Taxing Sugar-Sweetened Beverages: A Nonlinear Pricing Approach

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Abstract

Taxation is frequently implemented to discourage the consumption of sugary beverages. Despite their popularity, little is known about the impacts of taxes in markets where sellers deploy price discriminating techniques. To address this issue, we use a standard nonlinear pricing model with one product and two buyer types to study the effects of taxation on (i) consumption, (ii) consumer and producer surpluses, and (iii) the seller's choice of market segmentation scheme. We find that a tax would unambiguously lead to reductions in consumption, consumer surplus, and expected profit. Additionally, the measure increases the likelihood that the sellers would exclude buyers with low preferences for the beverage to exclusively serve buyers with high willingness to pay for the product.

Keywords: nonlinear pricing, soda taxes, sugar consumption

JEL classification: D82, H20, I18, L51, Q18

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Habitual and liberal consumption of sugar-sweetened beverages (SSBs) is linked to poor health outcomes associated with excess body-weight (Malik, Schulze, and Hu 2006; Malik et al. 2010; Stanhope 2016). In consequence, national and local governments around the world have implemented policies to discourage the intake of sugary drinks. Taxation of SSBs is a common tool adopted by authorities aiming to reduce the risk of excess weight and related non-communicable diseases. For example, seven cities in the United States have enacted taxes targeting SSBs since 2014, and 39 other countries around the world had implemented similar measures as of 2019 (Allcot, Lockwood, and Taubinsky 2019).[1] Concurrent with its widespread embrace as a regulatory instrument, taxation of SSBs and its effects are the subject of an extensive body of research by economists.

Works analyzing the impacts of taxing SSBs tend to adopt one of two main approaches. The first research path uses demand systems models to, for example, predict the effect of taxes on consumer welfare, identify potential substitution effects, and to compare the effects of taxation by volume as opposed to taxing calories (for example: Caro et al. 2017; Zhen, Brissette and Ruff 2014; Zhen et al. 2014). Substantially more voluminous, the second approach leverages actual soda taxes as quasi-experiments to measure and evaluate, for example, tax pass-through, impacts on caloric intake, and potential substitution effects (e.g. Cawley et al. 2021; Aguilar, Gutierrez and Sierra 2021; Grogger 2017).[2] However, studies in both traditions have paid little attention to the responses of price-discriminating sellers following the implementation of a tax. To address this paucity of research, we use a standard nonlinear pricing model to derive the effects of per-unit and *ad valorem* taxation on (classically defined) consumer surplus, consumption, expected profits, and the seller's market segmentation scheme.[3] We find that a tax would reduce the consumer surplus of buyers with high-preference for the product, reduce consumption across consumer types, decrease expected profits, and increase the likelihood that the seller would shrink her market coverage by excluding from service the buyers with low preference for the product.

We contribute to a young but growing literature that applies nonlinear pricing models to investigate the consequences of some food policy interventions (Nuño-Ledesma 2022; Nuno-Ledesma 2021; Bourquard and Wu 2020). So far, these efforts have concentrated their attention to study portion cap rules. We follow the methodological framework proposed by Bourquard and Wu (2020) and expand its scope to study the effects of taxes on sugary drinks. A significant point raised by this literature is that it is important to account for price discrimination when studying the welfare impacts of interventions. This is a critical point because price discrimination in the food retail industry is pervasive, as corroborated by both casual observation and an abundant economic literature (e.g. Bonnet and Réquillart 2013; Hendel and Nevo 2013; Holton 1957). Compared to standard textbook models with linear-pricing, nonlinear-pricing models are better suited to capture the complexities emerging due to price discrimination in the food retail industry including market segmentation induced by incentive-compatible pricing. In nonlinear pricing models, the seller is not assumed to be a passive price-taker, unlike the textbook supply-demand model without hidden consumer heterogeneity. This flexibility equips us with the analytical means to study response from the seller to the intervention beyond simple pass-through. Critical among such possible reactions are discrete changes in market segmentation that cannot be fully explained within the standard textbook models of taxation.

There is a dearth of research on how taxes on sugary drinks impact market coverage and product availability. To our knowledge, the sole paper explicitly tackling this question is Cawley et al. (2020), which leverages the 2017 Philadelphia tax and a city-wide tax credit aiming to encourage some stores to stock healthy drinks. The authors find that retailers ineligible for the tax credit responded to the SSB tax by increasing the availability of untaxed drinks and reducing the availability of taxed beverages. The nonlinear pricing model we use allows us to expose how a tax can cause the seller to change her screening practice altogether and move to serve consumers with a strong preference for soda only.[4]

Traditionally, economists and other social scientists dedicate the bulk of their attention to examine how demand is affect by different policies (Duvaleix-Treguer et al. 2012). Our work is closely related to the corpus of works examining the response of firms to nutritional and food policies (Unnevehr and Jagmanaite 2008; Moorman, Ferraro and Huber 2012; Bonnet and Réquillart 2013; Hamilton and Réquillart 2017, and Cremer, Goulão and Lozachmeur 2019). By refining our understanding of how sellers adapt their pricing and marketing strategies in reaction to health-guided interventions, we achieve a more complete delineation of the outcomes following food policy interventions needs to account for the reactions of both consumers and sellers.

