Studying a Sin Tax Scheme with Multiple Reforms*

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Abstract

Consumption taxes are important sources of tax revenue, and they are also used as means to correct for externalities or internalities (e.g. sin taxes). Demand elasticity is one of the key concepts for how effectively consumption taxes meet their policy goals. This paper studies the relationship between substitutability of taxed and non-taxed goods and the demand elasticity. We organize the paper through a simple model that yields as a result a highly convex relationship between the demand elasticity and how close non-taxed substitutes are available. Empirically we analyze a Finnish sin tax scheme for sweets, soda and ice cream providing us with quasi-experimental variation through multiple reforms. We have unique product-level data on sales and prices containing hundreds of millions of observations. We also develop survey evidence on substitution preferences across categories of goods. Our estimated consumption elasticity is close to zero for sweets and ice cream having intermediate non-taxed substitutes: cookies. In a stark contrast, when the tax rate was doubled for sugary soda but not for their close substitute non-sugary soda, consumption elasticity is close to unity. These estimates align well with our theory framework; even with intermediate non-taxed substitutes available the demand elasticity is close to zero, while it is close to unity when very close substitutes are available. We also provide evidence that the quasi-experimental price elasticity estimates in the previous literature align with our theory framework.

Key words: excise taxes, sin tax, consumption, substitution, sweets, soda

JEL Codes: H2, I18

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1 Introduction

Consumption taxes are fiscally important (OCED 2020). In addition, consumption taxes often have a corrective role for consumption. An example of the latter are sin taxes that target goods containing sugar, alcohol or nicotine (Andreyeva et al. 2010, Cawley et al. 2019 and Allcott et al. 2019b). An important factor affecting how consumption tax policies meet their policy goals is how elastic demand is with respect to prices. For example, although the optimal sin taxes relate to the size of the internality to be corrected, they also relate as a first order effect to the extent to which they reduce consumption of sin goods (see e.g. Allcott et al. 2019a). The extent to which sin taxes succeed in this is an important question, but the answer the research literature is able to provide thus far is to some extent uncertain. For example, for sin taxes previous studies have estimated consumption elasticities with an extremely wide range (Andreyeva et al. 2010, Cawley et al. 2019, Allcott et al. 2019a). A closely related question is how the possibility to substitute to goods, which are not facing consumption taxes or face lower tax rates, affect the overall demand response. Is the effect of substitution possibilities on overall demand elasticity modest or a determining one?

In this paper we revisit these questions by analyzing a sin tax scheme with multiple reforms in product-level data containing hundreds of millions of observations. We organize our results through a stylized framework with two goods that have two different characteristics following the Gorman-Lancaster tradition. In the model an excise tax is placed on one of the goods to analyze to what extent the demand shifts from the taxed to non-taxed good. In the model consumers derive utility from the characteristics the goods contain. If the two goods share the characteristics only a little, the consumers have low willingness to substitute from one good to another, a situation that can be illustrated with steep indifference curves. On the other hand, if the two goods have very similar characteristics meaning that the two goods are very similar, the consumers have a very high willingness to substitute the goods. This situation can be illustrated with almost flat indifference curves. Similarity in characteristics is interpreted as substitutability between goods.

The main result from the model is that when taxing one of the goods, the substitutability between goods largely determines the demand elasticity. With low or modest substitutability to the non-taxed good the demand elasticity is close to zero. Instead, with high substitutability between the goods the demand elasticity is very high. Thus the relationship between substitutability and the demand elasticity is such that only when the taxed and non-taxed good approach high substitutability, the demand elasticity starts to increase exponentially yielding a highly convex shape.[1] Structural literature on sin taxes has analyzed models resembling the framework in this paper in that the consumers derive utility from characteristics of goods, but have not produced analytical results such as the one described in this paper (see e.g. Dubois et al. 2020, Miravete et al. 2020).

We study these aspects empirically first by utilizing a sweets tax scheme that contain multiple reforms and second by matching elasticity estimates in previous literature with a substitution index.

The Finnish sweets tax scheme applying to sweets, soft drinks and ice creams was introduced in the beginning of January 2011 and had multiple subsequent reforms that we study. Different reforms applied to different product groups, and as a consequence left different product categories as the closest substitute that did not face any tax changes. The tax scheme was introduced in the beginning of January 2011. Perhaps the most interesting variation took place in 2014 when tax rates of liquids (such as soft drinks and juices) were separated so that the tax rate of sugary liquids (0.22€/l) became twice that of sugar-free liquids (0.11€/l). Hence, products that were otherwise very similar save for their sugar content were now taxed differently, such as sugary and artificially flavored soda from the same producer in a very similar container. The reforms in 2011, 2012 and 2017 treated very similar goods with the same tax changes, but still left fairly close goods outside of the tax scheme, such as chocolate (taxed) and chocolate-covered cookies (not taxed).

We have access to extremely large product-level data for the taxed and non-taxed

[1]The model has no income effects and adding them would increase the responsiveness in the absence of substitutes. However, for many excise tax and VAT/sales tax setting the targeted goods are a small part of households' consumption budget and thus the assumption of no income effect fits these settings.

goods. The unit of observation is a product sold in a store in a week. At this level, we observe how many products were sold and at what price. In total, we have about 500 millions observations for tens of thousands of products. The data originate from S-group, which is the largest grocery store chain in Finland having close to 50% market share. Hence, although the data is not a random sample, it describes in a meaningful way what happens to consumption of goods targeted by the tax scheme in Finland. The data infrastructure allows us to provide precise estimates and also investigate the role of potentially confounding factors, such as, overall trends in grocery consumption or the seasonality of the taxed products.

We also develop a survey that measures substitutability of different goods between each other allowing us to determine what are the closest non-taxed substitute categories in each reform. It is an online survey where we ask questions about pair of products that are randomly selected from a large pool of product-pairs. The main question of interest is asking how close substitutes the respondents perceive a pair of products to be on a scale from 0 to 10 with a higher number indicating closer substitutes.[2] The survey allows us to provide a prediction from our theory model on the demand elasticity of each product group targeted by the sweets tax reforms. We can then investigate to what extent our quasi-experimental results are in line with our theoretical framework.

We rely on the standard differences-in-differences strategy, where products in groups facing sweets tax changes are compared to groups not facing tax changes. We select the comparison groups taking into account how close substitutes they are to the taxed products based on our survey results. Otherwise the comparison group consist of similar products in terms of price and broad product category as the taxed products. We observe high seasonality in the sales of both the taxed products and the comparison groups. As we have observations over many cycles of seasonality, we can de-seasonalize the data. The taxed and comparison products exhibit remarkably parallel overall trends before the reform.

Our results for prices show that, in most cases, the sweets tax was either fully or even

[2]We also build other measures for substitutability that utilize product or store information, e.g. nutrients or distance between products in a typical store.

slightly over-shifted to prices. In total, the tax increases in 2011 and 2012 increased the prices of sweets by about 10%, and so did the 2014 reform for sugary drinks. In contrast, abolishing the tax in 2017 for sweets and ice cream led to a less than full pass-through with about 10% reduction in prices on average. An important observation is that prices change on average by similar amounts relative to a control group in different reforms.

The results for quantities sold show two very distinct results. First, the tax increases for sweets or ice cream do not seem to cause discernible changes in quantities sold, with quite precise estimates. The same applies to abolishing the tax in 2017 and to tax changes for drinks that treated sugary and non-sugary drinks equally. Second, the tax increase for sugary drinks in 2014 that left sugar-free drinks unaffected led to a drastic shift in quantities sold such that sales of sugary drinks fell at the reform while those of sugar-free drinks increased. When examining soft drinks as a whole, the reform in 2014 does not seem to have an effect on their total sales.

In terms of price elasticities the tax changes for sweets and ice-cream that left cookies as the closest substitute that did not face tax changes the elasticity estimates are below 0.1 in absolute value. On the other hand, the elasticity estimates for sugary soda that had as the closest substitute non-sugary soda produces an elasticity estimate close to 1.

Our next step is to combine the theory framework and the quasi-experimental estimates. We align our estimated demand elasticities for different product groups based on the substitution index from our survey. We predict with our model how large demand elasticities we would expect based on the substitution index and compare these predictions with our quasi-experimental demand elasticity estimates. The model predicts that for sweets and ice-cream that have as the closest substitute cookies the demand elasticity should be quite low, while for sugary soda that has as the closest substitute non-sugary soda the demand elasticity should be close to unity. This matches well with the quasi-experimental elasticity estimates we have as described above. Thus, our framework seems to perform well in predicting the demand elasticities based only on information about how substitutable different goods are.

Our second complimentary approach to empirically study the link between demand

elasticities and substitutability to non-taxed goods is to develop a substitution index that can be applied to price elasticity estimates from the literature. An increasingly active literature has analyzed the impacts of various consumption taxes on sales or consumption. The literature has found a large range of demand elasticities.

The substitution index we develop is based on product category tree from the TARIC (Integrated Tariff of the European Communities). The index is based on how many nods in the three one needs to cross to get from one product to the substitute group. The less nods the higher is the substitutability. We complement the TARIC information with information about geographical proximity (in case of cross-border shopping).

We then put products for which the literature has produced elasticity estimates into three categories based on how close substitutes that do not face tax changes are available; low, intermediate and high substitutability. When matching this substitution index with the elasticities the literature has estimated produces a good match with our theory model prediction. Thus, our framework of explaining demand elasticities through substitution does quite well also in the broader context of earlier literature on consumption taxes.

In more detail about the literature survey, our aim is to include all quasi-experimental studies that provide credibly causal evidence relating to price elasticity of demand. We then categorize these according to our substitution index into the three categories described above. The low substitutability category is characterized by close to zero demand elasticities. Studies on general consumption taxes or very broad based excise taxes are in this category (Kosonen 2015, Harju et al. 2018 and Benzarti et al. 2020). In the intermediate substitutability category the demand elasticity estimate is different from zero, but still quite low being below 0.2 on average. In this category are elasticity of driving distance with respect to fuel price variation (e.g. Levin et al. 2017 and Langer et al. 2017). In the high substitutability category the demand elasticity is on average close to unity in absolute value. In this category there are studies utilizing sin tax reforms, such as Berkeley soda tax, or price variation in otherwise similar products, such as traditional and e-cigarettes (surveyed partly in Cawley et al. 2019, also Allcott et al. 2022 and Cotti et al. 2022). Also studies on taxing new cars with CO2 based taxes, such as Harju et

al. (2020) fall into this category, as one can substitute higher CO2 emissions car with lower CO2 emissions car or a new car with used car, which is all substitution for lower taxed cars. Moreover, in this category is Fletcher et al. (2010) who document that while taxing soft drinks decreases the consumption in the US, it increases calories from whole milk consumption and has no impact on health outcomes.

Previous literature has more extensively studied the price incidence of consumption taxes than their effects on consumption. Berardi et al. (2016) study the soda tax pass-through in France using a data set similar to ours, with outlet-level super market prices. They find that it took six months to reach the full pass-through and that the pass-through differed by the retailing group and brand, and remained incomplete in the case of flavored waters.

Using city-level average prices, Grogger (2015) documents over-shifting in the prices as the response to the introduction of a soda tax in Mexico. Similarly, Bergman and Hansen (2016) find that excise taxes are over-shifted to sodas when analyzing Danish micro-data. They also document that pass-through rates are asymmetric so that tax increases are overshifted more than tax cuts. Also in our study, contrasting the 2011/2012 and 2017 price results show a modest degree of asymmetry in the pass-through, which is in qualitative terms consistent with the analysis of Benzarti et al. (2020) for VAT. Moreover, we find smaller pass-through rates when the tax was larger relative to the pre-reform price. Cawley and Frisvold (2017) document a pass through of 43% in a context in which a tax on sugar-sweetened beverages was levied only within a rather limited geographic area, providing some evidence about the impact of competition on the pass-through. Agrawal and Hoyt (2019) show that such over-shifting may also be a result of the presence of substitute goods.

Sin taxes have also been studied extensively in structural analysis (see e.g. Dubois et al. 2020, Miravete et al. 2020). The models some of these structural papers estimate share a feature with our framework in that they also model product characteristics as something consumers care about. One of the significant differences is that typically the structural models have much more complicated demand system that they estimate than our simple

theory framework. Our study complements this literature in providing analytical results and quasi-experimental support for the characteristics based consumption models.

The paper proceeds as follows: Section 2 presents our stylized theoretical model, Section 3 describes the institutions more precisely, Section 4 describes the data, Section 5 shows the empirical results for the sweets tax scheme and how they fit our theoretical framework, Section 6 discusses how our empirical estimates from previous literature and the substitution index we develop align with our theoretical framework, while Section 7 concludes.

2 Conceptual framework

In this section, we set up a stylized Gorman (1980) – Lancaster (1966) two-good model of consumption behavior that links a measure of similarity, and hence substitutability, between the two goods to their compensated demand elasticities. The model produces a highly convex relationship between the demand elasticity of a good and the substitutability of the two goods: for fairly substitutable goods, the elasticity is small, but for slightly more substitutable goods, the elasticity is considerably higher. We use this relationship to organize our empirical work. The treatment of the model in the main text emphasizes the intuition behind our results, but more formal and detailed derivations together with a model with multiple goods can be found in Appendix B.

2.1 Setup

The model is set up to consider the consumption choices between two goods containing potentially different set of characteristics of a single agent. A utility maximizing agent chooses the consumption of two goods $x = (x_1, x_2)'$ such that it satisfies their budget constraint. The agent has a strictly concave utility function $u(c)$ over bundles of characteristics $c = (c_1, c_2)'$, where characteristics provide a description of the consumption bundle. For example, a characteristic might be the amount of sugar in the bundle, it's weight, or the number of calories per ounce it contains. Good i then has a character-

istics vector $c^i = (c_{1i}, c_{2i})'$ which provides a similar description for a single good. The main idea here is that a model involving the characteristics of goods provides a way to measure the similarity and hence substitutability of goods without having to measure cross-elasticities.

We make the standard assumption of Gorman–Lancaster-type models, that consuming a bundle of goods x provides characteristics for the consumer through a linear relationship:

$$c = Cx,$$

where $C = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix}$ is a matrix of the characteristics of the goods. Put in another way, the amount of characteristics c the agent obtains from a given bundle of goods x, is given by

$$c = (c_{11}x_1 + c_{12}x_2, c_{21}x_1 + c_{22}x_2).$$

So that the amount of a given characteristic in a bundle is a weighted sum of that characteristic in the consumed goods and the weights are given by the amount consumed of each good. This assumption is natural if we think of additive characteristics: for example, if one characteristic is the amount of sugar the bundle contains, this is a simple sum of the sugar content of the two consumed goods. However, this assumption is not without its faults, as it rules out any other utility impacts such a bundle may have: for example, one might prefer obtaining sugar from two different goods instead of just one, but this is ruled out by the assumption of linearity.

The problem of the consumer can then be expressed as a maximization of utility over bundles of goods x while respecting the budget constraint:

$$\max_x u(Cx) \ s.t. \ p'x = w, \tag{1}$$

where p is the price vector and w is the income of the agent.[3] In the main body of text,

[3]This highlights the connection between a Gorman–Lancaster mdodel and the standard model of

we assume that the prices of the two goods are equal to begin with (i.e. $p_1 = p_2$) as this simplifies the analysis somewhat. However, this is not necessary to derive qualitatively similar results.

2.2 Impact of substitution possibilities on demand elasticities

We next explain how we measure substitutablility of different goods with each other in this setup, and how this measure of substitution possibilities is related to demand elasticities.

We denote by α the measure of how substitutable different goods are between each other. α is derived in the model through product characteristics. Assume that the characteristics vector of good 1 is c^1 and the characteristics vector of good 2 is c^2. Furthermore, assume that the goods are not substitutable at all. Just to provide intuition, one could think of e.g. a bottle of a sugar sweetened beverage versus a mile of travel by car. Let us think of a third good, good 3, which has a characteristics vector $c^3 == \alpha c^1 + (1-\alpha)c^2$, where α is between 0 and 1. In other words, good 3 has a characteristics vector that is somewhere between the characteristics vectors of goods 1 and 2. Consider then a situation where instead of choosing how to spend their budget between good 1 and good 2 the consumer is faced with a choice between good 1 and good 3. This would mean that when α is 0, good 3 is identical to good 2 and, hence, good 3 is not substitutable at all with good 1. When α is 1, good 3 is identical to good 1 so that they are completely substitutable. Note that when we increase α, both characteristics of good 3 become more similar to those of good 1, making the goods more substitutable with one another. This is why we take α as a measure of substitution possibilities in this stylized model.[4]

Figure 1 illustrates how α is related to the indifference curves between the two goods. We consider two cases: one where α is low to begin with, so that the goods are not very close substitutes (the left panel in figure 1), and one where α is high to begin with, so

consumer choice: if there are as many goods as characteristics and C is the identity matrix, we have the standard model.

[4]Note however, that the two characteristics may become more similar in other ways as well e.g. if only one of the characteristics becomes more similar. However, based on our results in Appendix B, this does not change the qualitative results, so that in the main text we concentrate only on α.

that the goods are already close substitutes before the change in α (right panel in figure 1). A small increase in substitutability α by $\Delta\alpha$ straightens out the indifference curve in both cases from the black indifference curve to the red one, so that the two goods become more elastic to price differences in both cases. The change in the responsiveness to price differences can also be seen in how the chosen bundle would react to a given tax change. This is outlined by the bundles x_0, which is the original bundle without tax changes, x_1, which is the bundle the consumer would choose after a tax change without the change in α, and $x_1(\Delta\alpha)$, which is the bundle the consumer would choose after a tax change with the increase in α. In both cases, the change from x_0 to $x_1(\Delta\alpha)$ is larger then the change from x_0 to x_1. However, when the goods are already very close substitutes (high α), the change from x_0 to $x_1(\Delta\alpha)$ is *much* larger than from x_0 to x_1 compared to the case when the goods are not very close substitutes (low α).

