepsilon-\upsilon)\left(1+\theta_p^b\right)+\varepsilon(\mu-\lambda)(1+\theta_j^s)}\right\} \quad (80)$$

$$p_p^t = w_p + \frac{\upsilon}{\varepsilon}\left(p_f - w_f\right) + \frac{\upsilon(\varepsilon-\upsilon)}{\varepsilon}\left\{\frac{\varepsilon\left[c(\mu-\lambda)+P_s^{ct}-w_p-m\right]-\upsilon\left(p_f-w_f\right)}{\upsilon(\varepsilon-\upsilon)\left(1+\theta_p^b\right)+\varepsilon(\mu-\lambda)(1+\theta_j^s)}\right\} \quad (81)$$

where x_j^t is the equilibrium quantity of fruit juice; and $p_j^{ct}$and p_p^t are the equilibrium consumer price of fruit juice and producer price of processed fruit under the SSB tax, respectively.

Solving the equilibrium expressions for p_j^{ct} and p_s^{ct} simultaneously and substituting into equations (72) to (81), we can derive the equilibrium prices and quantities as functions of the exogeneous parameters of the model such as the tax, consumer preferences, producer cost enhancement factors, and firms' market power. This enables us to quantify the impact of the policy on the welfare of the interest groups involved under different empirically relevant scenarios, which is the focus of the next section of this paper.

IV. Simulation Analysis

The objective of the simulation is to quantify the economic impacts of the nationwide SSB tax derived in the previous section of this study. We focus on the effects of the introduction of a $0.01 per ounce tax on the soda market as this is the rate that most cities have imposed. In particular, the SSB tax has been introduced in nine cities across the U.S., with five cities (Berkeley, San Francisco, and Oakland in California; Albany in New York; and Cook County in Illinois) having a tax rate of 1 cent/oz, and the other four cities (Boulder, Colorado; Portland, Oregon; Seattle, Washington; and Philadelphia, Pennsylvania) having tax rates ranging between 1.15 cents/oz and 2 cents/oz.

To measure the incidence of the tax policy, we start by parameterizing baseline parameters ($\mu, \lambda, \gamma, \delta, \varepsilon, \upsilon$) in the pre-SSB tax market equilibrium conditions using observed data on quantities, prices, market shares, market power, and the cost of production for crop and fruit producers. Next, we simulate the changes in market equilibriums, consumer and producer welfare, and firms' profits under the SSB tax policy.

Table IV.1 presents the data used for simulation and the calibrated parameters. Consumer prices of soda (p_s^c) and fruit juice (p_j^c) are averaged from different studies to reflect the retail prices of SSBs and non-SSBs in different regions. In particular, we used prices from Seiler et al. (2019) who collected price data at the UPC/store/week level (a total of 17,582 stores) from January 2015 through September 2018 in Philadelphia, and Leider and Powell (2019) who collected the data in late May and June 2017 from 581 stores in Cook County, MO, Sacramento, and Oakland, CA. The pre-tax equilibrium quantities for soda (x_s) and fruit juice (x_j) are used to reflect the beverage markets that are considered in the theoretical model. In particular, we consider the markets for soda (SSB), 100% fruit juice (non-SSB), and bottled water/milk (other types of beverages), while energy drinks, sports beverages, tea, and coffee are not considered in this study. The soybean and corn quantities (x_b, x_c), producer prices (p_b, p_c), and production costs (w_b, w_c) are derived from USDA NASS and ERS for the period 2010-2018. Fresh and processed fruit quantities (x_f, x_p), producer prices (p_f, p_p) and production costs (w_f, w_p) for the period 2014-2018 are collected from various resources as the data is limited; quantities are derived based on retail weights of total citrus and non-citrus, while producer prices and production costs correspond to apple and orange juices, which represent 70% of the U.S. juice market.

Table IV.1. Data and calibrated parameters

Parameter	Value (million oz)	Reference
Data:		
p_s^c	\$35,100	Seiler et al. (2019), Leider and Powell (2019)
p_j^c	\$71,500	Seiler et al. (2019)
x_s	1,257,108[5]	Beverage Marketing Corporation (2017)
x_j	282,000[3]	Beverage Marketing Corporation (2017), USDA ERS (2018)
p_b	\$7,641	USDA ERS (2010-2018)
p_c	\$1,195	USDA ERS (2010-2018)
w_b	\$4,761	USDA ERS (2010-2018)
w_c	\$945	USDA ERS (2010-2018)
x_b	373,735[6]	USDA ERS (2018)
x_c	1,257,108[4]	USDA ERS (2018)
p_f	\$23,522	USDA ERS (2016-2018)
p_p	\$6,999	Florida Department of Citrus, USDA ERS (2016-2018)
w_f	\$21,200	O`Connell et al. (2015),

[5] Soda, 100% fruit juice, and bottled water and milk markets account for 20%, 21%, and 29.6%, respectively, of the total beverage market.
[6] Corn and soybeans account for 37% and 11% of total crop market, respectively, while other type of crops represent cotton (46%), wheat (6%), and rice (1%) based on bushels and are converted to million oz (1bushel = 1191.57 oz) for the simulation.