The rest of the paper is organized as follows. The next section offers a brief outline of the model and the main results; the main goal of this section is to provide an intuitive description of the main features of our modelling framework. Next, we introduce the formal model and present the baseline unregulated outcomes. In the subsequent section, we modify the model to introduce taxation and discuss the impacts on quantity, prices, and welfare holding the seller's segmentation strategy constant. We proceed to examine how a tax can impact the retailer's choice of segmentation scheme. In the following part, a comparison of regulated versus unregulated outcomes permits us to examine policy implications. The last section concludes.

A Brief Overview of the Model and Results

Some of our results are consistent with predictions from the standard linear-pricing model. For instance, we find that the tax causes a reduction in both consumer surplus and portion sizes. At the same time, we reveal aspects that would remain hidden if we were to apply the textbook model to an environment where price discrimination is common. For example, the nonlinear pricing model illustrates how a strategic seller can modify all endogenous pricing variables within menus affecting serving sizes for all buyer types. Similarly, we show that the tax can influence the seller's market segmentation scheme. In sum, our model provides insights that are not attainable through the use of the textbook model alone while preserving continuity with existing literature suing the standard model.

To illustrate how, in the case of taxation, accounting for second-degree price discrimination can shed light on outcomes that would remain otherwise hidden, consider how our framework differs from the textbook linear-pricing model of demand and supply. Without intervention, the price-discriminating retailer is faced with an adverse selection problem when two types of consumers have private preferences for soda. To overcome this incomplete information problem, the seller designs a menu of options. The prices of the alternatives are tailored to provide self-selection incentives. The larger portion results in positive consumer surplus beyond the reservation value for the high-type consumer. The smaller alternative is priced exactly at the low-type's willingness to pay. We find that the enactment of a tax distorts pricing in a way that only reduces surplus for the consumer with high preference, and increases the possibility that the seller will remove smaller options from the menu.[5] In short, the nonlinear pricing model is able to show how the prices and portions offered to each type are connected: before and after the intervention the seller needs to calibrate the menu to maintain incentive compatibility. The naive model is silent with respect to this relation between options in the menu.

From the naive model we could (correctly) infer that the distribution of the tax burden would depend on the price-elasticity of demand of each segment. But we would be blind to the effects of incentive-compatibility and market segmentation. By ignoring that the seller aims to resolve a private-information problem, we would have to work with one of two implicit assumptions. Either presume that the seller can exercise first-degree price discrimination or work with an aggregate demand curve. The first of these assumption would lead us to conclude that the tax reduces surplus across segments and that changes in prices and quantities in one sub-market are independent from the pricing offered to the other. The second assumption implies that a single-item menu is offered before and after the tax and we would have no way to differentiate the proportion of dead-weight loss attributable to each market segment. In short, the naive model is silent with respect to (i) the interrelation of prices and quantities within the menu, (ii) the way consumer surplus is distributed across types when heterogeneous preferences are hidden, and (iii) the way the policy environment influences the discrete segmentation schemes adopted by retailers (and their associated number of alternatives).

To offer perspective, let us briefly compare our results to the outcomes of other interventions derived from similar modelling approaches. Consider the case of portion cap rules or serving size restrictions.[6] In a setting with discrete types like ours, Bourquard and Wu (2020) find that cap rules reduce consumer surplus (only for higher types) when the quantity limit forces the bunching of types. We find negative effects on surplus at any level of taxation. Additionally, Bourquard and Wu (2020) ascertain that a cap rule is unlikely to cause the seller to change her discrete segmentation scheme, as long as the cap does not reduce the size of the small portion offered without intervention. But even when the limit is so severe that it is set below the size of the unregulated small option, the seller will shift to an exclusive segmentation only if the proportion of low-type consumers is small enough. We document that any positive level of taxation increases the likelihood of such a switch of strategy.

Model Setup Without Regulations in Effect

We continue by establishing a benchmark for the seller's pricing behavior in the absence of regulation. This allows us to make subsequent comparisons with respect to the impact of regulation on serving sizes, expected profit and consumer welfare.

The seller (she) offers a menu of different price-size combinations to a privately informed buyer (he). There are two types of buyers, characterized by their preference for soda.[7] With probability $\beta \in [0,1]$, the buyer has low preference (low or L-type). With complementary probability probability $(1-\beta)$, the buyer has a higher willingness to pay (WTP) for large servings of soda (high or H-type). The buyers are characterized by a taste parameter θ_i for $i = H, L$, such that $\theta_H > \theta_L$. When an i-type purchases and consumes an alternative with q_i units of the product (for example, q_i ounces) and pays a price $p_i \equiv p(q_i)$, he earns consumer surplus:

$$U_i = \theta_i u(q_i) - p_i \tag{1}$$

Where $u(\cdot)$ is a well-behaved utility function. Note that p_i refers to the serving price, as opposed to per-unit (e.g. per-ounce) price. Note that if t is the average per-unit (e.g. per-ounce) price, then $p = t \cdot q$. Without loss of generality, we assume that seller and buyer have reservation values of zero. With regard to consumer welfare, we primarily focus on a classical definition of consumer surplus: gross utility from consumption of SSBs net of price paid. We do not account for potential health benefits from reduced sugar consumption for three reasons. First, much of the opposition against SSB regulations focus on how such regulations might hurt consumers via reduced choice and consumption. Second, incorporating health benefits in a model is fraught with arbitrary assumptions and it would be easy for us to generate nearly any conclusion by strategically choosing our assumptions. Our approach allows us to focus on the claim that regulation would reduce consumer welfare from consumption. Third, omitting health benefits makes our results robust to substitution effects in that, even if consumers shift to other unhealthy beverages, we do not run the danger of over-estimating consumer benefits. Indeed, one way to interpret our findings is how consumers might be impacted even if the regulations yield little to no net health benefits.