The main result from the theory framework intuitively derives from the changes in indifference curves when α increases. Because the indifference curves change at different original levels of substitutability differently, there is a nonlinear relationship between substitution possibilities and demand elasticities. Demand elasticities increase gradually at low levels of substitutability when slightly more substitutable pairs of goods are considered, but very fast when highly substitutable goods are replaced with slightly more substitutable goods. This relationship is outlined in figure 2, where the compensated own-price elasticity of a good is plotted as a function of how close substitute the other good is in terms of α. Indeed, we see that the relationship between the elasticity and substitution possibilities is highly convex: elasticity values would be low with quite similar goods (e.g. α around 0.9), but high when the goods are only slightly more substitutable. This gives the main result from our theory framework.

3 Background for the sweets tax

We study multiple reforms in the so called sweets tax scheme in Finland. On 1 January 2011, Finland introduced an excise tax on sweets, ice creams[5] and raised the existing

[5]Sweets tax applied also to chewing gums, and some other naturally or artificially sweetened products.

excise tax on soft drinks[6]. Together, these excise taxes are called the sweets tax. There were two subsequent tax rate increases in 2012 and in 2014 while the tax was abolished for sweets and ice cream on 1 January 2017.

The sweets tax is based on custom categories. As a result, some products are taxable while others, quite similar ones, are not. For example, cookies, sweet pastries or snack bars are not tax liable while chocolates and candy bars are. Within a category the tax was assigned based on weight or volume of the package. The tax was, thus, not based on the sugar content of the product. Moreover, since the tax is tied to the weight or the volume, the tax impact relative to before tax price of a product varies across the products within a taxed product category.

There was an excise tax rate on soft drinks of 0.045 €/l before the introduction of the sweets tax. Since 1 January 2011, the sweets tax rates amounted to 0.75 €/kg for the solid taxable products and 0.075 €/l for the liquid taxable products including soft drinks. The rates were subsequently increased so that, from 1 January 2012 onward, the valid rates were 0.95 €/kg for solid taxable products and 0.11 €/l for liquid taxable products. The 0.95 €/kg for sweets and ice creams was abolished on 1 January 2017, but the tax on soft drinks was not.

Importantly, the tax rates were also changed on 1 January 2014 so that the tax rate for the liquids including soda with a sugar content higher than 0.5 g per 100 g or 100 ml was raised to 0.22 €/l. The tax rate for liquids having lower sugar content than the threshold remained at 0.11 €/l. The purpose of this differentiated tax change was to channel consumption into sugar-free products. The definition of the sugar-free liquids was based on the regulation (EC) No 1924/2006 of the European Parliament and of the Council of 20 December 2006 on nutrition and health claims made on foods. An existing legal definition for sugar-free products decreased the administrative burden as the companies were already familiar with the definition and monitored for its appropriate use. Furthermore, it was very clear whether a product would fit the definition since the products below the threshold value were clearly sugar-free, such as waters or artificially

[6]These products are also subject to the reduced VAT rate (13% from July 2010 until December 2012 and 14% since January 2013). The VAT is calculated based on the sum of the price and the excise tax.

Table 1: Tax changes in 2010-2017

		Solid	Liquid	
Old excise tax	Before 2011	0 €/kg	0.045 €/l	
Sweets tax introduced	1 Jan 2011	0.75 €/kg	0.075 €/l	
Rate increase	1 Jan 2012	0.95 €/kg	0.11 €/l	
			Sugar free	Sugared
Rate differentiation	1 Jan 2014	unchanged	unchanged	0.22 €/l
Sweets tax scrapped; old excise tax remains	1 Jan 2017	0 €/kg	unchanged	unchanged

As of 1 January 2014, the liquids with a sugar content higher than 0.5 g per 100 g or 100 ml were defined as sugared. The definition of the sugar-free liquids was based on the regulation (EC) No 1924/2006 of the European Parliament and of the Council of 20 December 2006 on nutrition and health claims made on foods.

sweetened sodas, so that there was no sugar involved in any manufacturing phase.[7]

The sweets tax is carried out whenever products are provided for the consumption purposes from a tax-free warehouse or imported to Finland. Manufacturers, wholesale sellers and importers are the parties liable to tax. However, it is possible to export products from a tax-free warehouse without incurring tax liabilities. The Finnish Customs Office is responsible for carrying out the sweets tax collection and overseeing the producers.

There is no data on sweets smuggling but anecdotally it has been deemed unimportant. Since the law change was implemented, the Finnish Customs Office has paid special attention to inspecting companies that are tax-liable (Sokeriverotyöryhmän loppuraportti 2013).

[7]Additional to products in the customs categories for which the sweets tax did not apply, also some other products remained untaxed. Any sweets, ice cream or soft drinks used for manufacturing sweets, ice cream, soft drinks or other food products or exported to the other EU countries by a registered storage keeper are untaxed. Also untaxed remain any sweets or soft drinks that are used for manufacturing medicine, alcoholic drinks (having a different excise tax), clinical nutritional products, infant formulas, children's foods or weight-loss products, provided such products comply with the definitions of the respective laws. Finally, small-scale production is also exempt from the tax (Laki virvoitusjuomaverosta 17.12.2010/1127).

4 Data

4.1 Scanner data

Our data source is a large Finnish retail-chain called the S-group, and the data consist of their product-specific sales figures of all relevant food products at the outlet level aggregated to a weekly level from the last week of 2009 to the end of 2018. These outlets are evenly located all across the country and there are 1,077 of them. The total data consists of ca. 500 million observations. The market share of the S-group in the Finnish grocery market is roughly 45%, making the sales data quite representative of the consumption behavior in Finland, although it is not a random sample of stores in Finland. The S-group has various types of stores: they include small corner shops, larger market stores as well as big mall-type stores. Thus, S-group sales data represent purchases in various types of stores and demographies.

The data consists of taxed and non-taxed product groups. In the taxed group we have: sweets (chocolates, candy bars and assorted candies, chewing gums), ice creams, drinks (soft drinks, juices, juice concentrates, waters). In the non-taxed group we have: cookies, cakes, sweet and salty snack bars or pastries, sugars, honeys, syrups, and yogurts.

The data include the product name (e.g. Angry Birds Red Bird), its custom category (e.g. 2106), its detailed product category (e.g. fruit xylitol chewing gums with a package size larger than 60 g), its net consumer package size[8] in kilograms or liters (e.g. 0.07 g) and whether this refers to liters or kilograms. The data also include the total number of the items sold and the monetary value of the items sold as well as information on the number of the discounted items and the total monetary values of these discounts. All the product-specific information is summed up for each outlet for each week. Finally, we have data on the type of store and which region it is located in.

All the monetary data is in euros. There is no data on the wholesale prices or the identity of the producers. Based on the product names, the product categories and the custom categories, we impute which products are taxable and which are not. The

[8]The definition refers to the package size net of packaging and non-edible ingredients, making it equivalent to the legal definition of the excise tax base.

taxable custom categories are sweets without cocoa (1704), chocolate and other food items with cocoa (1806), ice cream, popsicles, and other iced products (2105), non-fermented or non-alcoholic juices (2009), diverse food products (2106) that consist mainly of juice concentrates, unflavored or unsweetened waters (2201), flavored or sweetened waters or other non-alcoholic beverages not in the group 2009 (2202), and other fermented beverages or mixtures (2206). There are also partially taxable custom categories, which are products similar to 1704 but not sugared (2106), consisting of xylitol chewing gums, stevia-sweetened or sugar-free candies and syrups. The untaxed custom categories are plain bread, cakes, cookies and biscuits and other pastries (1905), food products made from grain or grain product by swelling or baking (1904), cane and beet sugars and chemically clean sucrose (1701), other solid sugars (1702) and natural honey (409) (Laki virvoitusjuomaverosta 17.12.2010/1127).

Table 1 describes the data. The first two columns give statistics for prices and quantities for the treated products in the upper panel and for products not facing tax changes in the lower panel. In rows average refers to average value of weekly and store level observations, Standard deviation to standarddeviation of these weekly observations, N is the number of observations in the data and N*pieces is the total number of products sold in the data, derived as the sum of individual products sold over all stores and weeks observed. The last three columns describe similar statistics in three different sub-groups of taxable products: sweets, ice cream and soft drinks.

When imputing the mechanical full tax pass-through, we take into consideration the fact that the data consists of the retail prices, including the VAT. We impute the base price for each product as its mean price in November and the two first weeks of December 2010 prior to the tax change. Based on this product-specific base price, we impute the full pass-through as follows and take the logarithm over it:

$$\ln\left(p_{full,it}\right) = \ln\left(\left(1+\text{VAT }_{t}\right)\left(\frac{\text{base price}_{it}}{1+\text{VAT }_{t}} + \text{new ex. tax }_{it}\text{-old ex. tax}_{it}\right)\right) \quad (2)$$

The logarithms of the product-specific pass-through rates are then averaged over for the relevant product group (i.e. all the products, solids only etc.).

4.2 Survey and additional product data

In addition to the sales data, we conducted a survey eliciting preferences over substitutability across products. We also gathered additional product-level data in order to construct measures of substitutability between product groups.

The survey was administered both as a class assignment (voluntary or compulsory, depending on the course) on several economics courses in Finnish universities and through an open online link on the home page of Finnish Centre of Excellence in Tax Systems Research and the Labour Institute for Economic Research. The main body of the survey consists of questions about products presented in pairs. An example of a product pair in the survey with the related questions is presented in Figure A.1 in Appendix A. The product pairs are randomly chosen from a large pool of pairs such that one respondent answers the same questions for multiple product pairs.

An important part of the survey is a photo for each product. The survey shows each time photos of both products in product pair and below these are the questions. In order to get photos for all products we in some instances got a permission to use the official marketing photo for each product. Because we did not get the official phtos for all products, we also set up a photography studio with studio lights to take photos ourselves.

The main question in the survey is question 2 we use to construct a substitution index. The question asks how substitutable product A is with product B on a scale between 0 to 10. The higher the number the more substitutable the products are with each other. We then average the answers for each product pair to derive a substitution index across product pairs.

We also have a money metric question on the substitutability across products, which is question 3 of the survey. This question states that product A costs certain amount of euros, and what would the price of product B need to be in order you to substitute that product with product A.

In total, there were 911 respondents to the survey with 8,641 product pairs viewed in total.

We also gathered additional product-level data on a subgroup of the whole product

universe available in the sales data. This data was scraped from the Foodie.fi web page of the S-group with their permission using the EAN codes of the products. These data include information on the ingredients, nutritional content, and store-floor locations. We have data on ingredients for 6,546 products, nutrient data for 6,052 products, and store-floor locations (in a single hyper market) for 2,091 products.

5 Empirical results and empirical strategy

In this section we provide our empirical results both on the effects of the different sweets tax reforms on prices and quantities sold, and for the survey and related product data.

5.1 Price and quantity effects

In this subsection, we provide estimates of the impacts of the sweets tax on the prices of products both in a graphical event-study framework and in a difference-in-differences (DiD) setting. The graphs are based on estimations of the following equation for the logarithms of various outcome variables y_{it} for different product groups:

$$\ln y_{it} = \gamma_t + \mu_i + \epsilon_{it}, \tag{3}$$

where i refers to a product-outlet combination and t refers to time periods (either week or month, depending on the setup). γ_t refers to a set of time fixed effects. μ_i refers to product-outlet i fixed effects and ϵ_{it} is the error term. The outcome variables y_{it} consist of unit price and volume of products sold. The volume refers to kilograms or liters, depending on the product. The estimations are clustered at the product-outlet level. We estimate equation 3 for groups facing tax changes and their respective comparison or substitution groups separately and plot the time fixed effects γ_t from these estimations.

We quantify the impact of the sweets tax reforms with a DiD framework for the groups studied graphically above. We estimate the following equation:

$$\ln y_{it} = \gamma_t + \mu_i + \beta_{DD} 1\left(After * Target\right) + \beta_1 1\left(After\right)_t + \beta_2 1\left(Target\right)_i + \epsilon_{it}, \qquad (4)$$

where $1\left(After\right)_t$ is an indicator taking value one for after the reform period, $1\left(Target\right)_i$ is an indicator taking value one for the products in the taxable categories or the substitute categories of interest, $1\left(After * Target\right)$ is the interaction of the two indicator terms and thus β_{DD} is the main coefficient of interest. $\ln y_{it}$ is the logarithmic outcome variable, either unit price or the volumes or items sold. We may include product-outlet level fixed effects μ_i in which case the indicator for the treatment group is not included in the regression. ϵ_{it} is the error term, which is clustered at the product-outlet level.

5.1.1 Price effects

Figure 8 presents the development of prices around the 2011 and 2012 reforms for all taxed and non-taxed products pooled. The figure shows that taxed and non-taxed group prices follow the same trend in the year before the reform. Then at the reform the taxed group prices exhibit a clear increase. The prices do not jump immediately to the new level, but rather the increase is gradual over the period of three months. The prices end up at a higher level than what the mechanical full-pass through, marked to the figure with the horizontal purple line, would have indicated. But because the non-taxed group prices also increase during the same time interval, it seems that the net effect to taxed group prices is about full pass-through. The development of prices is slightly different in the 2012 tax increase. The prices in the taxed group jump within two weeks to the new level after this reform. Moreover, it seems that the net price increase was higher than what full pass through would have implied.

To provide some estimates for different subcategories Figure **??** presents the development of prices separately for ice creams, soft drinks, sweets and chocolates (as a special category of sweets). The general time-pattern in these sub-groups is quite similar than the average pattern for all goods. The two notable exceptions are ice creams and soft drinks. Ice creams are an exception since the prices increase by less than the amount

of the mechanical full pass-through in 2011 and by the full pass-through in 2012. This arises possibly due to the fact that the excise tax was larger relative to pre-reform prices among ice creams than among other taxed products. They tend to weigh more than other solid products and the tax impact increases with the weight. Soft drinks had the opposite feature to ice creams. For them the tax increase over the pre-existing tax was small relative to the pre-reform prices, but the pass-through seems to be more than full.

We also analyze the abolishment of the sweets tax from the beginning of 2017 in Figure A.8. Again, there is an immediate and large price response to the reform. However, on average the prices declined by less than what the full pass-through would have been, which suggests some modest asymmetric pass-through by comparison to the results for the tax introduction. The sub-group analysis in Figure A.9 show that for sweets the pass-through seems to be full for the tax abolishment, but for the other categories slightly less.

Table 4 shows the results for prices of the 2011 and Table 5 of the 2012 reform. The results indicate that the average pass-through was full for the 2011 reform. Moreover, the table confirms the intuition from the graphical analysis that for ice creams the pass-through was less than full and for soft drinks more than full. In the 2012 reform the average pass-through was more than full. A possible general pattern from these observations is that the smaller the mechanical impact of the tax on prices, the higher is the pass-through and vice versa, when the impact of the tax is higher the lower is the pass-through. In numbers it seems that the sweets tax were increased by about 10% after the two reforms relative to the control group.

We next turn to studying the 2014 tax increase for sugary soda that left the tax on sugar-free soda unchanged, the 2014 tax change doubled the tax rate for sugared liquids from 0.11 €/kg to 0.22 €/kg. Figure 7 shows that the consumer prices responded immediately and increased rapidly by an amount of mechanical full pass-through immediately after the reform. The figure also shows the prices of sugar-free liquids and the prices of a control group. Relative to the control group it seems that the sugar-free drinks exhibit initially some price increase after the reform, but this subsides and their prices return to the control group level. Importantly, the effect of the 2014 reform on prices of sugary

drinks is about 10%, which is very similar to the effect of introduction of the tax in 2011 and subsequent increase in 2012 for sweets and ice cream on average. Thus, when comparing the effects of these different reforms on quantities sold, any potential differences across reforms is difficult to explain with differential price impact.

5.1.2 Quantity effects

In this subsection, we provide estimates of the impacts of the sweets tax on quantities sold. In addition to standard comparison of products facing tax changes with other products we want to identify substitution effects. More precisely, we need to distinguish between those products not facing tax changes but could experience the effects of the reform through substitution effects from comparison groups not experiencing substitution effects. Therefore, in choosing a comparison group, we relied on our results from section 5.2 on the substitutability of different product groups. We proceeded as follows:

1. We compared a treated product group to a non-treated group that is similar to the treated one based on our survey results.

2. If the pre-trends of these two groups were not similar, we moved on to another, less substitutable non-treated group. We then iterated this step until we found a fairly close non-treated group with similar pre-trends to the treated group.

3. Based on the estimate of the quantity effect $\hat{\tau}_q$ obtained using the comparison group from step 2. we then did one of the following:

   (a) If the estimate of the quantity effect was close to zero, we stopped there, as 1) having a fairly close substitute group as a comparison group implies that the quantity estimate $\hat{\tau}_q$ provides a lower (upper) bound for the true effect τ_q in the case of a tax increase (decrease) due to possible substitution between the treated and non-treated groups, so that in this case $\tau_q \geq \hat{\tau}_q \approx 0$ ($\tau_q \leq \hat{\tau}_q \approx 0$), and 2) assuming that the treated products are normal goods implies that $\tau_q \leq 0$ ($\tau_q \geq 0$), so that 1) and 2) together imply that $\tau_q \approx 0 \approx \hat{\tau}_q$.

(b) If the estimate of the quantity effect was not close to zero, we combined the two groups and compared their combined sold quantities to a third group that had similar pre-trends but was a less close substitute to both. If the estimate of the combined quantity effect was close to zero, we stopped there and took the third group to be a pure control group due to a similar argument as in step 3.(a) above.

This procedure was sufficient to provide an estimate for all products facing a tax change in one of the reforms in our setting.