		Galinato et al. (2016), UC cooperative extension (2015), WSU extension (2015)
w_p	\$5,534	Klonsky and Don (2014), Singerman (2017, 2018), Galinato et al. (2016), UC cooperative extension (2014), UF extension center (2016)
x_f	495,636[7]	USDA ERS (2019)
x_p	282,000[5]	USDA ERS (2019)
θ_s^s	0.76	Dhar et al. (2005)
θ_j^s	0.70	Luckstead et al. (2015)
p_s^f	\$25,518 (27% of margin)	Yoffie (2009)
p_j^f	\$39,683 (45% of margin)	Luckstead et al. (2015)
p_h	\$2,716	
m	\$32,684	
k	\$22,802	
h	\$1,521	
t	\$10,000	Same as \$0.01/oz
Calibrated parameters[8]:		
θ_h^b	0.25	
θ_p^b	0.35	
μ	0.0179	
λ	0.0105	
γ	0.0036	
δ	0.0035	
ε	10.2	
υ	0.0226	

The economic model includes four variables that capture the market power soda and fruit juice firms are able to exercise on consumers and input suppliers. We use $\theta_s^s = 0.76$ (soda firms market power as seller) and $\theta_j^s = 0.7$ (fruit juice firms market power as seller). We were unable to find estimates of buyer's market power for soda and fruit juice firms.

[7] Fresh and processed fruit market share is computed by the retail weight, which is estimated at a primary distribution level, categorized as 'fresh (58%)' and 'processed' with 'frozen concentrate' (33%). Per capita availability of canned, dried fruits is utilized for calculating the market share of alternative types of fruits. Fruit includes both citrus (oranges, grapefruit, lemons, etc.) and non-citrus (apple, banana, cherries, grapes, papayas, etc.) and the units converted pounds to million oz (1 pound = 16 oz) for the simulation.
[8] Parameters are calibrated below 10% variation within the numerical data.

Therefore, we calibrate soda firms' buyer market power as $\theta_h^b = 0.25$ because the five major HFCS manufacturers (ADM, Cargill, A.E Staley, Cerestar, and CPC) face a relatively elastic corn supply curve (Evans et al., 2001), while two major buyers utilize most of HFCS for producing sweetened beverages in the market. The fruit juice firms' buyer market power is calibrated as $\theta_p^b = 0.35$. The juice market is also highly concentrated by processors, including Coca-Cola Co. and PepsiCo Inc. (the four-firm concentration ratio was 69% in 2006[9]) and vertically integrated from warehouses to retailers (Binkley et al., 2002). However, fruit juice producers' buyer market power can be reduced significantly as the supply of the processed fruit is occasionally decreased up to 90% due to a few days of freezing weather (Wang, 2006).

Firms' prices for soda and fruit juice (p_s^f, p_j^f) are derived from the consumer price and the estimated margin from Yoffie (2009) and Luckstead et al. (2015). Yoffie reported the soda firms' net profit margin was 22.1% in 2004, but we used 27% as the soda firm's margin gradually increases from 2000 (10.6%) to 2004 (22.1%). We use estimated fruit juice firms' margin from Luckstead et al. (2015), who analyzed the oligopolistic competition between Florida and Sao Paulo processors in the U.S. orange juice market. Other parameters such as the price of HFCS (p_h) and other inputs costs (*m*, *k*, *h*) are calculated using the formulas introduced in sections II.3.1 and II.3.2 (equations (40), (42), and (49)).

Using the parameter values indicated above, we calibrate the unknown consumers' preference parameters (μ and λ) and producers' cost enhancement factors associated with

[9] Guci and Brown (2007) reported that the four-firm concentration ratio increased from 42.6% in 1995-1996 to 68.5% in 2004-2006, and the eight-firm concentration ratio increased from 63% to 96.8% during the same period.

the production of soybean (γ), corn (δ), fresh fruit (ε), and processed fruit (υ). We find a small difference between the consumer preference parameters for soda and fruit juice. This small difference reflects the U.S. consumers' strong preference for soda compared to other beverages, which is also captured by the high market share of soda in the U.S. beverage market. Similarly close are the crop producers' cost enhancement factors, indicating small differences in the idiosyncratic costs (e.g., costs affected by the producer efficiency) of producing corn and soybeans. This is consistent with the fact that soybeans and corn are close substitutes, and producers can share many pieces of equipment in the production of these crops. On the other hand, fruit producers' cost enhancement factors are significantly different due to the requirements of different production practices and significantly greater costs when producing fresh fruit relative to producing processed fruit.