The seller has a per-unit cost of production of $c > 0$. The seller maximizes ehr expected profit subject to sets of incentive-compatibility, participation, and non-negativity constraints:

$$
\begin{aligned}
&\underset{(p_L,q_L),(p_H,q_H)}{\text{maximize}} \quad E[\pi] = (\beta)[p_L - cq_L] + (1-\beta)[p_H - cq_H] \\
&\text{subject to:} \\
&\text{ICH}: \theta_H u(q_H) - p_H \geq \theta_H u(q_L) - p_L \\
&\text{ICL}: \theta_L u(q_L) - p_L \geq \theta_L u(q_H) - p_H \\
&\text{PCH}: \theta_H u(q_H) - p_H \geq 0 \\
&\text{PCL}: \theta_L u(q_L) - p_L \geq 0 \\
&q_i \geq 0,\ i = H, L
\end{aligned} \tag{2}
$$

The seller's objective function weights the profit contribution (within square brackets) of serving a given buyer type by the probability of the customer she faces being of either type. As we will show, taxes affect the seller's behavior by distorting profit contributions. Because the first four restrictions in program 2 play an important role in determining pricing, allocation, and surplus distribution, we briefly discuss them.

The participation conditions labeled PC_i mean that the portion allocated to the i-type gives him a non-negative payoff. In other words, the participation constraints ensure that the buyers are at least indifferent between not participating and purchasing one of the options offered by the seller. As shown in the appendix, the satisfaction of PCL implies the satisfaction of PCH. From now onward, we will only consider the participation constraint for the low-type.

The incentive-compatibility constraints IC_i indicates that the profit-maximizing seller tailors prices and quantities so that i-type buyer should prefer the option with size q_i over the alternative. Recall that $\theta_H > \theta_L$, so that the Spence-Mirrlees or single-crossing condition is satisfied. Intuitively, single-crossing means that the marginal utility from consumption increases with the type. It is a standard result from screening models that single-crossing allows for the reduction of the number of IC constraints to keep only the “downward” restrictions (Bolton and Dewatripont 2005). In other words, higher types try to mimic lower types, but not *vice versa*. Therefore, from now on, we will only consider the incentive-compatibility constraint for the high-type.

At the optimum, ICH and PCL bind with equality, which gives us the following pricing rules:

$$p_L = \theta_L u(q_L) \tag{3}$$

$$p_H = \theta_H u(q_H) - (\theta_H - \theta_L)u(q_L) \tag{4}$$

Substituting 3 and 4 into the seller's objective function yields:

$$\begin{aligned} &\max_{q_L, q_H} \quad E[\pi] = \beta[\theta_L u(q_L) - cq_L] + (1-\beta)[\theta_H u(q_H) - (\theta_H - \theta_L)u(q_L) - cq_H] \\ &\text{subject to: } q_i \geq 0, \; i = H, L \end{aligned} \tag{5}$$

The terms in brackets in the objective function of problem 5 are surpluses distributed to the buyer two buyer types. The first term in bracket shows that the seller will appropriate all of the L-type buyer's surplus. From the second term in brackets we can note that the seller will extract the H-type's surplus but leave him with information rents equal to $(\theta_H - \theta_L)u(q_L)$; this rent increases with the q_L. The first order Kuhn-Tucker (KT) conditions of problem 5 are:

$$\text{FOC}[q_H] : \frac{\partial E[\pi]}{\partial q_H} = (1-\beta)[\theta_H u'(q_H) - c] \leq 0$$

(6) where:

$$q_H \geq 0 \text{ and } \frac{\partial E[\pi]}{\partial q_H} \cdot q_H = 0$$

$$\text{FOC}[q_L] : \frac{\partial E[\pi]}{\partial q_L} = \beta[\theta_L u'(q_L) - c] + (1-\beta)[-(\theta_H - \theta_L)u'(q_L)] \leq 0$$

(7) where:

$$q_L \geq 0 \text{ and } \frac{\partial E[\pi]}{\partial q_L} \cdot q_L = 0$$

We assume that the above KT conditions can encompass one of three schemes. The retailer can i) adopt a "separating" strategy: offer two differentiated price-size combinations intended to serve each type of buyer, ii) implement an "exclusive" scheme: concentrate on serving H-type buyers exclusively or iii) apply a "pooling" or one-size-fits-all strategy: attempt to cover the entire consumer base with a single price-size serving. For the unregulated case, we assume that the separating strategy is the default case which is consistent with the stylized observation that SSB retailers typically offer multiple sizes to customers. Later in the paper, we explore the possibility that a tax or size-restriction can cause the retailer to endogenously switch from a separating to an exclusive or pooling scheme.