An additional feature affecting the estimates is that the sales of the products in our sample exhibit strong seasonal fluctuation as exemplified in Figure 3, where the development of the sold quantities of taxable solids around the 2011 and 2012 reforms (mainly sweets, chocolate and ice cream) are compared to a set of non-taxable solids (mainly cookies, sweet and savoury pastry, pudding and yogurt). The extent of seasonality is that sales vary 20% around the annual average sales. We consider seasonality naturally arising from consumption varying with season, for example, influenced by temperature. However, not taking seasonality into account and picking up different points in year before and after a reform would cause a huge bias in estimations. This highlights the need to remove seasonal variation from the data, and stresses the value of a multiyear detailed datasets in settings similar to ours: without such detailed data, seasonal adjustment would be hard or even impossible to carry out. In order to adjust for the seasonality, we use the residuals from a regression that regresses the respective quantity variable on the product category-calendar month effect. The product categories are at a very precise level and there are 447 of them in our sample. All graphs are normalized to zero prior to the reform under study.

Figure A.2 presents the over time development of quantities for solid products with seasonal adjustment. The figure shows very clearly that the control and treatment groups develop on the same trend both before and after the 2011 and 2012 reforms. Thus, the comparison of groups seems reasonable based on parallel pre-trends. Moreover, the figure shows quite convincingly that the two reforms had no impact on the quantities as the two

groups move in parallel also after the reforms. Thus, it seems that consumed quantities do not change despite the fact that we observed above that the tax induced on average 10% price difference to emerge between these groups. This suggests that the demand elasticity with respect to price is close to zero in this case.

Figure A.3 shows the development of volumes of soft drinks relative to their control group. The pre-reform trends do not develop quite as nicely in parallel in this case, but overall it seems to distinguish any clear effect after the reform either. Figure A.4 presents the same four sub-groups as in the price analysis. The sweets and chocolate are quite similar than the overall analysis for solids. Ice creams and soft drinks (the same figure as above) have the same feature that their pre-trends are somewhat messy, but overall no clear impact of the reform is visible. The messy trends could be due to seasonality that we could not take into account.

The quantities develop again quite smoothly over the 2017 reform, shown in Figure A.4. Although there are some noise in the series, it seems that any responses are quite modest at best. This observations builds support for the idea that the demand elasticities in this case might be rather low.

Table 2 shows the differences-in-differences estimate for quantities. The regression takes as the pre-period year 2010 and as after-period 2011 to 2013. Thus the regression combines the 2011 and 2012 tax increases. All the coefficients are close to zero. The preferred estimate is in column (2), which combines reforms 2011 and 2012 and adds product-level fixed effects. The estimate is -0.003 and is statistically not significantly different form zero with quite tight confidence intervals. Thus, we conclude also based on this estimate that the reform had no impact on the amount of sweets sales.

Table A.1 show the DiD estimates for quantities in the 2017 reform. The estimates are non-zero but note that by switching the control group from all to sweet pastries, the coefficient switches sign. Thus, again these estimates can exclude any large quantity responses, and our best guess is that the demand elasticity suggested by these estimates is close to zero.

Figure A.6 shows the quantity evolution of sugary versus sugar-free drinks and Figure

A.7 the same comparison between the sugary and sugar-free soft drinks. The figures show that the two groups are on a parallel trend prior to the reform and that there is a clear separation between the sales of the two groups precisely at the time of the reform. Figure 5 adds to the previous figure a third group, a common control group consisting of ice cream, sweets and chocolates. The control group illustrates that at the 2014 reform the consumption of sugary soda declined and the consumption of sugar-free soda increased. This suggests that there was a substitution effect from sugary soda to sugar-free soda.

Table 3 shows the quantity regressions for the 2014 reform. Columns (1) through (3) are for all drinks and columns (4) through (6) focus on soda only. Column (1) shows that relative to a common control group the consumption of all drinks declined by about 1,6%. When separating the effects between sugary and sugar-free drinks, the effects are clearer and opposite: column (2) shows that the sugary drinks exhibit a decline of 4.2% while sugar-free drinks increase by about 5.6%. The total effect is negative because the group of sugary drinks is larger than the group of sugar-free drinks. The effects are to the same direction but more pronounced for soda. The total effect in column (4) shows a decline of 4.1%, and the consumption of sugary soda seems to have declined by 7.3% while the consumption of sugar-free drinks seems to have increased by 3%. We have to note that the division between the main and substitution effects is quite sensitive to the choice of the control group, and do not want to take the exact point estimates as certain. But in general we observe that there was a total effect on consumption of drinks due to this last reform and that there was a clear substitution from sugary drinks to sugar-free drinks. This last observation is also capable of explaining why we see such clear consumption effects here while earlier reforms having similar impact on prices did not have a clear impact on consumption of sweets or drinks for that matter.

5.2 Substitutability results from the survey and additional product data

In this subsection, we provide results on the substitutability of different product groups from our survey and additional product data. The main substitutability measure we

utilize is based on our online survey presented in the previous section.

Figure 9 shows the distributions of answers to question 2 in the survey asking on a scale between 0 to 10 how substitutable products are with higher number indicating more substitutable. We group the answers from this questions for four product categories facing tax increases in the reforms versus their closest category not facing tax changes at the same reform. The closest no-tax-change categories are chosen based on the answers to the same question and they are cookies for sweets, ice-cream and chocolate, and sugar-free soda for sugary soda. The figure shows the distribution of how substitutable respondents think the products in the tax-change category are with their closest product in no-tax-change category. The figure shows that the distribution has concentration of mass close to low substitutability values for sweets, and the values start to increase for ice-cream and chocolate to and reach concentration of high substitutability numbers for sugary soda. This indicates that according to our survey for example chocolate and cookies are less substitutable with one another than sugary and sugar-free soda. This is also shown in figure 10, which depicts the means of the data for each product category pair as well as the 95% confidence intervals of the means.

We also constructed alternative similarity measures based on our data on product ingredients, nutritional content and store floor locations. The mean values of these for the main taxed categories compared to their closest low-tax categories can be seen in figure A.10 along with the substitution index. Note that the baseline similarity measures have been transformed in this figure by continuous monotonic functions chosen so that the results will more closely match those of the substitution index. This can be done, as a continuous monotonic transformation of a given measure simply corresponds to changing the units of that measure. The baseline similarity measures based on store floor locations and nutritional content is simply a Euclidean distance between two products, i.e. the Euclidean distance between store floor co-ordinates and between nutritional information vectors (e.g. how much fat, protein etc. a product contains) respectively. The construction of the similarity measure based on product ingredients is more elaborate. First, as the ingredients of the groceries are mainly listed in the order of decreasing weight,

we collect up to 8 ingredients per product. Then for each product pair (x, y) we calculate a normalized distance based on the largest common sub-string between each ingredient of x and each ingredient of y, and choose the minimum distance for each ingredient. The ingredient based similarity measure between x and y is then the mean of the minimum distances for each ingredient of the pair.

5.3 Fitting the empirical estimates with our theory framework

We have presented above in Section 2 a theoretical framework according to which we align our empirical estimates. Here we review how the empirical results align with the theory framework matched with the substitution index from our survey.

We order the empirical results such that we consider to what extent sweets tax impacted the sales of taxed products when compared to their closest substitute group that is not taxed. We order these pairs of product groups in an increasing order of substitutability to the closest non-taxed group. The lowest substitution index is for sweets that are not chocolate when the closest substitution group is cookies. The next group is ice cream with again cookies as the substitution group. Next one is chocolates contrasted with cookies. The highest substitution group is sugary soft drinks that are contrasted with non-sugary soft drinks. Figure 9 shows the distribution of substitution preferences in the survey between these pairs of product groups. Figure 10 shows the mean of substitution index in the survey, which is increasing almost linearly from one pair to the next. Figure A.10 shows that our different alternative substitution indices are developing also roughly linearly from one pair to the next and have a similar slope than the survey based index.

The theory predicted that when substitutability is increasing over pairs of products linearly in the way our substitution index is increasing, the demand elasticity of the taxed products increases in highly non-linear fashion. To examine whether that holds in our empirical data, we provide demand elasticity estimates for the same pairs of product groups in Figure 12. The figure also provides in the shaded area the prediction of the model (that varies with chosen parameter values). One can observe from the figure that the estimates line up well with the model. We estimate a demand elasticity of close to zero

for the other pairs than soft drinks, meaning that no consumption seems to shift from the taxed group to the closest non-taxed substitute group. The effect is dramatically different for soft drinks whose demand seems to be quite sensitive to taxation in that consumption shifts from the sugary soft drinks to non-sugary soft drinks when their tax rates are separated and sugary soft drinks become taxed more heavily.

6 Evidence from previous literature

To further motivate our study, we conduct a review of past elasticity estimates and relate these to an empirical measure of substitution possibilities based on EU tariff-categories. We include in our meta-analysis papers that provide quasi-experimental price elasticity estimates of excise taxes and also sales tax / VAT on various products. We collected 34 different estimates from 28 studies (entries in the References: [4, 20, 13, 14, 15, 16, 18, 19, 21, 23, 25, 28, 31, 32, 35, 38, 43, 44, 45, 46, 50, 51, 52, 54, 57, 55, 26, 17]).

6.1 Assigning substitutability measures to previous literature

To understand the relationship between price elasticity estimates from previous literature and the substitutability possibilities underlying those elasticities, we build a simple index measuring substitution possibilities in each case. The index is based on the EU tariff goods-tree, which assigns categories to physical exports and imports. With the goods-tree, we measure substitution possibilities as a function of the shortest distance to a substitute good which price does not change. We apply the goods-tree with 2-levels of categories (4 digits), which are in the order of descending generality (e.g. for sugary soda, the code is 0422, where 04 stands for "Prepared foodstuffs; beverages, spirits, and vinegar; tobacco and manufactured tobacco substitutes", 22 stands for "Beverages, spirits and vinegar").

The main rule to we use to construct the index is as follows: for a given good in a given setting (i.e. sugary soda in 0422), we obtain a tariff category code at the 6-digit level. Next, using the goods-tree, we find a closest good available which price does not change

(e.g. artificially sweetened soda, which is in the same category 0422). This translates to four possible cases: 1) the closest substitute may be in the same category (as above), 2) the closest substitute may be in a neighboring category, so that the two leading figures of the code are the same, or 3) the closest substitute may not share any digits. Finally, for each of these cases, we assign an index number between 0 and 1 based on the idea that an index of 1 indicates the same good (i.e. the most substitutable situation) and an index of 0 indicates a good that is not substitutable at all (e.g. sugary soda versus a mile of travel by car). As we have three levels of substitutability, we divide the line from 0 to 1 into three parts[9] and assign the middle point of each interval to each category. Hence, the index-numbers go from 1/6 (substitute in the same category) to 5/6 (substitute in a completely different category).

However, not all goods and no services are covered by the EU tariff goods-tree, as they are not accounted for by the tariff authorities. Within our reviewed elasticity estimates, such goods are electricity, restaurant meals, hair-cuts at barbers and hair salons, and miles/kilometers of travel by car. We assign all these to the category with the least substitution possibilities (index of 1/6) based on the following reasoning: Electricity usage at the household-level could be substituted mostly in the case of heating by other heating sources (e.g. natural gas), but this takes time. Other household electricity consumption may be harder to find a substitute for. Restaurant meals could perhaps be substituted by home-prepared meals, but restaurants tend to be used for different types of occasions (e.g. parties or work lunches), and restaurant meals may ask for expert skills and equipment that one might not have available for home-prepared meals. Similar reasoning applies to hair-cuts, which might be substituted for by home production, but which may demand expert skill and equipment not available at home. Miles/kilometers of travel by car might be substituted with other forms of travel, but in many cases such other forms of travel may be nonexistent.

[9] I.e. from 0 to 1/3, 1/3 to 2/3, and from 2/3 to 1.

6.2 Elasticity estimates as a function of substitution possibilities in previous literature

We want to analyze whether differences in the elasticity estimates between these studies are related to study-level differences in substitution possibilities, and if so, do we find a convex relationship between the two as the stylized Gorman–Lancaster model would indicate. To that end, we group the elasticity estimates based on their substitutability index and plot the mean elasticities of these groups against their substitution index in figure 13. The figure would indicate that an increasing relationship is present and that, indeed, it seems to follow a convex shape.

7 Conclusions

We study how demand elasticities depend on characteristics of the goods that are taxed and other similar but not taxed goods. The idea is that much of responses to consumption taxes might be driven by substitution towards goods that are taxed at lower rates. We analyzed to this end Gorman-Lancaster model. The model provides a prediction that when goods become incrementally more similar, the demand elasticity behaves in very non-linear way. In particular, with lower levels of substitution the demand elasticity can be quite close to zero, but when substitution crosses a threshold, the demand elasticity can shoot up.

To provide empirical support for the characteristics model we studied the sweets tax introduced in Finland in 201 and subsequent tax increases in 2012 and 2014 and abolishment of the tax in 2017 for sweets and ice cream. Our findings show that the sweets tax was fully passed through to prices in the 2011 reform and over-shifted in the 2012 reform that was a smaller increase in the tax. The tax abolishment was slightly but statistically significantly under shifted to prices, indicating asymmetry to some degree, consistent with Benzarti et al. (2020) for VAT. We find that the tax increases in 2011 and 2012 or the tax abolishment in 2017 did not affect the consumption of sweets, ice creams or soda at all. In contrast, we find that the 2014 tax increase for sugary soda did reduce

the consumption of sugary soda. This reform left the tax of sugar-free soda, a close substitute, unchanged. We indeed find that there was substitution towards sugar-free soda while the consumption of the whole drinks segment did not decrease that much.

In order to link the theory model with the empirical results we also provided information on substitutability of the taxed goods in the sweets tax scheme with other goods not facing the sweets tax (or having a lower tax rate). We designed a survey asking about substitution preferences between pairs of products. The results indicate that substitution is increasing linearly such that sugary and non-sugary soft drinks have the highest substitutability while sweets and cookies the lowest between the different pairs of products groups affected by the sweets tax scheme.

If one feeds this kind of linearly increasing substitution index to the characteristics model one gets as the demand elasticity the highly non-linear pattern mentioned above. Our empirical estimates utilizing the sweets tax scheme provide exactly this kind of pattern, where we observe quite substantial demand elasticity for the soft drinks and low demand elasticities for the other taxed groups. Thus, the empirical results are capable of providing strong support for the Gorman-Lancaster model.

The characteristics-based consumption model has strong implications for the design of consumption taxes. For majority of products there are no close enough substitutes such that demand elasticities would be high. For that reason, it is likely that general consumption taxes such as VAT lead in these cases to a very low excess burden. For excise taxes that aim at changing consumption patterns in order to reduce externalities or internalities created by consumption the model has a different implication. In order for these types of taxes to work towards their goals, there needs to be a fairly close substitute group that does not cause the same externalities or internalities as the taxed group. The Finnish soft drinks tax for sugary soda is an example where both criteria seem to be fulfilled; close substitute from non-sugary soda that is deemed to be healthier than sugary soda.

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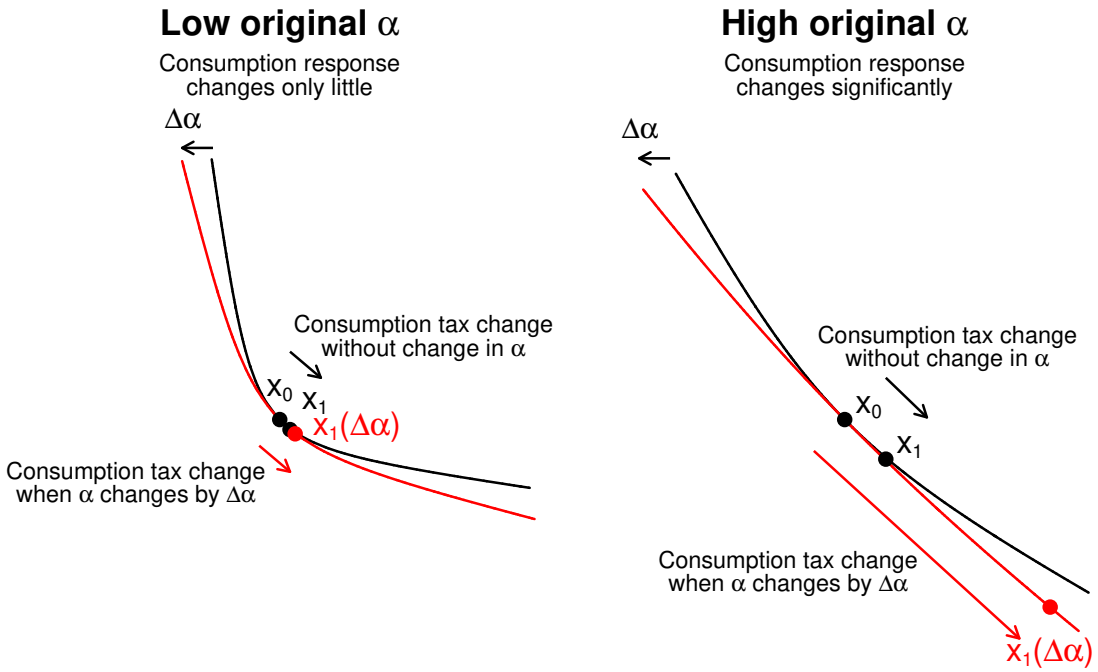
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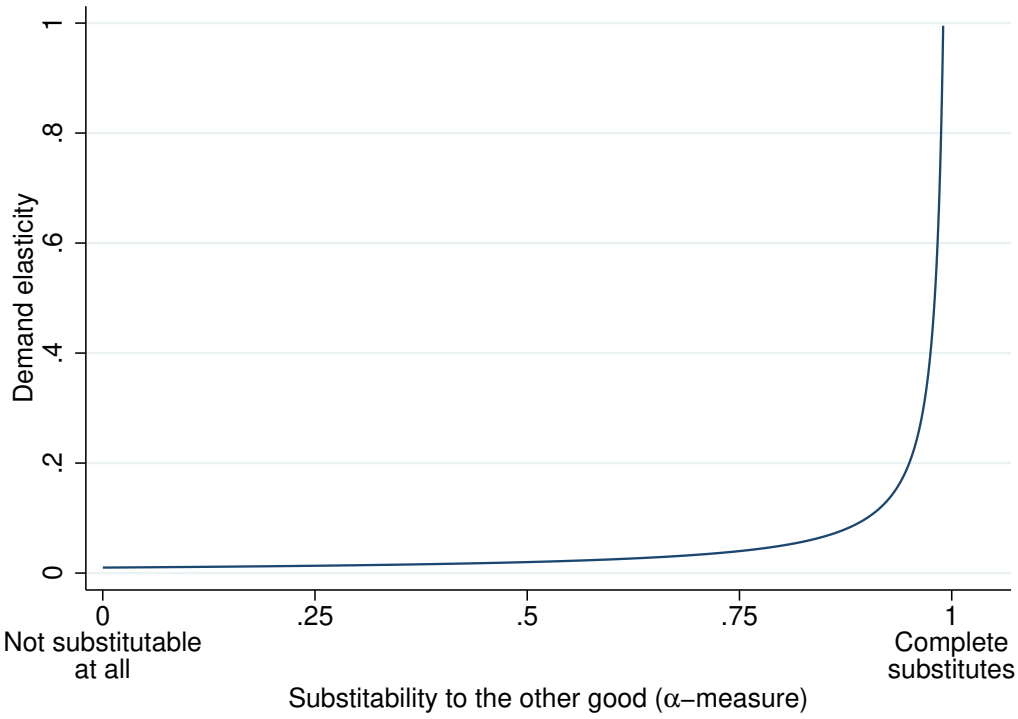
Figures