Table IV.2. summarizes the market and welfare effects after the introduction of the SSB tax. While it may seem minute, the $0.01 per ounce tax represents about 29% of the soda price and slightly above 27% of the price-cost margin of soda firms used in our simulation. The results show that this tax would cause a 23% increase in the consumer soda price, with 49% of the tax passed through to consumers. The result is similar to the estimates from Falbe et al. (2015), while other estimates have varied depending on the different tax rates and assumptions utilized. For example, a study of Cook county, IL, found that a penny-per-ounce tax would raise the price of soda by 29% when it is fully passed through to consumers (Leider, 2017), while a study of Berkeley, CA, found a 47% consumer tax pass-through for the individual size (less than 1L) of SSBs (Falbe et al., 2015), and a study of Philadelphia showed a 93% tax pass-through to consumers when a $0.02 per ounce tax rate is imposed (Cawley et al., 2019).

The higher price of soda leads to an 11.7% increase in the fruit juice price due to a significant reduction in the soda market share (61.1%) and a subsequent shift of consumer demand to high-quality substitutes. This causes an overall reduction in aggregate beverage consumer welfare by $8.9 billion per year, which represents 8.5% of the pre-tax market value of the total U.S. beverage market. As shown in the theoretical analysis, the magnitude of the welfare loss is much greater for consumers who continue consuming soda ($4.1 billion, 45% of total welfare loss) and those who switch from soda to other beverages ($3.9 billion, 44% of total welfare loss) under the tax policy, followed by consumers who continue consuming fruit juice beverages ($0.9 billion, 11% of total welfare loss).

The profits for soda firms decrease by 81.7% due to the reduced soda firms' price and demand for soda by 23.3% and 61.1%, respectively. With firms' cost of procuring inputs being affected less by the policy, the significant reduction in soda firms' price decreases the firms' margin and profits. A small change (0.2%) in corn prices due to the reduced demand for HFCS reduces the aggregate producer welfare by $6.8 million, which represents 0.02% of the pre-tax market value of the total crop market.

In addition to increasing the consumer price of juice, the higher demand for fruit juice raises the fruit juice firms' profits by 52.9%. The tax increases firms' cost by 19.1%, and it increases processed fruit price by 29.5%. The higher price of processed fruit results in a greater welfare gain for producers supplying fruit to juice producers ($1.5 billion, or 10.5%), while there is a relatively small gain for producers who switch from fresh fruit to processed fruit production ($0.3 billion, or 2.3%). The aggregate fruit producers' gain is

$1.8 billion that accounts for 12.8% of the total fruit market value prior to the introduction of the tax.

Table IV.2. Market and welfare effects of the SSB tax on the soda and fruit juice supply chains

SSB Tax Rate: $0.01/oz	**Soda**	**100% fruit juice**
Consumer price ($\Delta\, p_i^{ct}$)	+23.3%	+11.7%
Price received by firms ($\Delta\, p_i^{t}$)	-7%	
Cost of firms ($\Delta\, p_i^{ft}$)	-0.03%	+19.1%
Equilibrium quantity ($\Delta\, x_i^{t}$)	-61.1%	+69%
Producer price		
HFCS ($\Delta\, p_h^{t}$)	-0.1%	
Corn ($\Delta\, p_c^{t}$)	-0.2%	
Processed fruit ($\Delta\, p_p^{t}$)		+29.5%
Firm profits ($\Delta\, \pi_i^{t}$)	-81.7% (-$5 billion)	+52.9% (+$6.1 billion)
Consumer welfare (L_c)	-$8.9 billion (pre-tax market value: $105 billion)	
Consumers of soda	-$4.1 billion	
Consumers of fruit juice	-$0.9 billion	
Consumers of soda switching to other substitutes	-$3.9 billion	
Crop producer welfare (L_{cp})	-$6.8 million (pre-tax market value: $19.7 billion)	
Producers of corn	-$3.8 million	
Producers of corn switching to other crops	-$3 million	
Fruit producer welfare (G_p)	+$1.8 billion (pre-tax market value: $14.2 billion)	
Producers of processed fruit	+$1.5 billion	
Producers of other fruit types to processed fruit	+$0.3 billion	

Note: (1) $i = s, j$ where s is soda, j is 100% fruit juice
(2) + denotes welfare gains, - denotes welfare loss

1. Health externalities and welfare change in soda consumer

In the previous analysis, we focus on the market changes of introducing SSB tax and how these changes impact the welfare of relevant agents in the market. In this section, we looks for the externalities of drinking SSBs that are not part of our analysis. In particular, we focus on the health cost savings by reducing sugary drink consumption and how it changes our welfare analysis in the previous section.