Case IA - Unregulated Benchmark

Our default assumption is that, in the absence of regulation, the retailer uses a separating strategy by offering a menu of two distinct price-size options with $q_H > 0$ and $q_L > 0$. At the optimum, the KT conditions 6 and 7 bind with strict equality, yielding:

$$\theta_H u'(q_H) = c \tag{8}$$

$$\theta_L u'(q_L) = c + \left(\frac{1-\beta}{\beta}\right)(\theta_H - \theta_L)u'(q_L) \tag{9}$$

Note from equation 8 that the large cup contains the H-type's first-best quantity. In other words, there is no quantity distortion at the top of the type space. On the other hand, the small serving contains a quantity level that is lower than the L-type's first best. The origin of this distortion is the transfer the seller makes to the H-type to encourage self-selection. Incentive compatibility requires that the H-type receives an information rent to choose the larger cup.[8] The seller can compress this information rent by decreasing quantity in the the small serving q_L. The term $\left(\frac{1-\beta}{\beta}\right)(\theta_H - \theta_L)v'(q_L)$ that is attached to marginal cost of serving the L-type determines the optimal downward distortion of the small serving.[9]

The optimal per-serving prices are obtained from the pricing rules 3 and 4: $p_H^{ia} = \theta_H u(q_H^{ia}) - (\theta_H - \theta_L)u(q_L^{ia})$ and $p_L^{ia} = \theta_L u(q_L^{ia})$. If we let the superscript *ia* indicate the quantity values that characterize the characterize the optimal level of the objective function in case IA, the retailer's expected profit is the following:

(10) $$\pi^{ia} = (\beta)[\theta_L v(q_L^{ia}) - cq_L^{ia}] + (1-\beta)[\theta_H v(q_H^{ia}) - (\theta_H - \theta_L)v(q_L^{ia}) - cq_H^{ia}]$$

These results are summarized in proposition 1.

Proposition 1. *Suppose that the retailer adopts a separating strategy in the absence of regulation. Then:*

1. $\theta_H u'(q_H^{ia}) = c$ *so that H-types are offered an efficient serving size.*

2. $\theta_L u'(q_L^{ia}) = \frac{c}{\left[1-\left(\frac{1-\beta}{\beta}\right)\left(\frac{\theta_H-\theta_L}{\theta_L}\right)\right]} > c$ *so that L-types are offered a serving size that is distorted downward relative to first best.*

3. $p_H^{ia} = \theta_H u(q_H^{ia}) - (\theta_H - \theta_L)u(q_L^{ia})$ *so that the price of the H-type serving is discounted by an information rent.*

4. $p_L^{ia} = \theta_L u(q_L^{ia})$ *so that the price of the L-type serving extracts all of the surplus from L-type buyers.*

5. *The seller's value optimized profit is expressed in equation (10).*

6. *The H-type consumer's value function is* $U_H^{ia} = (\theta_H - \theta_L)u(q_L^{ia})$.

7. *The L-type consumer's value function is* $U_L^{ia} = 0$.

Simply put, the retailer will offer two differentiated price-size options to consumers. The L-type option is inefficiently small and priced so that the L-type is indifferent between buying and not buying. The H-type serving is larger and of efficient size for H-type consumers. Moreover, H-types receive a quantity discount that leaves them with some excess surplus above reservation level.

Incorporating Taxation into the Model

We expect a tax on SSBs to have two major effects: it could impact consumption and prices, and it may indirectly cause the retailer to alter her pricing strategy (change from a separating strategy to either an exclusive, or pooling segmentation scheme). We start by analyzing the direct effects of the tax on sizes and prices holding the seller's pricing strategy constant. We start by characterizing the maximized profit for each pricing strategy, then we leverage these characterizations to determine which strategy the retailer will adopt in response to a tax.

Let us define a tax regime (τ_s, τ_v) as any mixture of specific $(\tau_s \geq 0)$ and *ad valorem* $(\tau_v \in [0,1))$ taxes, such that both of them are not zero at the same time.[10] To avoid divisions by zero, we exclude combinations where $\tau_v = 1$. Note that $(\tau_s, \tau_v) = (0,0)$ represents the event of no taxation. Specific taxes modify the objective function in a way akin to a change in the principal's cost function.[11] *Ad valorem* taxes alter the objective function in two ways: by modifying the cost function, and scaling down expected profit. The seller's objective function now is:

$$E[\pi] = \beta\left[(1-\tau_v)p_L - (\tau_s + c)q_L\right] + (1-\beta)\left[(1-\tau_v)p_H - (\tau_s + c)q_H\right] \tag{11}$$

Plugging the pricing rules 3 and 4 into the seller's new objection function, we obtain the seller's new profit maximization program:

(12) $$\max_{q_L;q_H} E[\pi] = (1-\tau_v)\Big\{(\beta)\big[\theta_L u(q_L) - \Psi_L\big] + (1-\beta)\big[\theta_H u(q_H) - (\theta_H - \theta_L)u(q_L) - \Psi_H\big]\Big\}$$

where $\Psi_i \equiv (\tau_s q_i + cq_i) \div (1-\tau_v)$ is the effective cost function. Let $\psi \equiv \frac{d\Psi_i}{dq_i} = (\tau_s + c) \div (1-\tau_v)$ denote effective marginal cost. First order KT conditions are:

(13) $$\begin{aligned} &\text{FOC}[q_H] : \frac{\partial E[\pi]}{\partial q_H} = (1-\tau_v)(1-\beta)[\theta_H u'(q_H) - \psi] \leq 0 \\ &\text{where: } q_H \geq 0 \ \text{ and } \ \frac{\partial E[\pi]}{\partial q_H} \cdot q_H = 0 \end{aligned}$$

(14) $$\begin{aligned} &\text{FOC}[q_L] : \frac{\partial E[\pi]}{\partial q_L} = (1-\tau_v)\big\{\beta(\theta_L u'(q_L) - \psi) + (1-\beta)[-(\theta_H - \theta_L)u'(q_L)]\big\} \leq 0, \\ &\text{where: } q_L \geq 0 \ \text{ and } \ \frac{\partial E[\pi]}{\partial q_L} \cdot q_L = 0 \end{aligned}$$

Below, we describe how taxes affect outcomes, retailer profit, and consumer welfare within each major pricing strategy.

Taxed Case IIA: Separating Pricing Strategy

Under a separating menu, both types of consumers are offered consumption options such that $q_H > 0$ and $q_L > 0$. Thus, the KT conditions 13 and 14 hold with strict equality:

(15) $$\theta_H u'(q_H) = \psi$$

$$\theta_L u'(q_L) = \psi + \left(\frac{1-\beta}{\beta}\right)(\theta_H - \theta_L)u'(q_L) \tag{16}$$

These conditions indicate that the *effective* marginal cost of supplying a large option equals the H-type's marginal utility of consumption. Thus, while there is distortion relative to the baseline case, there is "no distortion at the top" relative to the *effective* marginal cost. The seller continues to distort the size of the small serving downwards even with respect to the effective marginal cost due to the presence of the term $\left(\frac{1-\beta}{\beta}\right)(\theta_H - \theta_L)u'(q_L)$. However, relative to the scenario without regulation, both types of consumers get less than their first-best optimal quantities because the effective marginal cost is altered by the enacted tax regime so that $\psi > c$. L-types receive an even smaller quantity compared to the intervention-free case I-A.

Letting the superscript indicate variables characterizing the optimal solution in this case, the price rule are $p_L^{iia} = \theta_L u(q_L^{iia})$, and $p_H^{iia} = \theta_H u(q_H^{iia}) - (\theta_H - \theta_L)u(q_L^{iia})$. The seller's expected profit is characterized as follows:

$$\pi^{iia} = (1-\tau_v)\Big\{(\beta)[\theta_L u(q_L^{iia}) - \psi q_L^{iia}] + (1-\beta)\big\{[\theta_H u(q_H^{iia}) - (\theta_H - \theta_L)u(q_L^{iia})] - \psi q_H^{iia}\big\}\Big\} \tag{17}$$

In the next proposition, we compare the outcomes above with the results from the benchmark case IA.

Proposition 2. *Assume the government enforces a tax regime (τ_s, τ_v) with at least one type of tax strictly positive. Suppose that the retailer serves both type of buyers with a separating pricing strategy. Then:*

1. *The tax reduces H-type serving sizes so that $q_H^{ia} > q_H^{iia}$.*

2. *The L-type serving size is still distorted downward. Additionally,* $q_L^{ia} > q_L^{iia}$ *so that serving size is even smaller under the tax.*

3. *The L-type per-serving serving price is lower under the tax; i.e.* $p_L^{ia} > p_L^{iia}$.

4. *The H-type serving price is lower under the tax; i.e.* $p_H^{ia} > p_H^{iia}$.

5. *The retailer's value function is given by (17) so that profit is lower under the tax; i.e.* $E\pi^{ia} > E\pi^{iia}$.

6. *The H-type buyer's value function is* $U_H^{iia} = (\theta_H - \theta_L)u(q_L^{iia})$ *so that there is consumer welfare loss for H-types; i.e.* $U_H^{ia} > U_H^{iia}$.

7. *L-type buyer's value function remains* $U_L = 0$*; i.e.* $U_L^{ia} = U_L^{iia}$.

The proof is omitted because it consists of straightforward comparisons. In sum and compared to the corresponding benchmark, both packages are smaller due to distortions caused by the tax regime.[12] The H-type consumer still receives information rents, although these are smaller so there is welfare loss. The L-type is held at his reservation values, and the seller sees her expected profit unambiguously diminished. While it may seem counter-intuitive that serving prices are lower after a tax, keep in mind that we focus on prices per-serving as opposed to per-unit prices (e.g. price per-ounce).[13]

Taxed Case II-B: The Seller Serves only H-type consumers

We now consider the case where the seller serves only H-types ($q_H > 0$ and $q_L = 0$). We ultimately want to learn whether a tax regime can cause the retailer to switch away from the default separating strategy.