Figure 1: Impact of increased substitutability (α) on indifference curves in a stylized Gorman–Lancaster model



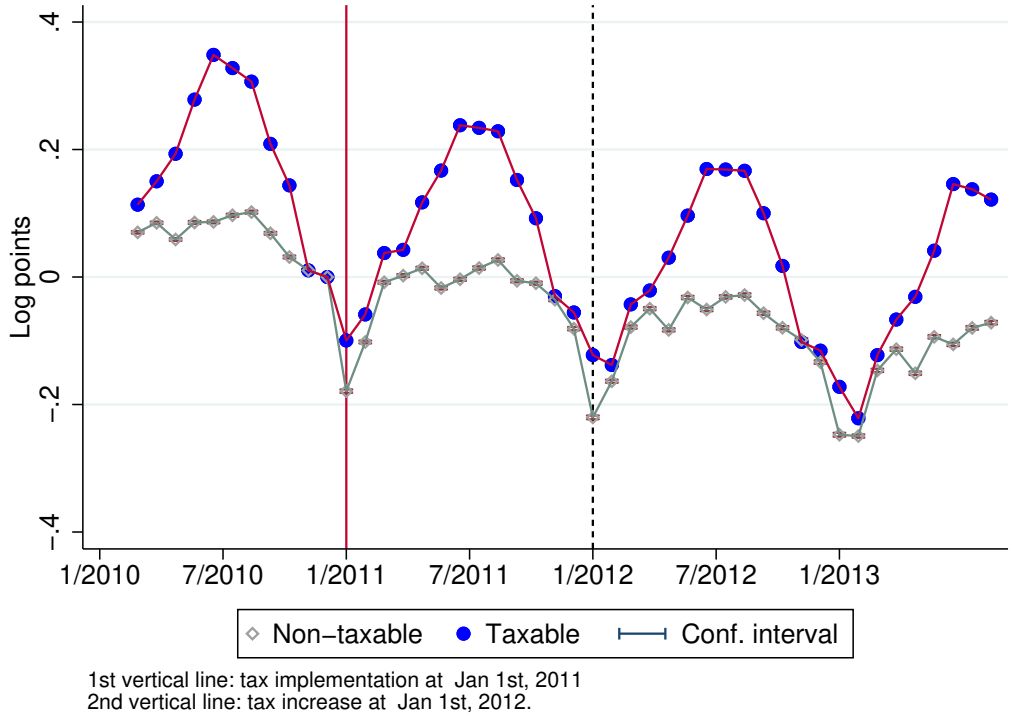
Note: The figure illustrates how increasing substitutability (labeled α) between goods in a stylized two-good Gorman–Lancaster model impacts the indifference curves between the two goods. This is measured by how similar the characteristics vectors of the goods are as outlined in section 2, so that when $\alpha = 0$, the goods are not substitutable at all, and when $\alpha = 1$, the goods are perfect substitutes. The impact of a small increase in substitutability ($\Delta\alpha$) on the curvature of the indifference curve is dependent on the original level of substitutability between the goods. In the left panel of the figure we have a situation with low original substitutability between the two goods (low α) whereas in the right panel, we have a situation with high original substitutability between the two goods (high α). The increase in substitutability by $\Delta\alpha$ moves the indifference curves from the black indifference curve to the red one in both panels. If we consider a tax change and the resulting change in the consumption bundle either from x_0 to x_1 (without $\Delta\alpha$) or from x_0 to $x_1(\Delta\alpha)$ (with $\Delta\alpha$), we can see, that when the goods are close substitutes to begin with (right panel), the impact is of the slight increase in substitutability ($\Delta\alpha$) induces a much larger change in the response to the tax change than when the goods are not close substitutes (left panel). This implies a nonlinear, convex relationship between demand elasticities and substitutability between the two goods, as outlined in figure 2.

Figure 2: Demand elasticity as a function of substitutability to the other good in a stylized two-good Gorman-Lancaster model



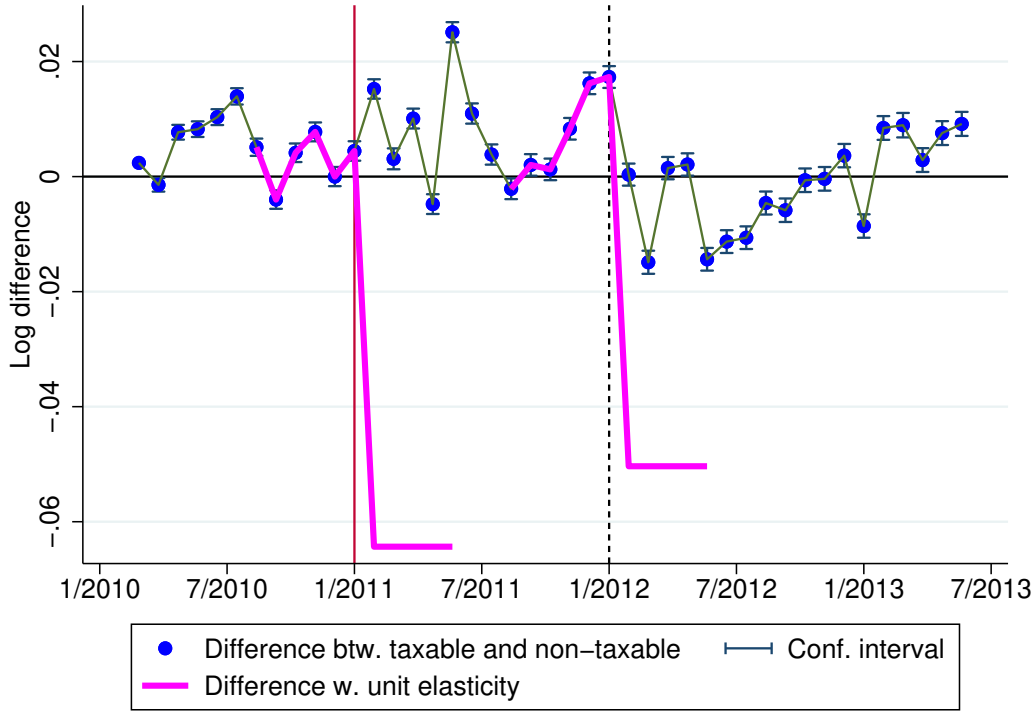
Note: The figure shows the (compensated) own-price demand elasticity of a good in a two-good, two-characteristics Gorman-Lancaster model as a function of how substitutable the goods are with each other. This is measured by how similar the characteristics vectors of the goods are as outlined in section 2, so that when $\alpha = 0$, the goods are not substitutable at all, and when $\alpha = 1$, the goods are perfect substitutes. Based on this stylized model, we would expect to find a convex relationship between substitutability and demand elasticities. This could potentially explain some of the large variation in elasticity estimates in different studies examining seemingly similar situations and goods.

Figure 3: Development of unseasonalized quantities, solid products in the 2011 and 2012 reforms



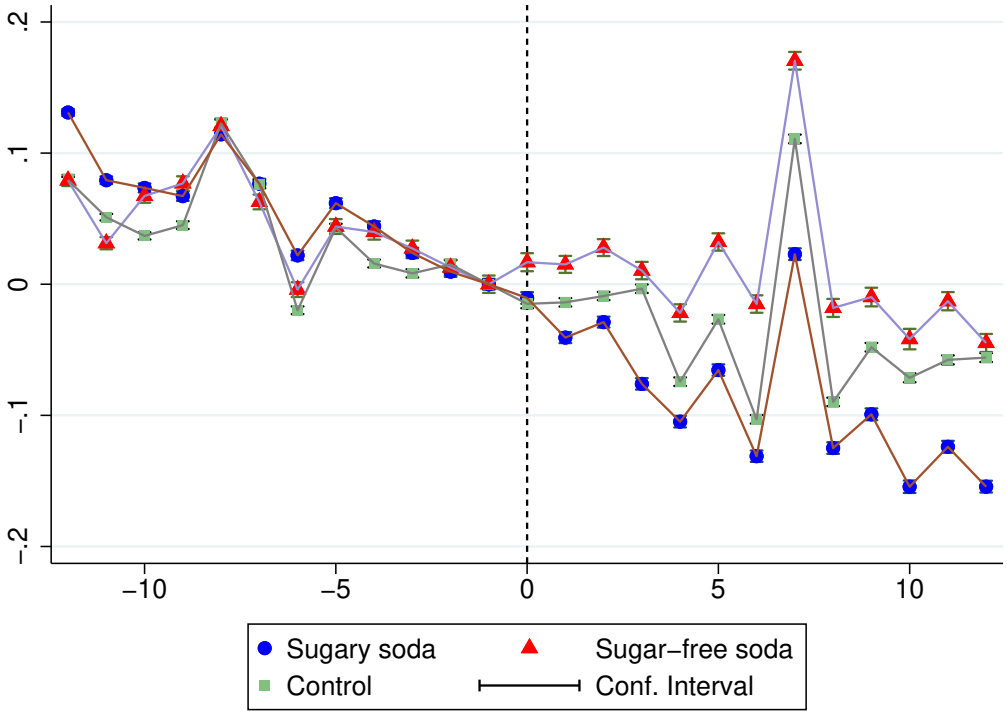
Note: The figure shows regression coefficients for month dummies from regressions of log number of products sold with product-outlet fixed effects (estimates of equation (3)). Taxable products include all solid taxable products in the 2011 and 2012 reforms: mainly sweets, chocolate and ice cream. Non-taxable products include solid products that were not included in the 2011 and 2012 reforms: mainly cookies, sweet and savoury pastry, pudding and yogurt. The figure includes 95% confidence intervals surrounding the coefficients based on standard errors that are clustered at the product-outlet level. Vertical lines indicate the 2011 sweets tax introduction and the 2012 tax increase. The series are normalized to zero at the last week prior to the 2011 reform.

Figure 4: Development of seasonalized quantities, solid products in the 2011 and 2012 reforms



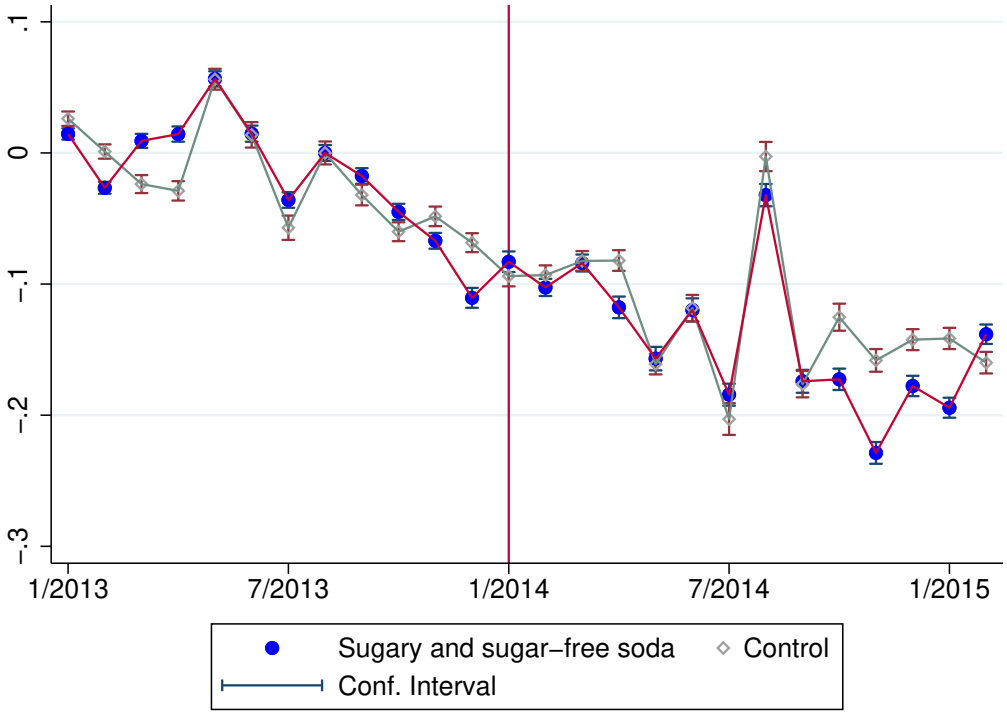
Note: The figure shows regression coefficients for month dummies from regressions of log number of products sold with product-outlet fixed effects (estimates of equation (3)). Taxable products include all solid taxable products in the 2011 and 2012 reforms: mainly sweets, chocolate and ice cream. Non-taxable products include solid products that were not included in the 2011 and 2012 reforms: mainly cookies, sweet and savoury pastry, pudding and yogurt. The figure includes 95% confidence intervals surrounding the coefficients based on standard errors that are clustered at the product-outlet level. Change with unit elasticity in solid pink line shows how sold quantities of the taxable products would have developed with unit elasticity, had they otherwise followed the quantities of non-taxable products post-reform. Vertical lines indicate the 2011 sweets tax introduction and the 2012 tax increase. The series are normalized to zero at the last week prior to the 2011 reform and are seasonally corrected.

Figure 5: Development of sugary vs sugar-free soda vs common control group sales in the 2014 reform



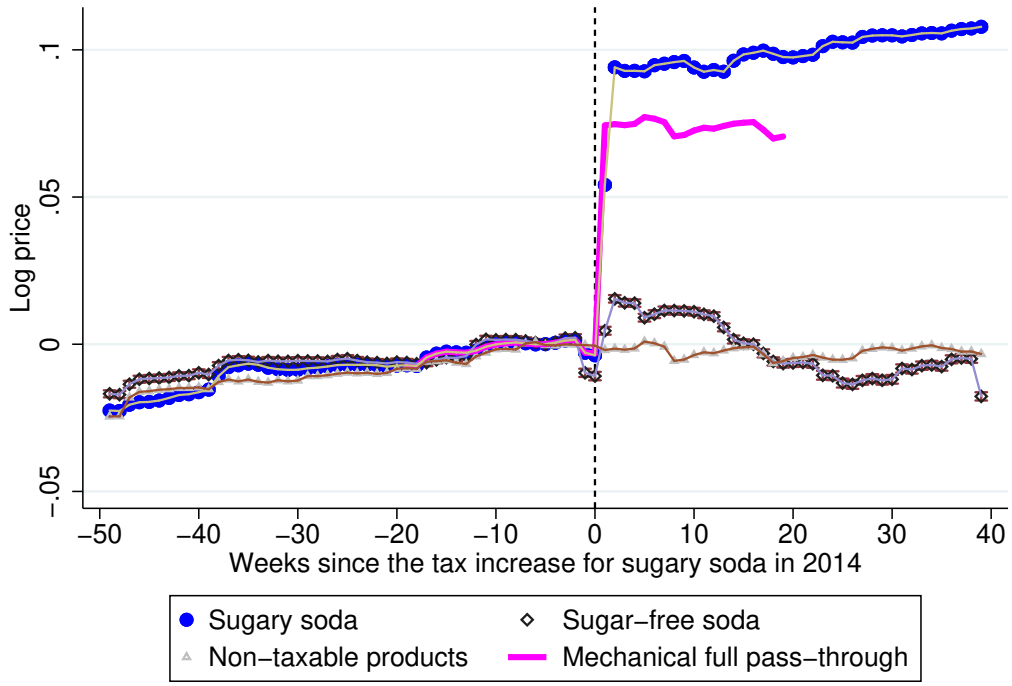
Note: The figure shows regression coefficients for month dummies from regressions of log volume of products sold with product-outlet fixed effects (estimates of equation (3)) for sugary (subject to reform) and sugar-free soda (not subject to reform) and a control group of ice-cream (not subject to reform). The figure includes 95% confidence intervals surrounding the coefficients based on standard errors that are clustered at the product-outlet level. Vertical line is at the 2014 reform. The series are normalized to zero at two months prior to 2014 reform. The control group consists of ice-creams, which did not face a tax change in 2014.