Consuming sugary drinks harms human health through diabetes, cardiovascular disease, obesity (weight gain), resulting in increased private and social costs (Allcott et al., 2019). SSBs contain a high level of rapidly digestible sugars, which means that glucose is released into the bloodstream fast and increases the corresponding amount of insulin. Constantly elevated blood glucose and insulin cause a higher risk of having diabetes (Raben et al., 2011). Malik et al. (2010) found that overconsuming SSBs (drink more than 8 ounces per day) causes a 26% more chance of developing diabetes than people who consume less than 8 ounces per day.

Refined carbohydrates and added sugar in SSBs increase the risk of cardiovascular disease. Xi et al. (2015) found that people who consume one additional serving of sugary drinks per day have a higher risk of coronary heart disease risk. In addition, as drinking SSBs cannot make people feel satiated, it causes excessive overall calorie intake that is associated with obesity and weight gain. DiMeglio and Mattes (2000) show that people intake more calories when consuming liquids than solid foods (e.g., milk and cheese), while Hu (2013) argues that a higher intake of SSBs (more than 12 oz of SSBs per month) increases the risk of obesity by 55%.

These health impacts of excessive SSB consumption cause private income losses, non-financial losses (e.g., reduced lifetime expectation, increased risk of other chronic diseases), private medical costs, and public medical costs (Bhattacharya and Neeraj Sood, 2011; Allcott et al., 2019). The former three can be categorized as private costs, and the latter is categorized as public (external) costs (Allcott et al., 2019). Our study shows that consumers realize welfare losses under the SSB tax due to the increased prices of both SSBs and non-SSBs. However, to determine the desirability of the U.S. nationwide SSB tax, it is necessary to account for health costs to the private and public sectors under the current SSB consumption.

In this section, we only consider externalized costs to consumers who must pay by themselves for health treatments while consuming excessive amounts of sugary drinks. This implies that consumers have enough nutrition knowledge or control themselves to drink SSBs based on their evaluation. In other words, soda consumers' utility function in our framework does not change because they take into account the health outcomes from SSBs consumption. To analyze the consumer health benefits from reduced SSBs consumption and their impact on the consumer welfare changes, we use the estimated health cost savings from Wilde et al. (2019) and Long et al. (2015). Wilde et al. (2019) estimated the health impact and cost-effectiveness of SSB tax when the tax rate is \$0.01/oz using a validated microsimulation model that predicts reduced cardiovascular disease. In particular, this study focused on six different consumer categories differing in their insurance statuses, such as private, Medicare, Medicaid, dual-eligible (Medicare and Medicaid), other government (state-sponsored), and no coverage. They examined how these relevant private costs are reduced because of the decreased number of events in myocardial infarction (MI), stroke, ischemic heart disease (IHD), and increased life expectancy. The data, including insurance status, SSBs intake, and baseline risk factors, were obtained from the National Health and Nutrition Examination Survey (NHANES) for the period 2005 - 2012.

The primary reason we use the Wilde et al. (2019) estimates of health cost savings is that the study breaks down the healthcare costs as government and household insurance premium/out-of-pocket cost, which represents the public and private costs, respectively. Although Wilde et al. (2019) estimate health cost-effectiveness associated with reducing cases of cardiovascular diseases rather than reducing soda consumption, these estimates provide insights on the healthcare cost savings associated with the various tax passed-through rates and reduced sugary drink consumption.