Let the superscript *iib* denote variables that solve the seller's objective function in this case. The exclusive segmentation scheme implies that FOC$[q_L]$ in 14 does not bind with equality. Using FOC$[q_H]$ from 13, pricing rule (4), and our normalizing assumption $u(0) = 0$, we obtain:

$$\theta_H u'(q_H^{iib}) = \psi \tag{18}$$

$$p_H^{iib} = \theta_H u(q_H^{iib}) \tag{19}$$

The seller no longer grants information rents because she does not need to elicit truthful revelation of private preferences.[14] Expected profit is:

$$\pi^{iib} = (1-\tau_v)(1-\beta)[\theta_H v(q_H^{iib}) - \psi q_H^{iib}] \tag{20}$$

Proposition 3. *Assume that the government enforces a tax regime (τ_s, τ_v) with at least one type of tax strictly positive. Suppose that the retailer decides to offer one single cup size designed to serve H-type buyers solely. Then:*

1. $\theta_H u'(q_H^{iib}) = \psi > c$. *There is a tax induced reduction in q_H^{iib} below first best. Thus, $q_H^{iib} < q_H^{ia}$*

2. *L-type buyers are excluded and do not engage in trade.*

3. *The serving price is $p_H^{iib} = \theta_H u(q_H^{iib})$ which does not include an information rent.*

4. *The seller's value functions is expressed by equation 20.*

5. *Both buyer types are held at their reservation values; i.e.* $U_H = U_L = 0$.

The proof is a direct comparison, so we omit it.

Taxed Case II-C: One-Size-Fits-All

Another case that must be considered is when the retailer designs a menu with a single alternative to serve both types of buyers. In this case, the retailer's optimization problem can be written as follows:

$$\begin{aligned} &\max_{p,q} E[\pi] = (1-\tau_v)p_L - (\tau_s + c)q_L \\ &\text{subject to:} \\ &\text{PCL}: \theta_L u(q) - p_L \geq 0 \end{aligned} \tag{21}$$

Recall that, given $\theta_H > \theta_L$, if the L-type's participation constraint is satisfied, then the H-type's will be satisfied as well. The optimization conditions imply:

$$\theta_L u'(q_L^{iic}) = \psi \tag{22}$$

$$p_L^{iic} = \theta_L u(q_L^{iic}) \tag{23}$$

Again, superscripts indicate that the variables solve the optimization problem faced by the seller in case *iic*. While 22 implies marginal benefits are equal to marginal cost, recall that ψ is the effective marginal cost post-tax. Thus, the L-type does not get his first-best level of consumption. The value functions for the seller and buyers are:

$$\pi^{iic} = (1-\tau_v)[\theta_L u(q_L^{iic}) - \psi \cdot q_L^{iic}] \tag{24}$$

$$\begin{aligned} U_L^{iic} &= 0 \\ U_H^{iic} &= (\theta_H - \theta_L)u(q_L^{iic}) \end{aligned} \tag{25}$$

We summarize the results in the next proposition.

Proposition 4. *Assume the government enforces a tax regime* (τ_s, τ_v) *with at least one type of tax strictly positive. If the retailer decides not to screen the market and offers a one-size-fits-all package designed to serve both types of buyers, then:*

1. $\theta_L u'(q_L^{iic}) = \psi$ *so that buyers are provided with a quantity,* q_L^{iic}*, that is smaller than the L-type first best.*
2. *The price per serving is* $p_L^{iic} = \theta_L u(q_L^{iic})$*.*
3. *The seller's value function is given by equation (24).*
4. *The L-type consumer value function is* $U_L^{iic} = 0$*.*
5. *The H-type consumer value function is* $U_H^{iic} = (\theta_H - \theta_L)u(q_L^{iic}) > 0$*.*

Again, the proof is constituted by simple direct comparisons and therefore excluded. Note that H-type buyers still earn excess rents though this is not due to screening driven information rents.

How does taxation affect retailers' choice of scheme?

In the previous section, we examined how the tax might affect outcomes under each discrete pricing strategy. Recall that, in the absence of regulation, we assume that the retailer adopts the separating screening strategy. In other words, we assume that the seller practices second-degree price discrimination before a tax regime is implemented. The question now is: will this change after a tax?

Answering the question we pose in this section is straightforward. Given that we now have the retailer's value function under each discrete strategy, we can compare them and note which would be chosen by a profit-maximizing seller once a tax is enacted. First, we want to know whether the implementation of a tax might cause the retailer to switch from the default separating strategy to an H-exclusive strategy. To help answer this, we make the following claim.

Claim 1. *The separating strategy is more profitable than the H-exclusive strategy if and only if* $\beta \geq \underline{\beta}_E = \frac{[\theta_H - \theta_L] v(q_L^{iia})}{\theta_H v(q_L^{iia}) - c q_L^{iia}}$.

Recall that β denotes the probability that a given buyer has a low preference for the sugary drink. The claim above pins down a minimum threshold $\underline{\beta}_E$ that β must exceed in order for the separating strategy to be more profitable than a H-exclusive strategy. Claim 1 then leads naturally to a key result.

Proposition 5. *Suppose that a tax regime,* (τ_s, τ_v)*, comes into effect. Then,* $\underline{\beta}_E$ *increases, which reduces the range of* β *for which the separating strategy is more profitable than the H-exclusive* *strategy.*

The proof is in the appendix. Because a tax reduces the range of β for which the separating strategy is more profitable than the H-exclusive strategy, it increases the possibility that retailers might endogenously switch to the H-exclusive strategy. We will discuss the welfare implications of this switch in more detail in a subsequent section.

The next question is, how might a tax influence the retailer's propensity to switch away from the initial separating strategy to adopt one-size-fits-all strategy?