Figure 6: Development of total soda sales in the 2014 reform



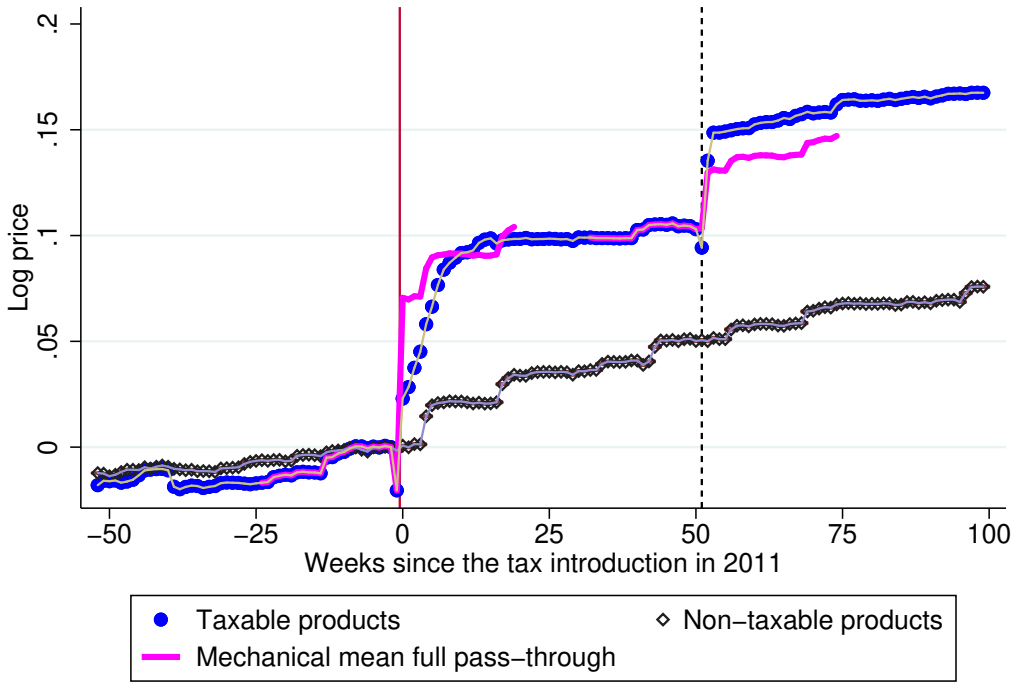
Note: The figure shows regression coefficients for month dummies from regressions of log volume of products sold with product-outlet fixed effects (estimates of equation (3)). The observations have been weighted by total volumes sold of each product at each outlet in 2013, so that the estimates approximately correspond to the development of log total volumes. The figure includes 95% confidence intervals surrounding the coefficients based on standard errors that are clustered at the product-outlet level. Vertical line is at the 2014 reform. The series are normalized to zero at five months prior to 2014 reform. The control group consists of ice-creams, which did not face a tax change in 2014.

Figure 7: Development of log soda price by sugar content and comparison prices in the 2014 reform



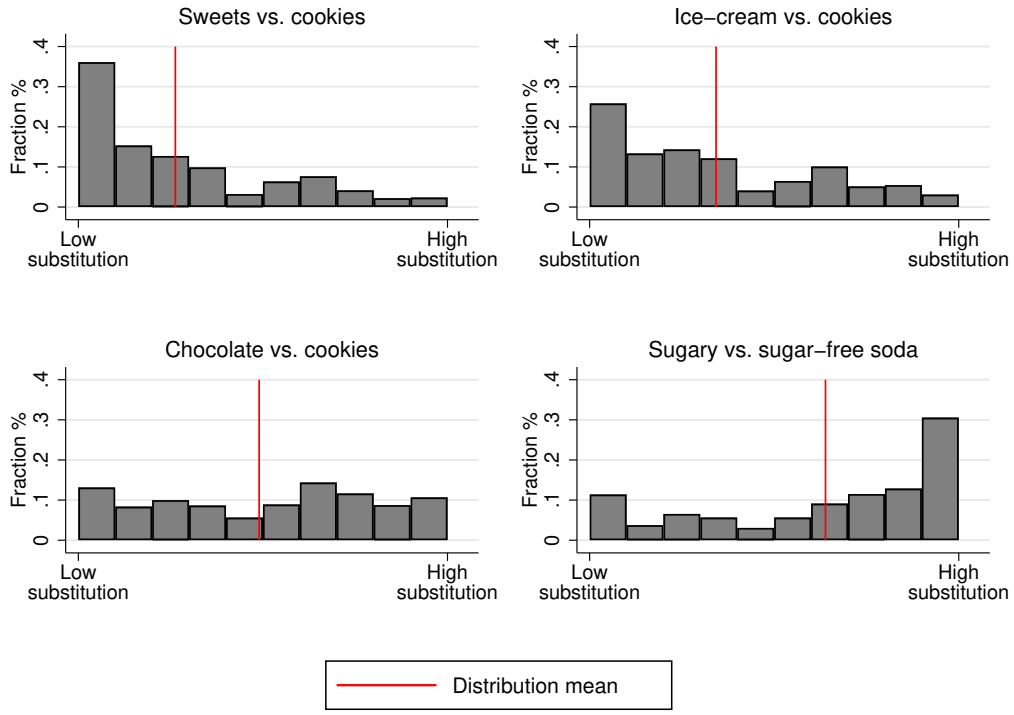
Note: The figure shows regression coefficients for week dummies from regressions of log volume-based prices with product-outlet fixed effects (estimates of equation (3)) for sugary (subject to reform) and sugar-free soda (not subject to reform) and a comparison group of non-taxable products. Non-taxable products include solid products that were not included in the 2017 reform: mainly cookies, sweet and savoury pastry, sweeteners, yogurt, and pudding. The figure includes 95% confidence intervals surrounding the coefficients based on standard errors that are clustered at the product-outlet level. Mechanical full pass-through in solid pink line shows how sugary soda prices would have developed with full pass-through of tax to prices, had they otherwise followed the prices of the comparison group post-reform. Vertical line is at the 2014 tax reform. The series are normalized to zero at three weeks prior to the 2014 reform.

Figure 8: Development of log unit prices in the 2011 and 2012 reforms



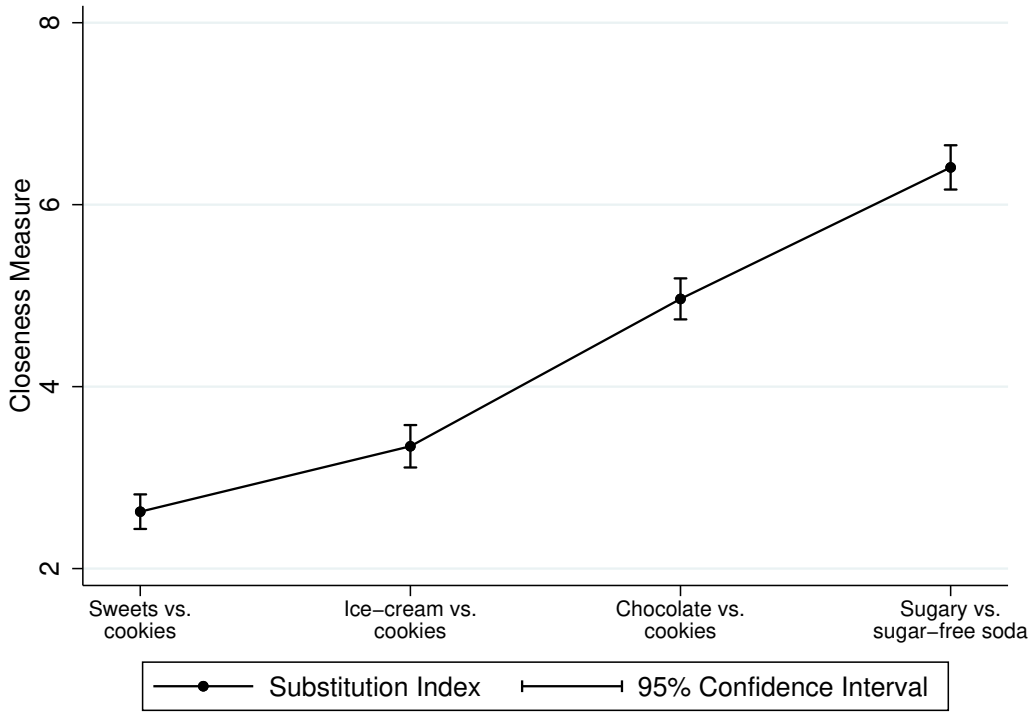
Note: The figure shows regression coefficients for week dummies from regressions of log unit prices with product-outlet fixed effects (estimates of equation (3)). Taxable products include all taxable products in the 2011 and 2012 reforms: mainly sweets, chocolate, ice cream and both sugary and sugar free soft drinks. Non-taxable products include all products in our data that were not included in the 2011 and 2012 reforms: mainly cookies, sweet and savoury pastry, sweeteners, yogurt and pudding. The figure includes 95% confidence intervals surrounding the coefficients based on standard errors that are clustered at the product-outlet level. Mechanical full pass-through in solid pink line shows how taxable product prices would have developed with full pass-through of tax change to prices, had they otherwise followed the prices of non-taxable products post-reform. Vertical lines at the 2011 and 2012 reforms. The series are normalized to zero at two weeks prior to the 2011 reform.

Figure 9: Distributions of substitution preferences



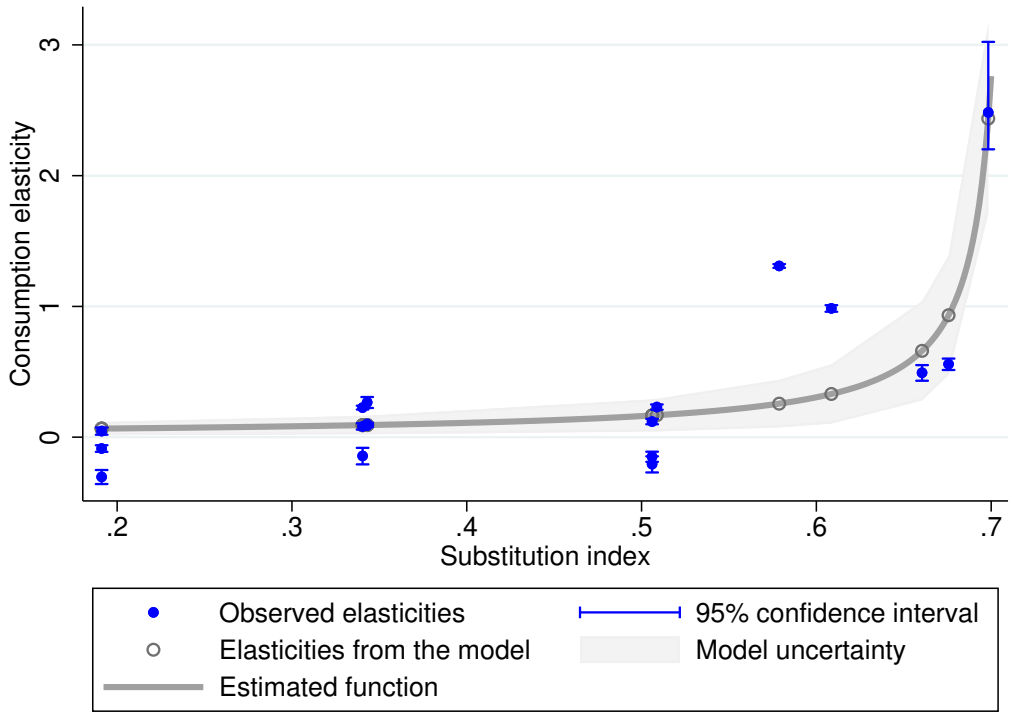
Note: The figure shows distributions of the answers to the survey question "On a scale from 0 to 10, how substitutable are these products for you?" for taxed product categories compared to their closest non-tax category. The closest non-tax category is chosen by the same index. The more the distribution is located to the right, the more substitutable the respondents have viewed the categories to be.

Figure 10: Means of substitution preferences



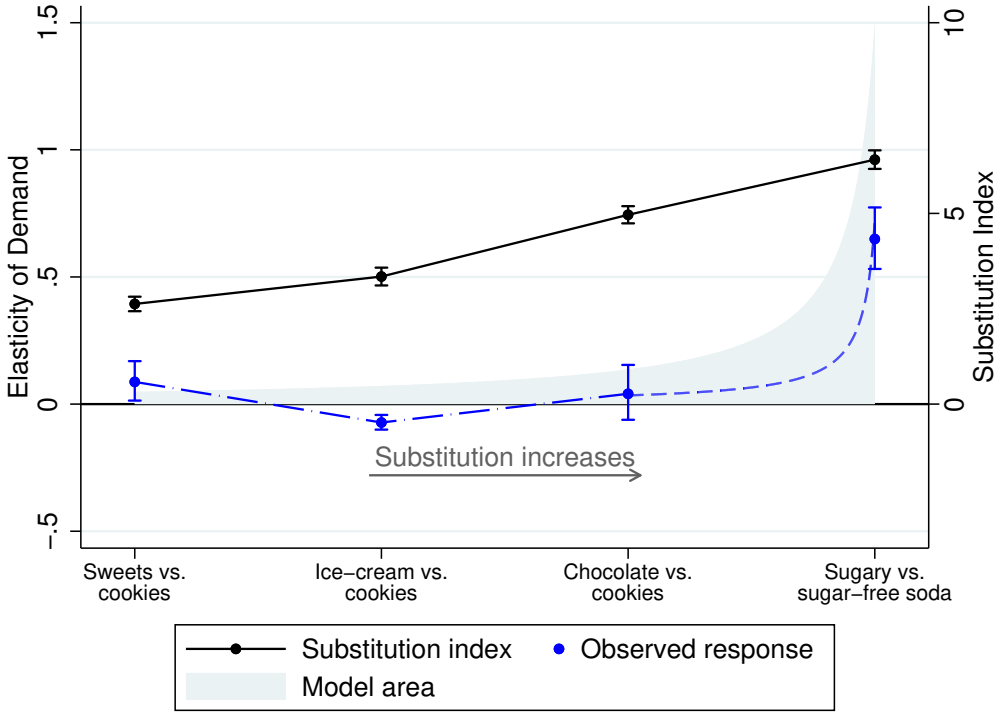
Note: The figure shows mean values of the answers to the survey question "On a scale from 0 to 10, how substitutable are these products for you?" for taxed product categories compared to their closest low-tax category. The closest low-tax category is chosen by the same index. The higher the value of the index, the more substitutable the respondents have viewed the categories to be. 95% confidence intervals are also included.

Figure 11: Fitted values of the model



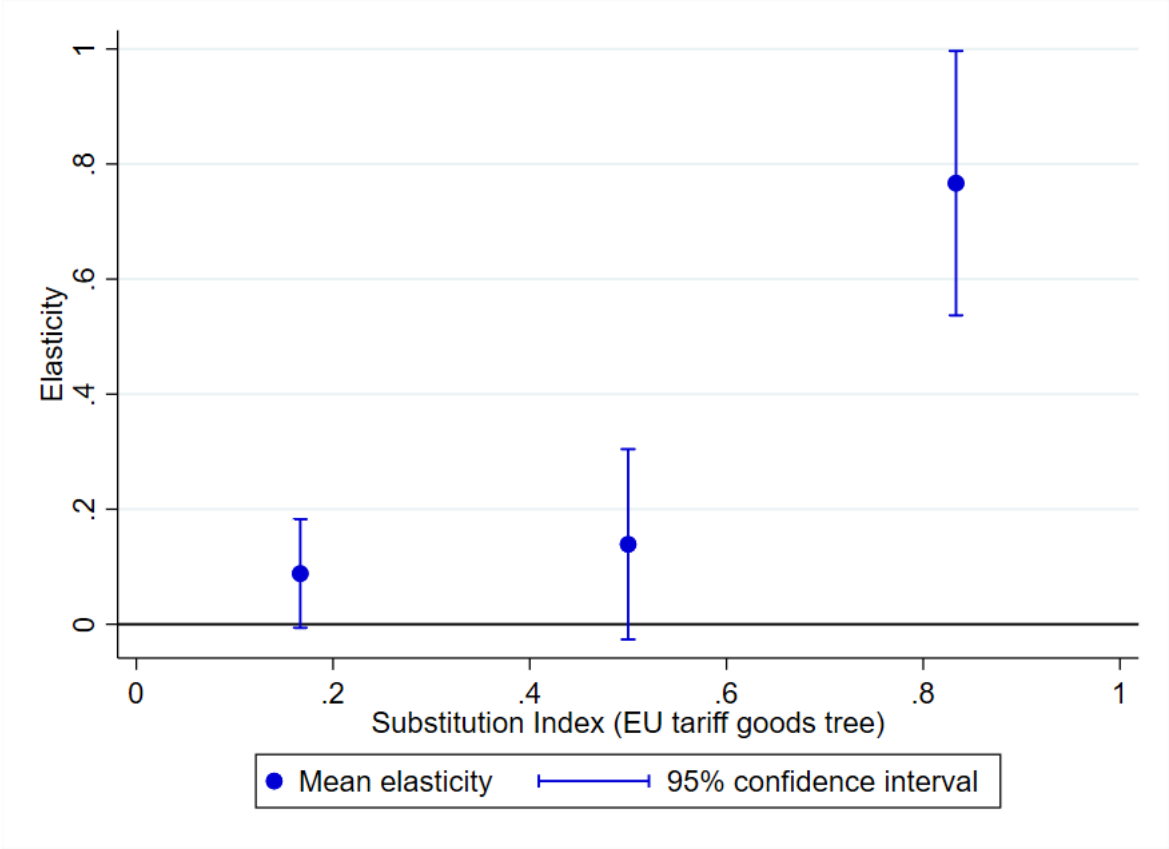
Note: The figure shows subgroup level estimates of demand elasticities and fitted values from an empirically applicable version of our model.