Long et al. (2015), on the other hand, focus on the BMI reduction and healthcare expenditure savings related to child and adult obesity after implementing the same rate of SSB tax nationally. They simulate the impact of the tax on BMI and calculate obesity-oriented healthcare costs by using the Medical Expenditure Panel Survey from Gortmaker et al. (2015). They assume that the proposed tax would increase the SSBs prices by approximately 16% and use an average demand elasticity from Powell et al. (2014), which is -1.21 (range, -0.69 to -3.87). Our study, on the other hand, finds the prices would increase by 23.2%, and the demand elasticity is calculated by -2.61, which is higher than the value used by Powell et al. (2014). Due to these disparities, the estimated savings from obesity-oriented healthcare expenditures could be lower than the loss of consumer welfare in our analysis. However, the study from Long et al. (2015) can provide the cost savings caused by obesity separately and capture the short-term effects (approximately ten years) of excessive consumption of sugary drinks. In addition, this study has similarities with Wilde et al. (2019), in that they used quality-adjusted life-years gained and estimated the health care costs in 2014 dollars (Wilde and other researchers used 2013 dollars) with 3% of the discounted rate annually.

According to Wilde et al. (2019), the present value of cardiovascular disease health cost savings was $23.05 billion presented in 2013 dollars, converted to $23.74 billion in 2014 dollars with a 3% inflation rate. Then, the private sector's healthcare cost savings are $18.1 billion (in 2013 dollars) as a lifetime quality-adjusted value, representing 76.2%[10] of the total health cost savings. The model used population data with the U.S. adults aged 35 to 85 years and assumed the mean survival is 85, which is 1.9 years more of the lifetime expectation without SSB tax (83.1). By calculating the present value of healthcare costs[11], we find that the private cost-savings associated with cardiovascular disease over a ten-year period is $24.47 billion presented in 2014 dollars. Using a similar approach, ten years of obesity-oriented healthcare cost savings are $23.61 billion in 2014 dollars find that Long et al. (2015). Therefore, the total healthcare cost savings for ten years after implementing a penny-per-ounce tax would be $48.08 billion.

Based on the simulation analysis of our study, soda consumers who consume soda before and after the SSB tax lose $4 billion per year, while consumers who switch from soda to other substitutes lose $3.9 billion per year due to the higher prices that follow the introduction of the SSB tax. Using the 3% discount rate used in the literature, the

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[10] Based on Table H in supplemental materials in Wilde et al. (2019).

[11] $PV = \sum_{t=1}^{n} \frac{C^t}{(1+r)^t} \; where \; r = 0.03.$

soda consumers' loss within ten years would be approximately $70 billion in 2014 dollars. This implies that if we consider health benefits from reduced obesity and cardiovascular disease, consumer welfare losses would be reduced to $21.9 billion due to the reduced SSBs consumption over a ten years period. This result also implies that other healthcare cost savings from the relevant diseases such as diabetes would further reduce consumers' welfare losses and might outweigh these losses from a national SSB tax policy.

V. Conclusions

This research develops an empirically relevant model of heterogeneous consumers, heterogeneous producers, and imperfectly competitive beverage firms to analyze the market and welfare impacts of a nationwide SSB tax policy. Analytical results show that soda and fruit juice prices increase after introducing the SSB tax, while there is a negative impact on soda firms' profit as the price that firms receive decreases. Fruit juice firms' profits increase due to the greater demand for high-quality beverages, resulting in welfare gains for fruit producers, while consumers and crop producers realize welfare losses under the tax policy. The magnitude of the different consumer and producer groups' welfare changes vary depending on the strength of the consumer preferences for high-quality beverages and the producer efficiency levels.

Simulation results find a significant reduction in the soda market share (61.1%) and a subsequent shift of consumer demand to the high-quality substitutes after a nationwide penny-per-ounce SSB tax is introduced in the U.S. This result reveals the effectiveness of the SSB tax in achieving the objectives of the policy. Although the consumer soda price is increased to 11.7%, the soda firms experience a significant 81.7% reduction in their profits ($5 billion) due to the decreased price and market share. On the other hand, fruit juice firms realize a 69% increase in their market share and a 52.9% increase in profits ($6.1 billion) because of an increased fruit juice price and a number of soda consumers switching to fruit juice. The price received by soda firms decreases by 7%, while the input costs for HFCS are less affected under the SSB tax, and these changes contribute to a substantial decrease in soda firms' profits. The margins for both soda and juice firms decrease by about 6.4% and 4.5%, respectively, because the juice firms' cost of procuring inputs increases more than the consumer price of fruit juice.

The simulation results also indicate that the SSB tax reduces consumer and crop producer welfare by $8.9 billion and $6.8 million, respectively, while increasing fruit producer welfare by $1.8 billion. While the SSB tax was designed for consumers benefits, their welfare loss from the market effects of the policy is the highest among the interest groups involved as the policy raises prices of both SSBs and non-SSBs in the market. This result might change when considering the health benefits and reduced healthcare costs associated with the reduced consumption of SSBs due to the tax policy. In particular, the net consumer welfare loss is decreased from $74.4 billion to $20.2 billion in 2021 dollars for a ten-year period (approximately $2 billion per year) when the health benefits from reduced obesity and cardiovascular disease are taken into account. Additional consideration of healthcare cost savings from reduced diabetes and tooth decay would further reduce consumers' welfare losses and could even outweigh the losses from the SSB tax policy.