Claim 2. *The separating strategy is more profitable than the one-size-fits-all pricing strategy if and only if* $\beta \geq \underline{\beta}_O = \frac{[\theta_H - \theta_L]v(q_L^{iia}) + \theta_L v(q_L^{iic}) - \psi q_L^{iic} - [\theta_H v(q_H^{iia}) - \psi q_H^{iia}]}{\theta_H v(q_L^{iia}) - \psi q_L^{iia} - [\theta_H v(q_H^{iia}) - \psi q_H^{iia}]}$.

Proof is in the appendix. The above claim specifies the minimum threshold, $\underline{\beta}_O$, that β must exceed for the separating strategy to remain more profitable than the one-size-fits-all strategy.

Proposition 6. *Suppose that a tax regime* (τ_s, τ_v)*, comes into effect. Then* $\underline{\beta}_O$ *decreases, which increases the range of* β *for which the separating strategy is more profitable than the one-size-fits-all strategy.*

We show a proof in the appendix. In contrast to the previous proposition, proposition 6 suggests that a tax actually increases the probability that retailers will not alter their pricing to adopt a one-size-fits-all strategy. The intuition is that a one-size-fits-all-strategy has to be priced reasonably low to ensure that L-type consumers participate. Thus, it is a relatively low profit margin strategy that relies on volume to make money. However, a rise in taxes raises marginal cost which puts pressure on the already low margins.

The key take-away is that if the retailer chooses the separating strategy pre-tax, which is true by assumption, then the retailer will not switch to an one-size-fits-all strategy post-tax. Thus, we need not consider the one-size-fits-all strategy further when assessing the tax.

Policy Implications

First, we address whether the tax will have the intended effect of reducing consumption of SSBs. Previous work suggests that consumption of sugary drinks does decrease following such a measure (Cawley et al. 2019).[15] Second, we want to know how the tax affects consumer surplus because political opponents of SSB regulations often claim that these regulations hurt consumers and/or are regressive in that certain demographic groups are disproportionately affected (Grynbaum 2014; Nestle 2012). Finally, we want to know how the tax affects sellers of SSB.

Effects on Quantity

An important question is whether a tax achieves the intended effect of reducing intake. To answer this question, we compare the size of the packages offered in the pre-tax scenario I-A to the relevant post-tax packages. The relevant tax cases under consideration are cases IIA and IIB: the separating and H-exclusive strategies.

Proposition 7. *Suppose that a tax regime* (τ_s, τ_v) *is implemented. Then serving sizes for both types of consumers decline.*

To understand the intuition, previous propositions suggest that a tax will either cause the retailer to remain with the separating strategy or switch to the exclusive strategy. In the former case, a tax reduces the serving size of both consumer types. In the latter case, the post-tax H-exclusive strategy delivers the same serving size as the post-tax separating strategy, which is smaller than the pre-tax separating strategy. The L-type is no longer served. So in either case, consumption is reduced.

Effect of Taxation on Consumers' Surplus

The impact on consumer surplus is arguably one of the most important policy effects given that consumer welfare is often mentioned in political debates over SSB regulation. policy success may depend on how consumer surplus is impacted.

Proposition 8. *Suppose that a tax regime (τ_s, τ_v) is implemented. Then consumer surplus for the H-type buyer declines. Consumer surplus for the L-type is unaffected.*

Intuitively, if a tax does not cause the retailer to switch away from a separating strategy, the tax still causes the L-type serving size to drop, which lowers the H-type information rent. Thus, H-type consumer welfare decreases from $U_H^{ia} = (\theta_H - \theta_L)u(q_L^{ia})$ to U_H^{iia} to $(\theta_H - \theta_L)u(q_L^{iia})$ where $q_L^{ia} > q_L^{iia}$. If instead, the tax causes the retailer to switch to a H-type exclusive strategy, then since the retailer need not worry about screening and paying an information rent, the retailer can just hold the H-type to his reservation utility. In either case, the H-type consumer surplus declines.

L-type consumer surplus is unaffected by the tax because the L-type earns reservation utility in all relevant scenarios. While technically, the L-type is no longer served under the H-type exclusive scheme, the L-type is consuming his next best beverage and thus still earns the reservation utility.

Effect of Taxation on Seller Surplus

Another political argument against SSB taxes is that they put pressure on businesses. According to White (2019), the beverage industry launched a campaign to influence the business community in Pennsylvania to pressure legislators to pass a state law that would prohibit Pennsylvania cities from passing local soda taxes. Our model predicts that indeed SSB taxes will reduce retailer profitability irrespective of whether retailers switch away from the separating strategy or not.

Proposition 9. *Suppose that a tax regime* (τ_s, τ_v) *is implemented. Then retailer surplus unambiguously declines.*

Intuitively, the tax causes the sizes of the servings under the separating strategy to be distorted downward relative to the optimal sizes that maximize the retailer's profits. Even if the tax induces the retailer to switch to the H-exclusive strategy, this only means the H-exclusive strategy is more profitable than the post-tax separating strategy, not the pre-tax separating strategy.

Conclusion

To our knowledge, our study is one of the first to study the impact of SSBtaxes on the behavior of a price-discriminating seller within a nonlinear pricing framework. Nonlinear pricing is consistent with the way SSBs are sold in retail and quick-service restaurants, where discrete alternatives are offered. Thus, our study can add nuanced economic content to the debate on how SSB regulations might impact this market.