Figure 12: Main results combined



The figure collects main results of the sweets tax reforms: elasticity estimates at four subgroups in blue (sweets, ice-cream, chocolate, and sugary soda), with their related substitution indices in versus their closest substitute categories based on survey evidence (cookise, cookise, cookies, and sugar free soda, respectively). The light blue area give a rough indication of where our stylized model would predict the elasticities to lie in.

Figure 13: Elasticities from the literature versus the substitution index from the EU tariff goods tree



Note: This figure plots mean elasticities from previous literature in three categories, where these categories are based on the distance to a closest substitute with no price changes based on the EU tariff goods tree. This distance is then formed into a substitution index with values between 0 (not substitutable at all) and 1 (complete substitute, i.e. same good) (see section 6 for details on how the substitution index is formed).

Tables

Table 1: Descriptive statistics by tax status

				Prices		
	Stat	Price	Pieces	Sweets	Ice	Drinks
Tax	Mean	1.89	11.73	1.86	2.62	1.99
	SD	1.31	28.75	1.51	1.57	1.12
	N	2.22e+08	2.22e+08	5.42e+07	3.74e+07	2.68e+07
	N*pieces	2.60e+09	2.60e+09	6.37e+08	3.17e+08	3.85e+08
	Products*stores	2.29e+06	2.29e+06			
Non-taxed	Mean	2.64	9.90			
	SD	2.21	57.99			
	N	9.04e+07	9.04e+07			
	N*pieces	8.95e+08	8.95e+08			
	Products*stores	1.01e+06	1.01e+06			

Note: The table shows descriptive statistics for our main data. Prices are in euros and Pieces are number of sold products per week. Tax refers to the to tax liable products, non-tax refers to non-taxed products in our data. The statistics are for the whole data. Mean indicates the average and SD the standard deviation. N refers to total number of observations in weekly level data. N*pieces refers to the total number of sold products are behind the data by multiplying the number of observations with the number of times the products are sold per week. Products*stores refers to the number of different products multiplied by number of different outlets in our data.

Table 2: Difference-in-difference estimates for the 2011 tax introduction and 2012 tax increase on sold quantities

	(1)	(2)	(3)
VARs	All	All	Sweets
DiD	0.007***	-0.003	0.007*
	(0.002)	(0.002)	(0.003)
Tax dummy	-0.002		
	(0.002)		
N 1,000s	33,388	33,388	22,317
R^2	0.012	0.134	0.137
Product fe		X	X

Note: The table shows regression coefficients for DiD indicators of the 2011 and 2012 tax reforms by having 2010 as the pre-period and 2011-2013 as the post period from regressions of log unit prices with product-outlet and four-week ("month") fixed effects (estimates of equation (4)). The non-taxed group in the regressions consists of all the untaxed solid products (mainly cookies and pastries). Standard errors are clustered at the product-outlet level. *** p¡0.01, ** p¡0.05, * p¡0.1

Table 3: Difference-in-difference estimates for the 2014 tax increase on sold quantities

	(1)	(2)	(3)	(4)	(5)	(6)
		Drinks			Soda	
Dep. variable	All	Sugary	Sugar-free	All	Sugary	Sugar-free
DiD	-0.016***	-0.042***	0.053***	-0.041***	-0.073***	0.030***
	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
N	18,622,752	16,303,592	12,278,244	12,411,675	11,715,429	10,655,871
R^2	0.252	0.250	0.236	0.237	0.235	0.228
Product fe	X	X	X	X	X	X

The table shows regression coefficients for DiD indicators of the 2014 sweets tax increase for sugary drinks by having 2013 as the pre-period and 2014 as the post period from regressions of log number of products sold per month with product-outlet and four-week ("month") fixed effects (estimates of equation (4)). The treatment group in column (1) is all drinks, in column (2) sugary drinks, in column (3) sugar-free drinks, in column (4) all soda, in column (5) sugary soda and in column (6) sugar-free soda. The comparison group includes non-taxed solids as well as sweets and ice cream which did not experience any tax changes in 2014. Standard errors are clustered at the product-outlet level. *** p¡0.01, ** p¡0.05, * p¡0.1

Table 4: Difference-in-difference estimates for the 2011 tax introduction: prices

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Sample	All	All	Kg	Sweets	Chocolate	Ice cream	Soda
DiD	0.077***	0.072***	0.083***	0.067***	0.060***	0.137***	0.043***
	(0.003)	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)
Tax dummy	-0.492***						
	(0.008)						
Full pass-thr.		0.062	0.087	0.064	0.067	0.150	0.025
N	96,952,759	96,952,759	68,413,067	43,200,452	33,741,918	37,331,691	33,605,331
R^2	0.091	0.992	0.993	0.994	0.996	0.990	0.994
Product fe		X	X	X	X	X	X

Note: The table shows regression coefficients for DiD indicators of the 2011 tax reform from regressions of log unit prices with product-outlet and week fixed effects (estimates of equation (4)). The volume price is kg/l based. The non-taxed group in the regressions consists of all the untaxed products (mainly cookies and pastries). The regressions include only the observations from 2010 and 2011. Standard errors are clustered at the product-outlet level. *** p¡0.01, ** p¡0.05, * p¡0.1

Table 5: Difference-in-difference estimates for the 2012 tax increase: prices

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Vars	All	All	Kg	Sweets	Chocolate	Ice cream	Soda
DiD	0.045***	0.047***	0.042***	0.041***	0.039***	0.034***	0.058***
	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)
Tax dummy	-0.411***						
	(0.007)						
Full pass-thr.		0.023	0.020	0.015	0.015	0.033	0.021
N	93,736,671	93,736,671	65,322,911	40,699,710	32,395,559	35,392,988	32,222,605
R^2	0.067	0.994	0.995	0.996	0.997	0.992	0.995
Product fe		X	X	X	X	X	X

Note: The table shows regression coefficients for DiD indicators of the 2012 tax reform from regressions of log unit prices with product-outlet and week fixed effects (estimates of equation (4)). The volume price is kg/l based. The estimates are very close for item prices. The non-taxed group in the regressions consists of all the untaxed products (mainly cookies and pastries) as all the products belonging to the respective categories are tax-liable. The regressions include only the observations from 2011 and 2012. Standard errors are clustered at the product-outlet level. *** p¡0.01, ** p¡0.05, * p¡0.1

Table 6: Difference-in-difference estimates for the 2014 tax increase for sugary drinks on prices

Dep. variable	(1) Sugary drink	(2) Sugar-free drink	(3) Sugary soda	(4) Sugar-free soda
DiD	0.097***	-0.010***	0.075***	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Full pass-through	0.081	-	0.074	-
N	51,588,608	36,457,156	34,236,966	30,107,380
R^2	0.992	0.992	0.991	0.992
Product fe	X	X	X	X

The table shows regression coefficients for DiD indicators of the 2014 sweets tax increase for sugary drinks by having 2013 as the pre-period and 2014 as the post period from regressions of log unit prices with product-outlet and week fixed effects (estimates of equation (4)). The taxed group in columns (1) and (2) are all sugary drinks and in columns (3) and (4) sugary soda. The comparison group includes non-taxed solids as well as sweets and ice cream which did not experience any tax changes in 2014. Standard errors are clustered at the product-outlet level. *** p¡0.01, ** p¡0.05, * p¡0.1

Table 7: Elasticity estimates based on difference-in-differences results for prices and quantities sold

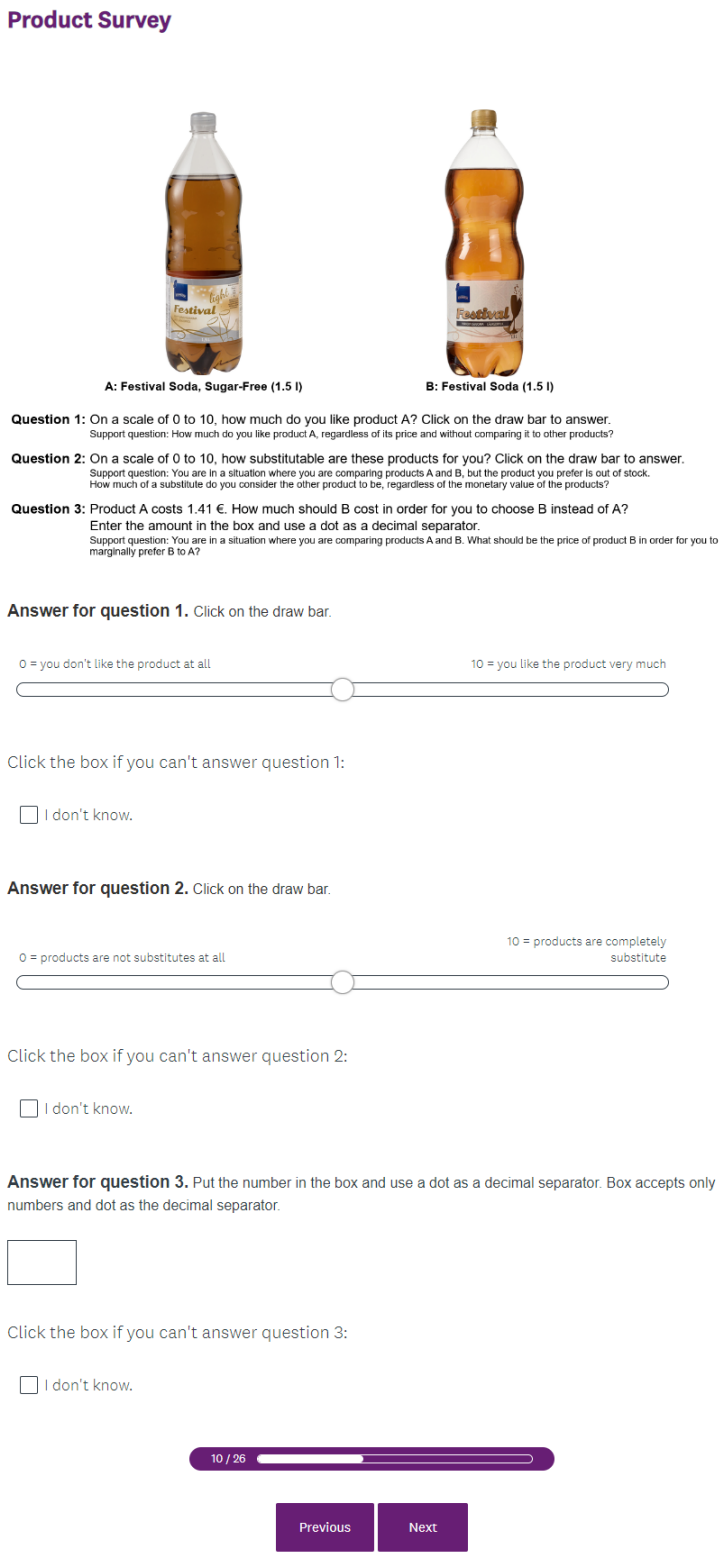
	(1)	(2)	(3)	(4)
	Sweets	Ice-cream	Chocolate	Sugary soda
Price change %	12.945	16.816	8.190	9.176
	(0.047)	(0.081)	(0.062)	(0.081)
Quantity change %	2.136	3.003	1.957	9.038
	(0.332)	(0.238)	(0.184)	(0.394)
Elasticity	**0.083**	**0.089**	**0.119**	**0.985**

Note: The table shows regression coefficients for DiD indicators of the 2014 sweets tax increase for sugary drinks by having 2013 as the pre-period and 2014 as the post period from regressions of log unit prices with product-outlet and week fixed effects (estimates of equation (4)). The taxed group in columns (1) and (2) are all sugary drinks and in columns (3) and (4) sugary soda. The comparison group includes non-taxed solids as well as sweets and ice cream which did not experience any tax changes in 2014. Standard errors are clustered at the product-outlet level.

The table collects price and quantity difference-in-differences estimates for four subgroups of products and calculate elasticities based on these (quantity change point estimate divided by the price change point estimate). Estimates for sweets, ice-cream and chocolate combine 2011 and 2012 reforms, using 2010 as the pre-period and 2012 as the post-period. Estimates for sugary soda uses the 2014 reform with 2013 as the pre-period and 2014 as the post-period. The comparison groups are cookies for sweets, ice-cream and chocolate, and ice-cream for sugary soda.

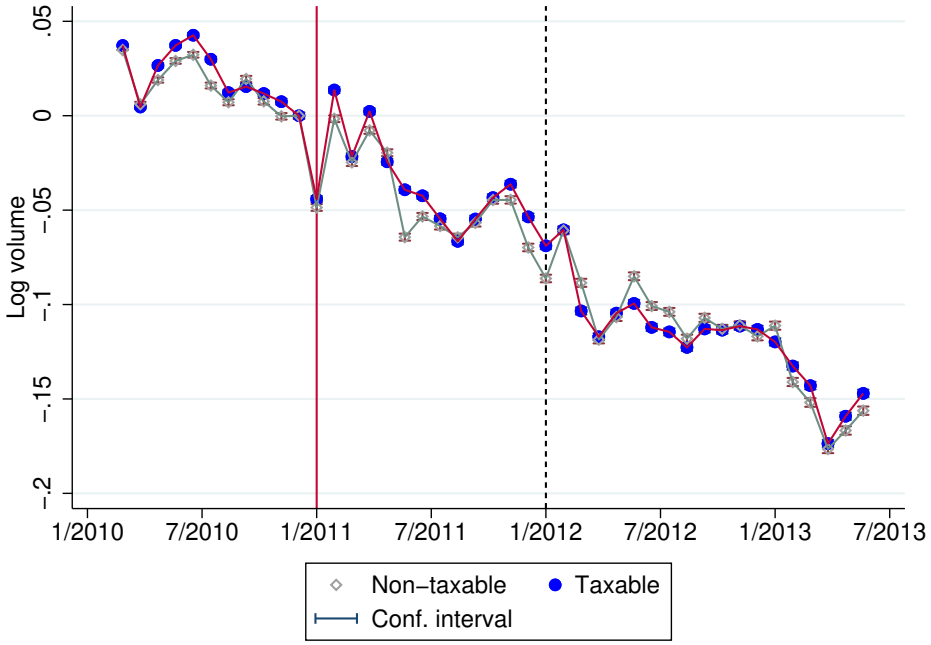
A APPENDIX

Figure A.1: Example of the substitution survey



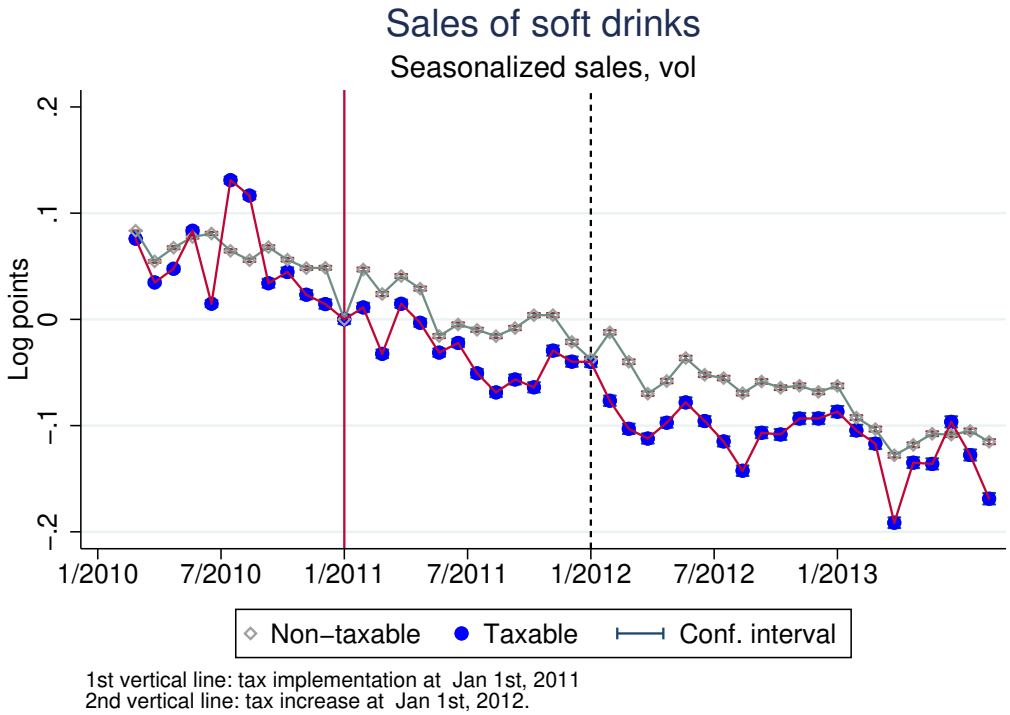
B APPENDIX - Additional figures and tables

Figure A.2: Development of seasonalized quantities, solid products in the 2011 and 2012 reforms



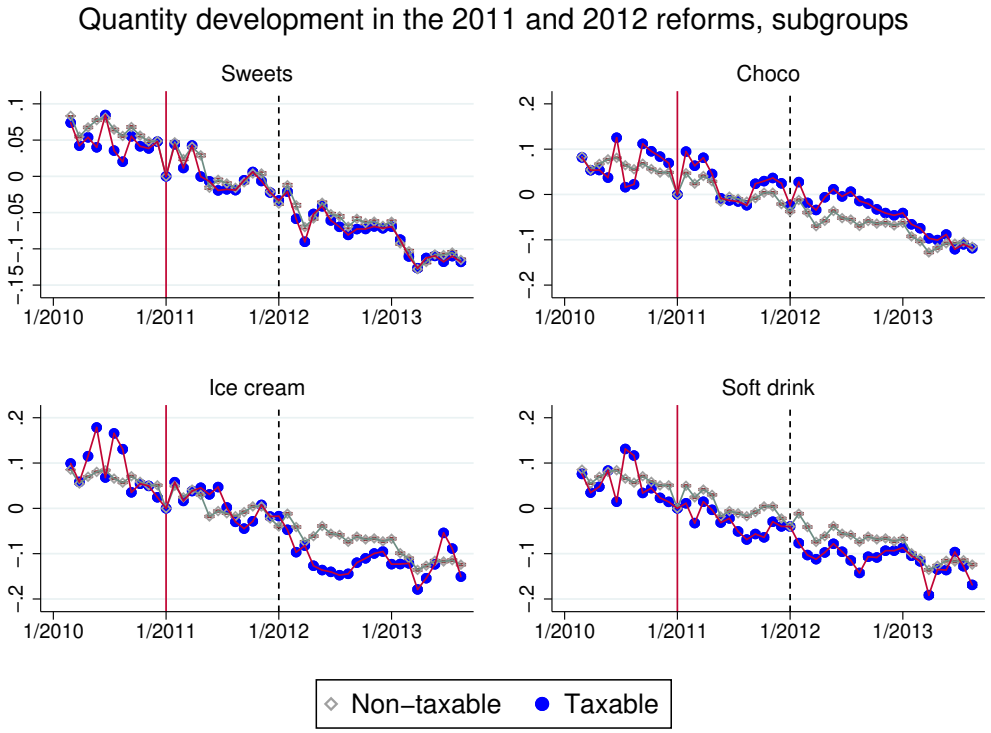
Note: The figure shows regression coefficients for month dummies from regressions of log number of products sold with product-outlet fixed effects (estimates of equation (3)). Taxable products include all solid taxable products in the 2011 and 2012 reforms: mainly sweets, chocolate and ice cream. Non-taxable products include solid products that were not included in the 2011 and 2012 reforms: mainly cookies, sweet and savoury pastry, pudding and yogurt. The figure includes 95% confidence intervals surrounding the coefficients based on standard errors that are clustered at the product-outlet level. Change with unit elasticity in solid pink line shows how sold quantities of the taxable products would have developed with unit elasticity, had they otherwise followed the quantities of non-taxable products post-reform. Vertical lines indicate the 2011 sweets tax introduction and the 2012 tax increase. The series are normalized to zero at the last week prior to the 2011 reform and are seasonally corrected.