This study can be extended in a number of ways. Our theoretical consumer model can be expanded to include more substitutes of soda, such as coffee or sports drinks (30% of market share), which will enable the determination of the market and welfare impacts of the policy in these markets. If coffee or sports drinks are also close substitutes to fruit juice, then the substitution effects of the policy on fruit juice firms' profit and disaggregated consumer and producer welfare will be different than those in our analysis.

Before concluding this study, it is important to note that the introduction of the SSB tax creates winners and losers among consumers, producers, and firms in the beverage industry. Our study's disaggregated market and welfare effects can provide valuable insights on the potential economic impacts of nationwide implementation of the SSB tax and the desirability of such policy by the different interest groups involved. A key message from this paper is that taxing soda is an effective way to stimulate consumers' choice of healthier beverage options and reduce the soda consumption. Although the SSB tax would reduce consumer welfare the most among the interest groups involved, market effects of the consumer welfare losses can be offset by the healthcare cost savings from reduced SSBs consumption.

References

Allcott, H., Lockwood, B. B., and D., Taubinsky. 2019. “Should We Tax Sugar-sweetened Beverages? An Overview of Theory and Evidence.” *Journal of Economic Perspectives* 33(3): 202-27.

Allcott, H., Lockwood, B.B. and D., Taubinsky. 2019. "Regressive Sin Taxes, with an Application to the Optimal Soda Tax.” *The Quarterly Journal of Economics* 134(3): 1557-1626.

Backholer, K., Blake, M., and S. Vandevijvere. 2016. “Have We Reached a Tipping Point for Sugar-sweetened Beverage Taxes?” *Public Health Nutrition* 19: 3057-3061.

Backholer, K., Blake, M., and S. Vandevijvere. 2017. “Sugar-sweetened Beverage Taxation: An Update on the Year that was 2017.” *Public Health Nutrition* 20: 3219-3224.

Basu, S., Vellakkal, S., Agrawal, S., Stuckler, D., Popkin, B., and S. Ebrahim. 2014. “Averting Obesity and Type 2 Diabetes in India through Sugar-sweetened Beverage Taxation: An Economic-epidemiologic Modeling Study.” *PLoS Medicine* 11

Beverage Marketing Corporation. 2017. “The Shifting Beverage Landscape and What It Means for Packaging.” *The Packaging Conference*, February 6, 2017

Bhattacharya, J., and N., Sood. 2011. “Who Pays for Obesity?” *Journal of Economic Perspectives* 25(1): 139-58.

Binkley, J.K., Canning, P.N., Dooley, R., and J.S., Eales. 2002. *Consolidated Markets, Brand Competition, and Orange Juice Prices.* (No. 1474-2016-120893).

Briggs, A.D., Mytton, O.T., Kehlbacher, A., Tiffin, R., Rayner, M., and P. Scarborough. 2013a. “Overall and Income Specific Effect on Prevalence of Overweight and Obesity of 20% Sugar Sweetened Drink Tax in UK: Econometric and Comparative Risk Assessment Modelling Study.” *Bmj* 347.

Briggs, A.D., Mytton, O.T., Madden, D., O’Shea, D., Rayner, M., and P. Scarborough. 2013b. “The Potential Impact on Obesity of a 10% Tax on Sugar-sweetened Beverages in Ireland, an Effect Assessment Modelling Study.” *BMC Public Health* 13: 860.

Cawley, J., Thow, A.M., Wen, K., and D. Frisvold. 2019. “The Economics of Taxes on Sugar-Sweetened Beverages: A Review of the Effects on Prices, Sales, Cross-border Shopping, and Consumption.” *Annual Review of Nutrition* 39: 317-338.

DiMeglio, D.P. and R.D., Mattes. 2000. “Liquid versus Solid Carbohydrate: Effects on Food Intake and Body Weight.” *International Journal of Obesity* 24(6):794-800.

Dhar, T., Chavas, J.P., Cotterill, R.W., and B.W. Gould. 2005. “An Econometric Analysis of Brand-Level Strategic Pricing Between Coca-Cola Company and PepsiCo.” *Journal of Economics and Management Strategy* 14: 905-931.

Escobar, M.A.C., Veerman, J.L., Tollman, S.M., Bertram, M.Y., and K.J. Hofman. 2013. “Evidence that a Tax on Sugar-sweetened Beverages Reduces the Obesity Rate: A Meta-analysis.” *BMC Public Health* 13: 1072.