We find that, when private preferences are instances from a discrete binary distribution, the tax can reduce consumption, but it would reduce consumer surplus. This reduction in consumer surplus is attributable to welfare losses from the market segment with high willingness to pay for the product. Expected profit falls following the enactment of a tax. Interestingly, the measure increases the likelihood that the seller would stop serving buyers with low preference to exclusively target buyers with high valuation for the good.

The analysis we present in this paper is based on a partial equilibrium model with adverse selection but no market failures. This limits the degree to which our conclusions can be applied to normative questions about government intervention. Our main hope is to provide a starting point for judging the strengths and weaknesses of taxes in markets where price discrimination is prevalent. This type of analysis is important because whether a measure is implemented or not, often hinges on how well proponents are able to highlight its benefits over its costs.

Other researchers can extend our work in multiple ways. Future work should perform studies in more context-rich environments. We encourage the study of markets with multidimensional preferences, continuous types, commodity bundling, and imperfect policy enforcement. Both field and laboratory experiments can be performed to corroborate our hypotheses. Comparisons of the effects of taxation with the impacts of alternative interventions can be highly valuable. The role of repeat trading remains understudied. Future researchers can study the implications of potential inter-temporal compensation of large portions with, say, smaller meals later in the day (Anderson and Matsa 2011).

Notes

[1]The trend continues in more recent years. The Canadian province of Newfoundland and Labrador implemented its own tax on artificially sweetened drinks in September 2022 (Lee, 2022).

[2]Cawley et al. (2019) offer a survey of works using the quasi-experimental approach

[3]A nonlinear pricing schedule is a second-degree price-discriminating structure where purchase prices are not proportional to quantity sold. In food and soda retailing, nonlinear pricing frequently appears in the form of per-unit price discounts. This marketing scheme produces menus where "small" and "large" portions have large differences in quantity but small price differentials.

[4]Because they find that the tax influences the seller's menu composition, we believe the findings by Cawley et al. (2020) can be seen as an echo of ours. However, they find that the impact on availability does not vary by container size. This does not constitute a refutation of our conclusions. Their econometric analysis is appropriate to compare the availability of regular soda, diet soda, and untaxed drinks while holding the container size constant. We ask a

slightly different question: are small containers going to be less available compared to large containers *within the same beverage category*?

[5]The low-type buyer is held at his reservation value across policy environments.

[6]A portion cap rule is a form of regulation that directly limits the maximum default quantity at which a product can be offered for sale.

[7]We decide to include two buyer types in our model for three reasons. First, we see fit to use the same nonlinear pricing setting used by previously published work to more clearly show how taxation uniquely affects nonlinear pricing schedules. Second, adding more types would complicate the analysis and reduce clarity without altering the general conclusions: the tax always reduces surplus and nudges the seller to shrink market coverage. Lastly, continuous modelling imply continuous (potentially infinite) serving options. We want to use a model that produces discrete options to more closely mirror menu pricing as observed in soda and food retailing.

[8]The information rent is the excess rent that the H-type must receive from choosing the large serving. This ensures incentive compatibility because the H-type earns at least as much utility from choosing the package meant for her rather than the small serving that is meant for the L-type.

[9]It is not optimal to decrease the size of the small cup beyond this point because it becomes increasingly distortionary. Thus, the seller must weigh the gains from information rent savings against the profit loss from serving L-types in a distortionary manner.

[10]Even though virtually all SSB taxes in the United States are per-unit, we include *ad valorem* taxation in our analysis to broaden the applicability of our analysis. Jurisdictions where *ad valorem* taxation already takes place or it has been discussed as an alternative include Chile and Canada (Cuadrado et al. 2020; Jones, Veerman and Hammond 2017).

[11]Throughout the analysis, we implicitly assume that the effects of cross-border shopping and other tax-avoidance behaviors are minimul. Thus, our results better apply to situations where the geographic scope of a tax is broad (e.g., national or state-wide taxes).

[12]This reaction from sellers is similar to the observed phenomenon of "shrinkflation." Shrinkflation is a response of retailers to inflationary pressures that consists in reducing the amount of product in a container while leaving the price of the item unchanged (Bennett 2022). Recall that, in our model, taxation plays a similar role to an increase in cost

of production. Thus, sellers treat increased taxation as they treat increased input prices due to inflation. The current environment of high inflation provides a proxy natural experiment for increased taxes. A recent NPR article point out that Gatorade has began phasing out 32-ounce bottles in favor of 28-ounce ones (Durbin 2022). Even though produces often allege that changes of this nature are unrelated to specific macroeconomic circumstances, new alternatives are often more expensive than the options they replace.

[13]In the standard textbook problem, a tax causes the demand function to shift downward and lead to a higher uniform price for all units. However, in the nonlinear pricing problem that we study, a serving price is designed to extract as much consumer surplus as possible. As such, the implicit unit price may vary across different units.

[14]The L-type buyer drops out of the market because he would earn negative surplus given the price of the only option in the menu.

[15]On the other hand, there is also evidence pointing that food consumers may compensate a big meal with smaller portions afterward (Anderson and Matsa 2011).

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