Figure A.3: Development of sold volumes, soft drinks in the 2011 and 2012 reforms



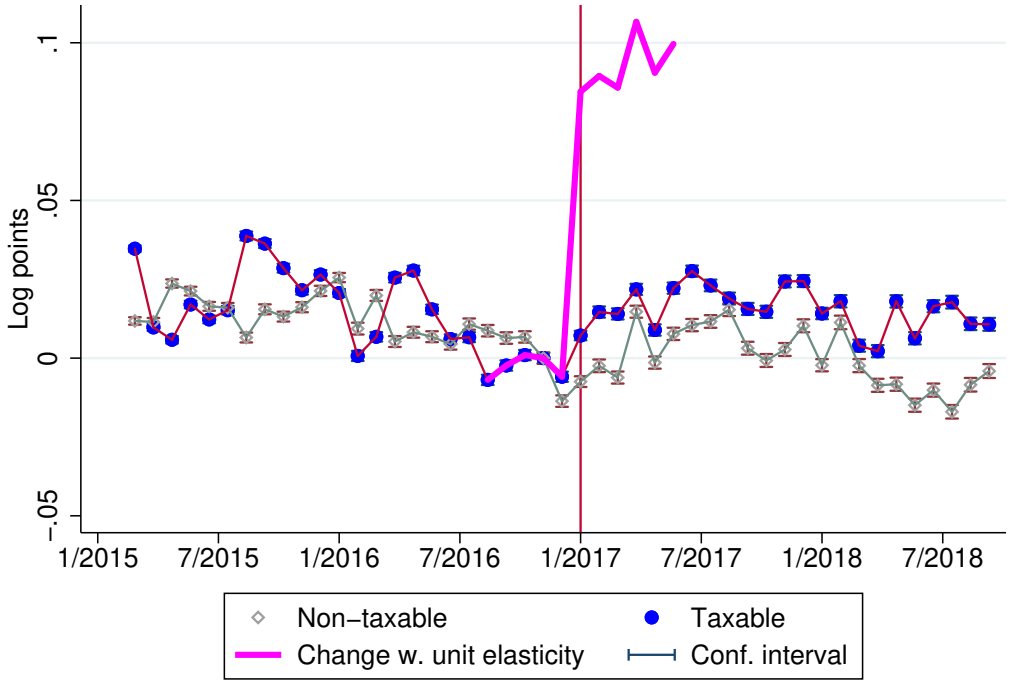
Note: The figure shows regression coefficients for month dummies from regressions of log volume of products sold with product-outlet fixed effects (estimates of equation (3)). Taxable products include soft drinks. Non-taxable products include solid products that were not included in the 2011 and 2012 reforms: mainly cookies, sweet and savoury pastry, pudding and yogurt. The figure includes 95% confidence intervals surrounding the coefficients based on standard errors that are clustered at the product-outlet level. Vertical lines indicate the 2011 sweets tax introduction and the 2012 tax increase. The series are normalized to zero at the last month prior to the 2011 reform.

Figure A.4: Development of quantities, various sub-categories of taxable products in the 2011 and 2012 reforms



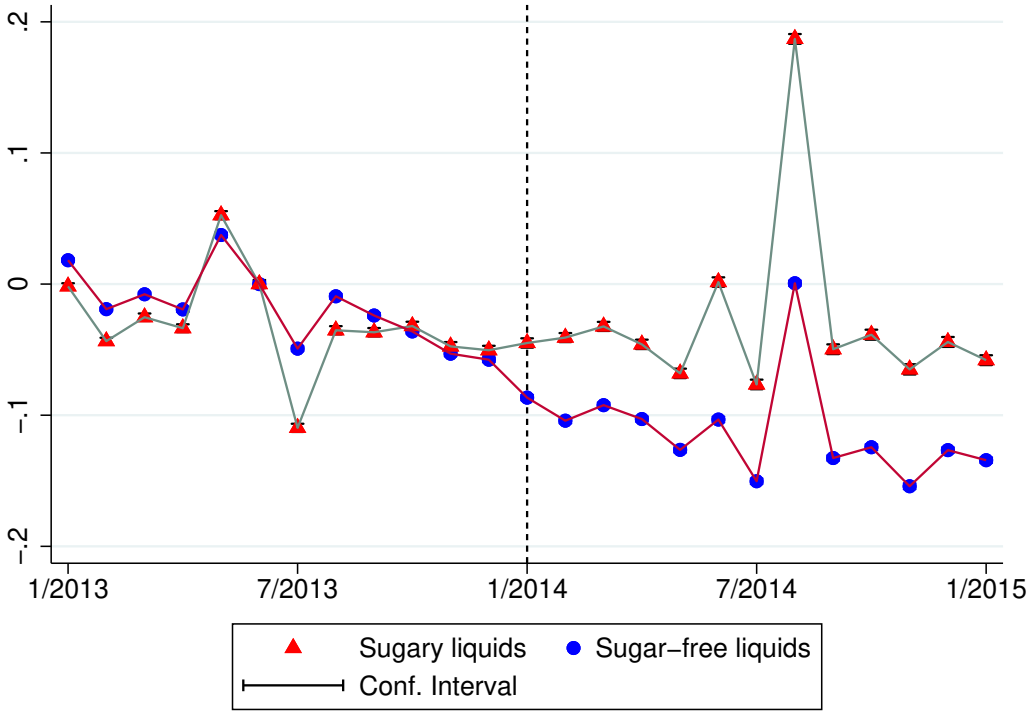
Note: The figure shows regression coefficients for month dummies from regressions of log volume of products sold with product-outlet fixed effects (estimates of equation (3)). Taxable products include sweets, chocolate, ice cream, and soft drinks, respectively. Non-taxable products include solid products that were not included in the 2011 and 2012 reforms: mainly cookies, sweet and savoury pastry, pudding and yogurt. The figure includes 95% confidence intervals surrounding the coefficients based on standard errors that are clustered at the product-outlet level. Vertical lines indicate the 2011 sweets tax introduction and the 2012 tax increase. The series are normalized to zero at the last month prior to the 2011 reform.

Figure A.5: Development of quantities in the 2017 reform



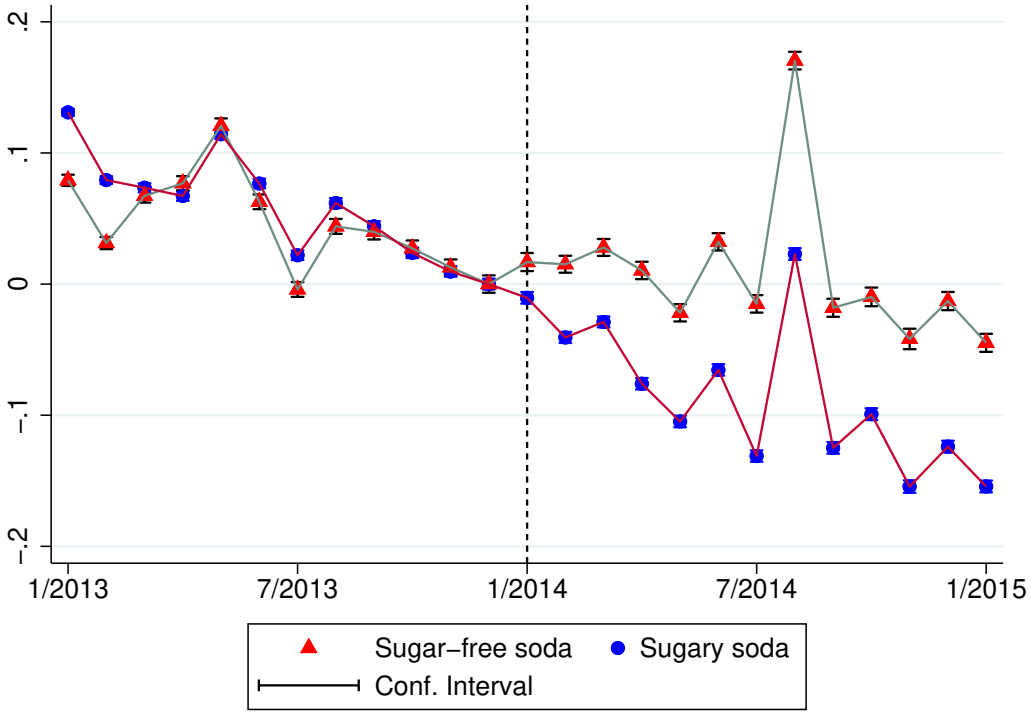
Note: The figure shows regression coefficients for month dummies from regressions of log number of products sold with product-outlet fixed effects (estimates of equation (3)). Taxable products include all taxable products in the 2017 tax removal: mainly sweets, chocolate and ice cream, but no liquids. Non-taxable products include most solid products that were not included in the 2017 reform: mainly cookies, sweet and savoury pastry, yogurt, and pudding. The figure includes 95% confidence intervals surrounding the coefficients based on standard errors that are clustered at the product-outlet level. Change with unit elasticity in solid pink line shows how sold quantities of the taxable products would have developed with unit elasticity, had they otherwise followed the quantities of non-taxable products post-reform. Vertical line is at the 2017 tax abolishment. The series are normalized to zero at two months prior to the 2017 reform.

Figure A.6: Development of sugary vs sugar-free liquids sales in the 2014 reform



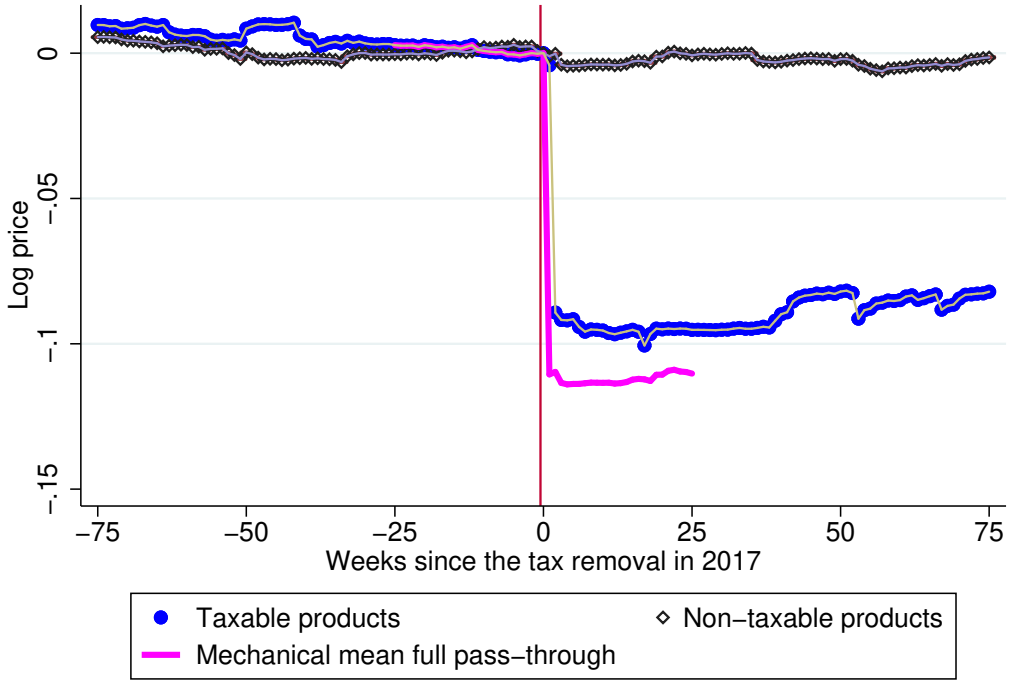
Note: The figure shows regression coefficients for month dummies from regressions of log volume of products sold with product-outlet fixed effects (estimates of equation (3)) for sugary (subject to reform) and sugar-free liquids (not subject to reform). The figure includes 95% confidence intervals surrounding the coefficients based on standard errors that are clustered at the product-outlet level. Vertical line is at the 2014 reform. The series are normalized to zero at seven months prior to the 2014 reform.

Figure A.7: Development of sugary vs sugar-free soda sales in the 2014 reform



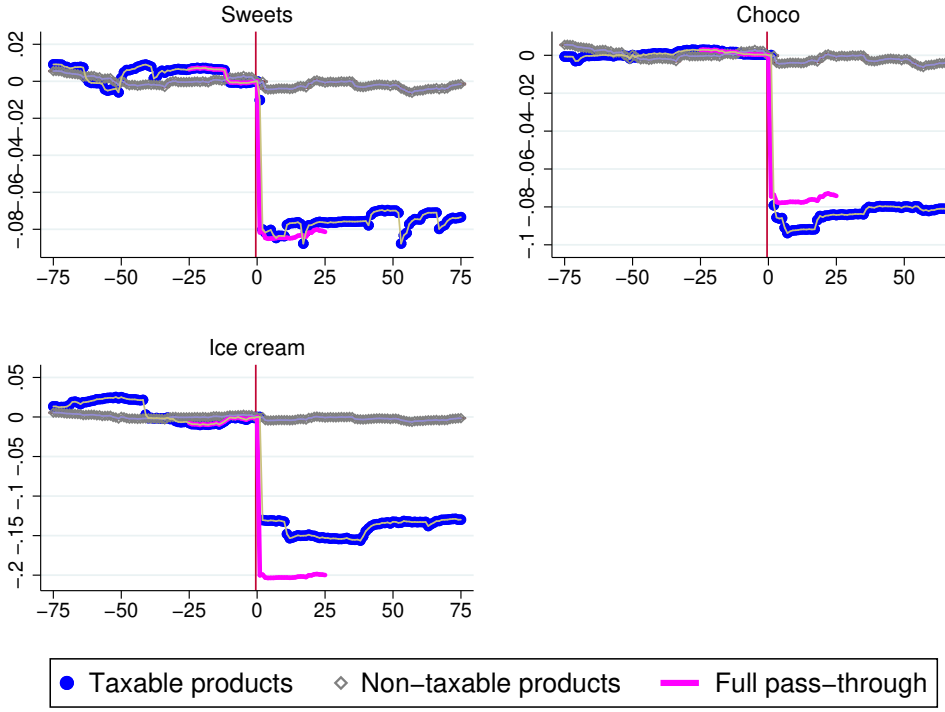
Note: The figure shows regression coefficients for month dummies from regressions of log volume of products sold with product-outlet fixed effects (estimates of equation (3)) for sugary (subject to reform) and sugar-free soda (not subject to reform). The figure includes 95% confidence intervals surrounding the coefficients based on standard errors that are clustered at the product-outlet level. Vertical line is at the 2014 reform. The series are normalized to zero at two months prior to the 2014 reform.