Evans, E.A., Ward, R.W., and C.G., Davis. 2001. “Time Varying Parameters in The Demand for High Fructose Corn Syrup” (No. 374-2016-19689).

Florida Department of Citrus. 2017. *Citrus Reference Book. Available at: https://www.floridacitrus.org/grower/economic-market-resources/economic-reports/*

Galinato, S.P., Gallardo, R.K., and Y.A. Hong. 2016. "2014 Cost Estimates of Establishing, Producing, and Packing Organic Gala apples in Washington." Washington State University Extension Center.

Giannakas, K. 2019. *Accounting for Agent Heterogeneous in Market and Policy Analysis.* Available at: http://www.theheterogeneitybook.com/

Gortmaker, S.L., Long, M.W., Resch, S.C., Ward, Z.J., Cradock, A.L., Barrett, J.L., Wright, D.R., Sonneville, K.R., Giles, C.M., Carter, R.C. and M.L., Moodie. 2015. "Cost effectiveness of Childhood Obesity Interventions: Evidence and Methods for CHOICES." *American Journal of Preventive Medicine* 49(1): 102-111.

Guci, L., and M.G. Brown. 2007. "Changes in the Structure of the Florida Processed Orange Industry and Potential Impacts on Competition."

Holt, M. 1992. "A Multimarket Bounded Price Variation Model under Rational Expectations: Corn and Soybeans in the United States." *American Journal of Agricultural Economics* 74: 10–20.

Hu, F. B. 2013. "Resolved: There is Sufficient Scientific Evidence that Decreasing Sugar-sweetened Beverage Consumption Will Reduce the Prevalence of Obesity and Obesity-related Diseases." *Obesity Reviews* 14(8):606-619.

Klonsky K.M., and S. Don. 2014. “Sample Costs to Produce Organic Processing Apples.” University of California Cooperative Extension. Available at: https://coststudyfiles.ucdavis.edu/uploads/cs_public/fe/91/fe916bab-978e-474f-ac30-30ff498aa569/apples-santa-cruz-org-processing.pdf

Lee, M.M., Falbe, J., Schillinger, D., Basu, S., McCulloch, C.E., and K.A. Madsen. 2019. “Sugar-sweetened Beverage Consumption 3 Years after the Berkeley, California, Sugar-sweetened Beverage Tax.” *American Journal of Public Health* 109: 637-639.

Leider, J., and L.M. Powell. 2019. “Sugar-sweetened Beverage Prices: Variations by Beverage, Food Store, and Neighborhood Characteristics, 2017” *Preventive medicine reports* 15: 100883.

Luckstead, J., Devadoss, S., and R.C. Mittelhammer. 2015. “Imperfect Competition between Florida and São Paulo (Brazil) Orange Fruit juice Producers in the US and European Markets.” *Journal of Agricultural and Resource Economics* 164-178.

Long, M.W., Gortmaker, S.L., Ward, Z.J., Resch, S.C., Moodie, M.L., Sacks, G., Swinburn, B.A., Carter, R.C. and Y.C., Wang. 2015. “Cost Effectiveness of a Sugar-sweetened Beverage Excise Tax in the US.” *American Journal of Preventive Medicine* 49(1): 112-123.

Malik, V.S., Willett, W.C. and F.B., Hu. 2009. “Sugar-sweetened Beverages and BMI in Children and Adolescents: Reanalyses of a Meta-analysis.” *The American Journal of Clinical Nutrition* 89(1): 438-439.

Novak, L.N., and K.D. Brownell. 2011. "Taxation as Prevention and as a Treatment for Obesity: The Case of Sugar-sweetened Beverages." *Current Pharmaceutical Design* 17: 1218-1222.

O`Connell N.V., Kallsen, C.E., Klonsky, K.M., and K.P. Tumber. 2015. "Sample Costs to Establish an Orange Orchard and Produce." University of California Cooperative Extension. Available at: https://coststudyfiles.ucdavis.edu/uploads/cs_public/19/d4/19d4f1bb-408a-443e-a759-36fd53a2948f/oranges_vs_2015.pdf

Park, H., and S. Yu. 2019. "Policy Review: Implication of Tax on Sugar-sweetened Beverages for Reducing Obesity and Improving Heart Health." *Health Policy and Technology* 8: 92-95.

Powell L.M., Wada R., Persky J.J., and F.J., Chaloupka. 2014. "Employment Impact of sugar-sweetened Beverage Taxes." *American Journal of Public Health* 104(4): 672-677.

Raben, A., Møller, B., Flint, A., Vasilaras, T., Christina Møller, A., Juul Holst, J. and A., Astrup. 2011. "Increased Postprandial Glycaemia, Insulinemia, and Lipidemia after 10 Weeks' Sucrose-Rich Diet Compared to an Artificially Sweetened Diet: A Randomised Controlled Trial." *Food & Nutrition Research* 55(1):5961.

Schwendicke, F., and M. Stolpe. 2017. "Taxing Sugar-sweetened Beverages: Impact on Overweight and Obesity in Germany." *BMC Public Health* 17: 88.

Seiler, S., Tuchman, A., and S. Yao. 2019. "The Impact of Soda Taxes: Pass-through, Tax Avoidance, and Nutritional effects."

Singerman, A., and P. Useche. 2016. "Impact of Citrus Greening on Citrus Operations in Florida." University of Florida/Institute of Food and Agricultural Sciences Extension Center.

Singerman, A. 2017. "Cost of Production for Processed Oranges Grown in Southwest Florida, 2015/16." University of Florida/Institute of Food and Agricultural Science Extension Center.

Singerman, A. 2018. "Cost of Production for Processed Oranges Grown in Southwest Florida, 2016/17." University of Florida/Institute of Food and Agricultural Science Extension Center.

Thompson, S., Garcia, P., and L.D., Wildman. 1996. "The Demise of the High Fructose Corn Syrup Futures Contract: A Case Study." *The Journal of Futures Markets* 16: 697.

Ubilava, D. 2012. "Modeling Nonlinearities in the US Soybean-to-corn Price ratio: A Smooth Transition Autoregression Approach." *Agribusiness* 28: 29-41.

US Census Bureau, Health and Nutrition. *2018 Per Capita Consumption of Selected Beverages by Type.*

USDA Agricultural Marketing Service (AMS). 2020. *Net Cost of Corn Starch to U.S. Wet-millers, Midwest markets, quarterly.*

USDA Economic Research Service (ERS). 2011. *Food Consumption, Prices, and Expenditures, annual.* Food Consumption (Per Capita) Data System.

USDA Economic Research Service (ERS). 2020. *Commodity Costs and Returns.* Available at: https://www.ers.usda.gov/data-products/commodity-costs-and-returns

USDA Economic Research Service (ERS). 2020. *Feed Grains Custom Query.* Available at: https://data.ers.usda.gov/FEED-GRAINS-custom-query.aspx

USDA Economic Research Service (ERS). 2020. *Fruit and Tree Nuts Data/Yearbook.* Available at: https://www.ers.usda.gov/data-products/fruit-and-tree-nuts-data/

USDA National Agricultural Statistics Service Information (NASS). 2018. *Acreage Crop Production Supplement.*

Veerman, J.L., Sacks, G., Antonopoulos, N., and J. Martin. 2016. "The Impact of a Tax on Sugar-sweetened Beverages on Health and Health Care Costs: A Modelling Study." *PloS One* 11.

Wang, E.Y. 2015. "The Impact of Soda Taxes on Consumer Welfare: Implications of Storability and Taste Heterogeneity." *The RAND Journal of Economics* 46: 409-441.

White, J.S., and T.A. Nicklas. 2016. "High-fructose Corn Syrup Use in Beverages: Composition, Manufacturing, Properties, Consumption, and Health Effects." *Beverage Impacts on Health and Nutrition* Humana Press, Cham.

Wilde, P., Huang, Y., Sy, S., Abrahams-Gessel, S., Jardim, T.V., Paarlberg, R., Mozaffarian, D., Micha, R. and T., Gaziano. 2019. "Cost-effectiveness of a US National Sugar-sweetened Beverage Tax with a Multistakeholder Approach: Who Pays and Who Benefits." *American Journal of Public Health* 109(2): 276-284.

Williams, J.D., and P. Goldsworthy. 2011. “Breaking Down the Chain: A Guide to the Soft Drink Industry.” *Public Health Law and Policy* National Policy and Legal Analysis Network.

Yoffie, D.B., and Y., Wang. 2006. “Cola Wars Continue: Coke and Pepsi in 2006.” Boston, MA: Harvard Business School.

Xi, B., Huang, Y., Reilly, K. H., Li, S., Zheng, R., Barrio-Lopez, M. T., Martinez-Gonzalez, M.A. and D., Zhou. 2015. “Sugar-sweetened Beverages and Risk of Hypertension and CVD: a Dose–response Meta-analysis.” *British Journal of Nutrition* 113(5): 709-717.