Figure A.8: Development of log unit prices in the 2017 reform



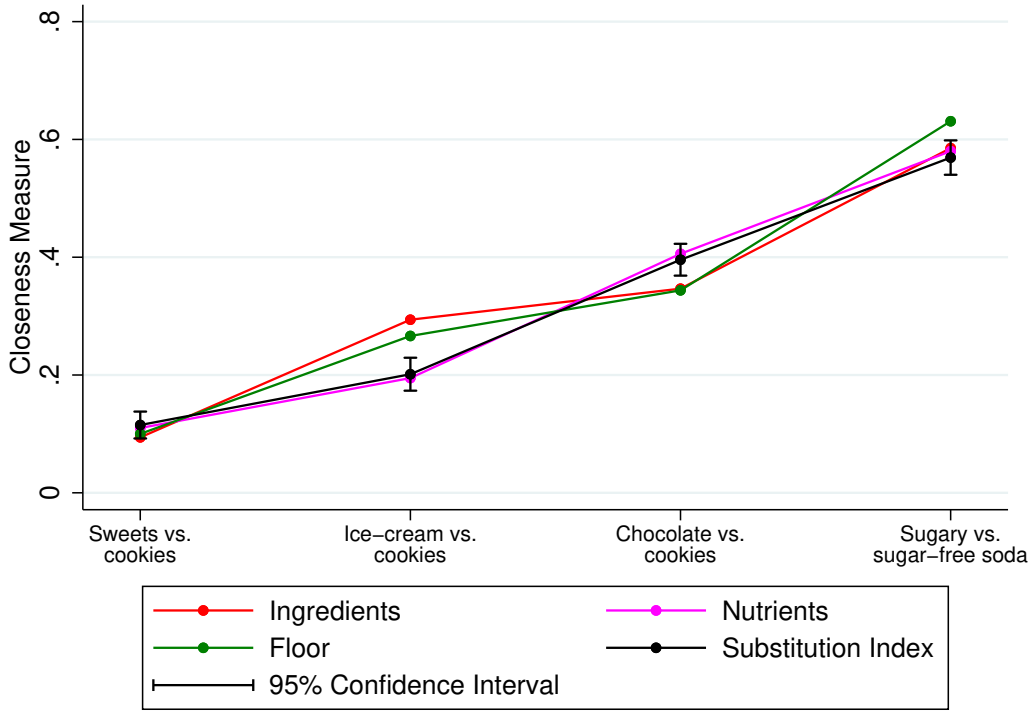
Note: The figure shows regression coefficients for week dummies from regressions of log unit prices with product-outlet fixed effects (estimates of equation (3)). Taxable products include all taxable products in the 2017 tax removal: mainly sweets, chocolate and ice cream, but no liquids. Non-taxable products include all products in our data that were not included in the 2017 reform: mainly cookies, sweet and savoury pastry, sweeteners, yogurt, pudding, and soft drinks. The figure includes 95% confidence intervals surrounding the coefficients based on standard errors that are clustered at the product-outlet level. Mechanical full pass-through in solid pink line shows how taxable product prices would have developed with full pass-through of tax to prices, had they otherwise followed the prices of non-taxable products post-reform. Vertical line is at the 2017 abolishment of the sweets tax. The series are normalized to zero at the last week prior to the 2017 reform.

Figure A.9: Development of log unit prices, various sub-categories of taxable products in the 2017 reform



Note: The figures show regression coefficients for week dummies from regressions of log unit prices with product-outlet fixed effects (estimates of equation (3)). Taxable products include sweets, chocolate and ice cream, respectively. Non-taxable products include all products in our data that were not included in the 2017 reform: mainly cookies, sweet and savoury pastry, sweeteners, yogurt, pudding, and soft drinks. The figure includes 95% confidence intervals surrounding the coefficients based on standard errors that are clustered at the product-outlet level. Mechanical full pass-through in solid pink line shows how taxable product prices would have developed with full pass-through of tax to prices, had they otherwise followed the prices of non-taxable products post-reform. Vertical lines is at the 2017 tax abolishment. The series are normalized to zero at one week prior to the 2017 reform.

Figure A.10: Alternative measures of similarity between taxed and closest non-taxed goods category



Note: The figure shows mean values of four similarity measures: the survey based substitution index and measures related to the ingredients, nutrient content and store floor location of products. The similarity measures are relative to the closest low-tax category for each product group. The closest low-tax category is chosen by the substitution index and is cookies for sweets, ice-cream and chocolate, and sugar-free soda for sugary soda. The higher the value of a measure, the more closer the categories are to their low-tax counterpart. 95% confidence intervals are also included for the substitution index.

Table A.1: Difference-in-difference estimates for the 2017 sweets tax abolishment : quantities

	(1)	(2)	(3)
VARs	No sweetener	All	Pastr.
DiD	0.011***	0.009***	-0.012*
	(0.002)	(0.002)	(0.007)
N	35,484,478	37,516,839	20,990,392
R^2	0.035	0.036	0.039

Note: The table shows regression coefficients for DiD indicators of the 2017 sweets tax abolishment for sweets and ice cream by having 2016 as the pre-period and 2017 as the post period from regressions of log unit prices with product-outlet and four-week ("month") fixed effects (estimates of equation (4)). The treatment group in all columns are tax liable solids. The control group for the regressions are: (1) non-taxed solids excl. sweeteners, (2) all non-taxed solids, (3) non-taxed sweet pastry. Observations are at the four-week ("month") level and time effects are controlled. Standard errors are clustered at the product-outlet level. *** p¡0.01, ** p¡0.05, * p¡0.1

C APPENDIX - Derivations for the general model

Consider a Gorman-Lancaster model (Gorman 1980, Lancaster 1966) where an agent derives utility from the characteristics of the goods she consumes, not from the goods themselves. Assume that there are n goods and $m \leq n$ characteristics. If there are more characteristics then goods, the characteristics representation is not feasible (Lancaster 1966). Moreover, note that the consumer will consume only m goods in equilibrium, so that we will proceed as if there were only m goods.

The utility function of the agent is then given by $u(c_1, c_2, ..., c_m) = u(c)$, where c is a vector of characteristics consumption. The vector is formed by consuming goods $x = (x_1, x_2, ..., x_m)'$ so that:

$$c = Cx,$$

where $C = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1m} \\ c_{21} & c_{22} & \cdots & c_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ c_{m1} & c_{m2} & \cdots & c_{mm} \end{bmatrix}$ is a $m \times m$ matrix, and c_{ij} is the characteristics coefficient of good j to characteristic i. Assuming that C is invertible[10], we have:

$$x = C^{-1}c. \tag{5}$$

As there is an equal number of goods and characteristics, there exists a one-to-one mapping between the characteristics space and the goods space. Hence, the problem of the consumer can be written as:

$$\max_c u(c) \, s.t. \, p'x = w,$$

where $p = (p_1, p_2, ..., p_m)'$ is a vector of product prices, and w is the level of income.

[10]This is equivalent to assuming that none of the characteristics vectors of the goods is a linear combination of the others, so that none of the goods are redundant.

Role of closeness

Consider a situation where good 2 moves closer to good 1 by moving on the budget surface in the characteristics space. This is achieved if the characteristics vector of good 2 becomes $(\alpha r c_{11} + (1-\alpha)c_{12}, ..., \alpha r c_{m1} + (1-\alpha)c_{m2})$ for some $\alpha \in [0, 1[$, and where $r = \frac{p_2}{p_1}$ is the price ratio of goods 2 and 1 before any price changes. We denote the new characteristics matrix in this situation by $C(\alpha)$. Note that $C = C(\alpha|\alpha = 0)$ is the original characteristics matrix.

Expression for $\frac{\partial x(\alpha)}{\partial \alpha}$

Notice also that the gradient of the budget surface in the characteristics space does not change when α changes. Hence, assuming the change does not result in a corner solution, we have $\frac{\partial c}{\partial \alpha} = 0$. As $c = C(\alpha)x(\alpha)$, we have that:

$$\frac{\partial C(\alpha)x(\alpha)}{\partial \alpha} = \frac{\partial C(\alpha)}{\partial \alpha}x(\alpha) + C(\alpha)\frac{\partial x(\alpha)}{\partial \alpha} = 0.$$

Re-arranging and pre-multiplying by $C(\alpha)^{-1}$, we have:

$$\frac{\partial x(\alpha)}{\partial \alpha} = -C(\alpha)^{-1}\frac{\partial C(\alpha)}{\partial \alpha}x(\alpha). \tag{6}$$

Note here that $\frac{\partial C(\alpha)}{\partial \alpha} = \begin{bmatrix} 0 & rc_{11} - c_{12} & 0 & \cdots & 0 \\ 0 & rc_{21} - c_{22} & 0 & \cdots & 0 \\ 0 & rc_{31} - c_{32} & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & 0 \\ 0 & rc_{m1} - c_{m2} & 0 & \cdots & 0 \end{bmatrix} = r[0_{m\times 1}, C_{(1)}(\alpha), 0_{m\times 1}, ..., 0_{m\times 1}] -$
$[0_{m\times 1}, C_{(2)}, 0_{m\times 1}, ..., 0_{m\times 1}]$ where $C_{(1)}(\alpha)$ is the first column of $C(\alpha)$ and $C_{(2)}$ is the second column of $C = C(\alpha|\alpha = 0)$. Hence, we have that:

$$\begin{aligned} C(\alpha)^{-1}\frac{\partial C(\alpha)}{\partial \alpha} = r[&C(\alpha)^{-1}0_{m\times 1}, C(\alpha)^{-1}C_{(1)}(\alpha), C(\alpha)^{-1}0_{m\times 1}, ..., C(\alpha)^{-1}0_{m\times 1}] \\ &- [C(\alpha)^{-1}0_{m\times 1}, C(\alpha)^{-1}C_{(2)}, C(\alpha)^{-1}0_{m\times 1}, ..., C(\alpha)^{-1}0_{m\times 1}]. \end{aligned}$$

So that, as $C(\alpha)^{-1}0_{m\times 1} = 0_{m\times 1}$ and $C(\alpha)^{-1}C_{(1)}(\alpha) = (1, 0, ..., 0)'$, we have:

$$C(\alpha)^{-1}\frac{\partial C(\alpha)}{\partial \alpha} = \begin{bmatrix} 0 & r & \cdots & 0 \\ 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \cdots & 0 \end{bmatrix} - [0_{m\times 1}, C(\alpha)^{-1}C_{(2)}, 0_{m\times 1}, ..., 0_{m\times 1}]. \tag{7}$$

Hence, we are left with the problem of finding a closed form expression for $C(\alpha)^{-1}C_{(2)}$. Notice that the second column of $C(\alpha)$ is $C_{(2)}(\alpha) = \alpha r C_{(1)}(\alpha) + (1-\alpha)C_{(2)}$, so that:

$$C(\alpha)^{-1}C_{(2)}(\alpha) = \alpha r C(\alpha)^{-1}C_{(1)}(\alpha) + (1-\alpha)C(\alpha)^{-1}C_{(2)}.$$

Re-arranging, we have that:

$$C(\alpha)^{-1}C_{(2)} = \frac{1}{1-\alpha}C(\alpha)^{-1}C_{(2)}(\alpha) - \frac{\alpha}{1-\alpha}rC(\alpha)^{-1}C_{(1)}(\alpha).$$

As $C(\alpha)^{-1}C_{(2)}(\alpha) = [0, 1, 0, ..., 0]'$ and $C(\alpha)^{-1}C_{(1)}(\alpha) = [1, 0, ..., 0]'$, we get:

$$[0_{m\times 1}, C(\alpha)^{-1}C_{(2)}, 0_{m\times 1}, ..., 0_{m\times 1}] = \begin{bmatrix} 0 & -\frac{\alpha}{1-\alpha}r & \cdots & 0 \\ 0 & \frac{1}{1-\alpha} & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \cdots & 0 \end{bmatrix}.$$

Inserting this to 7, we have that:

$$C(\alpha)^{-1}\frac{\partial C(\alpha)}{\partial \alpha} = \begin{bmatrix} 0 & \frac{1}{1-\alpha}r & \cdots & 0 \\ 0 & -\frac{1}{1-\alpha} & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \cdots & 0 \end{bmatrix}.$$

So that inserting this expression to 6 we have:

$$\frac{\partial x(\alpha)}{\partial \alpha} = \begin{bmatrix} 0 & -\frac{1}{1-\alpha}r & \cdots & 0 \\ 0 & \frac{1}{1-\alpha} & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \cdots & 0 \end{bmatrix} x(\alpha) = \begin{bmatrix} -\frac{1}{1-\alpha}rx_2(\alpha) \\ \frac{1}{1-\alpha}x_2(\alpha) \\ 0 \\ \vdots \\ 0 \end{bmatrix}. \tag{8}$$

Note that, by 5, $x_2(\alpha) = C(\alpha)_2^{-1}c$ where $C(\alpha)_2^{-1}$ is the second row of $C(\alpha)^{-1}$. Using Cramer's rule, we have that:

$$x_2(\alpha) = C(\alpha)_2^{-1}c = \frac{1}{detC(\alpha)}[D_{12}(\alpha), D_{22}(\alpha), ..., D_{m2}(\alpha)]c, \tag{9}$$

where $D_{ij}(\alpha)$ is the (i,j)-th entry of the cofactor matrix of $C(\alpha)$. As a cofactor $D_{ij}(\alpha)$ depends only on the entries outside the i-th row and j-th column of $C(\alpha)$, none of the cofactors in 9 depend on the second column of $C(\alpha)$. As only the second column of $C(\alpha)$ depends on α, none of the cofactors in 9 depend on α. I.e. $D_{i2}(\alpha) = D_{i2}(\alpha|\alpha = 0) = D_{i2}$. Moreover, note that $C(\alpha)$ can be constructed from C by two elementary column operations: 1) multiplying the second column of C by $(1-\alpha)$, and 2) adding the first column multiplied by αr to the second column. As the first operation leads to the multiplication of the determinant by $(1-\alpha)$ and the second operation does not change the determinant, $detC(\alpha) = (1-\alpha)detC$. Therefore, we have from 9 that:

$$\begin{aligned} x_2(\alpha) &= C(\alpha)_2^{-1}c \\ &= \frac{1}{detC(\alpha)}[D_{12}(\alpha), D_{22}(\alpha), ..., D_{m2}(\alpha)]c \\ &= \frac{1}{1-\alpha}\frac{1}{detC}[D_{12}, D_{22}, ..., D_{m2}]c \\ &= \frac{1}{1-\alpha}C(\alpha|\alpha = 0)_2^{-1}c \\ &= \frac{1}{1-\alpha}x_2(\alpha|\alpha = 0) \\ &= \frac{1}{1-\alpha}x_2. \end{aligned} \tag{10}$$

Combining 10 with 8, we arrive at an expression for $\frac{\partial x}{\partial \alpha}$ based solely on α, the original price ratio r, and the demand for good 2 when $\alpha = 0$:

$$\frac{\partial x(\alpha)}{\partial \alpha} = \begin{bmatrix} -\frac{1}{(1-\alpha)^2} r x_2 \\ \frac{1}{(1-\alpha)^2} x_2 \\ 0 \\ \vdots \\ 0 \end{bmatrix}. \tag{11}$$

Expression for $x(\alpha)$

Note that, by 11, the demands for all the other goods apart from 1 and 2 are constant with respect to α. Hence, when α changes, the budget share of those goods remains the same. This implies that the total budget share of goods 1 and 2 stays the same, so that:

$$p_1 x_1 + p_2 x_2 = p_1(x_1 + \int_0^\alpha \frac{\partial x_1(h)}{\partial h} dh) + p_2(x_2 + \int_0^\alpha \frac{\partial x_2(h)}{\partial h} dh).$$

Simplifying and using information from 11, we have:

$$p_1 \int_0^\alpha \frac{\partial x_1(h)}{\partial h} dh = p_2 x_2 \int_0^\alpha \frac{1}{(1-h)^2} dh$$

so that, by integration, we have:

$$p_1(x_1(\alpha) - x_1) = \left(\frac{1}{1-\alpha} - 1\right) p_2 x_2.$$

Re-arranging it gives us:

$$x_1(\alpha) = x_1 - \frac{\alpha}{1-\alpha} r x_2.$$

Combining this information with 10 and, as the demand for other goods is not affected by α, we have:

$$x(\alpha) = \begin{bmatrix} x_1 - \frac{\alpha}{1-\alpha} r x_2 \\ \frac{1}{1-\alpha} x_2 \\ x_3 \\ \vdots \\ x_m \end{bmatrix} \tag{12}$$

Expression for $\varepsilon_1(\alpha) \equiv \frac{\partial x_1(\alpha)}{\partial p_1} \frac{p_1}{x_1(\alpha)}$

From 12 we have that:

$$\frac{\partial x_1(\alpha)}{\partial p_1} = \frac{\partial x_1}{\partial p_1} - \frac{\alpha}{1-\alpha} r \frac{\partial x_2}{\partial p_1}$$

as r here is the original price ratio (and thus does not change). Multiplying with p_1 and dividing by $x_1(\alpha)$ from equation 12, we have:

$$\varepsilon_1(\alpha) = \frac{\frac{\partial x_1}{\partial p_1} p_1 - \frac{\alpha}{1-\alpha} \frac{\partial x_2}{\partial p_1} p_2}{x_1 - \frac{\alpha}{1-\alpha} \frac{p_2}{p_1} x_2}.$$

Then, dividing both the numerator and the denominator by $(1-\alpha)x_1$ on the RHS and re-arranging, we have:

$$\varepsilon_1(\alpha) = \frac{(1-\alpha)\varepsilon_1 - \alpha \frac{b_2}{b_1} \varepsilon_{21}}{1 - \alpha - \alpha \frac{b_2}{b_1}},$$

where b_i is the budget share of good i. Decomposing ε_1 and ε_{21} by the Slutsky equation, we then have:

$$\varepsilon_1(\alpha) = \frac{\varepsilon_1^h - \alpha(\frac{b_2}{b_1}\varepsilon_{21}^h + \varepsilon_1^h)}{1 - \alpha - \alpha \frac{b_2}{b_1}} - \frac{(1-\alpha)\varepsilon_1^w b_1 - \alpha \varepsilon_2^w b_2}{1 - \alpha - \alpha \frac{b_2}{b_1}}.$$

Noting that, by the budget constraint $\frac{b_2}{b_1}\varepsilon_{21}^h + \varepsilon_1^h = -\sum_{i=3}^m \frac{b_i}{b_1}\varepsilon_{i1}^h$ and that by Slutsky symmetry $\frac{b_i}{b_1}\varepsilon_{i1}^h = \varepsilon_{1i}^h$, we have that:

$$\varepsilon_1(\alpha) = \frac{1}{1 - \alpha - \alpha \frac{b_2}{b_1}} \varepsilon_1^h + \frac{\alpha}{1 - \alpha - \alpha \frac{b_2}{b_1}} \sum_{i=3}^m \varepsilon_{1i}^h - \frac{1}{1 - \alpha - \alpha \frac{b_2}{b_1}} ((1-\alpha)\varepsilon_1^w b_1 - \alpha \varepsilon_2^w b_2).$$

Choosing the reference point so that $\frac{b_2}{b_1} \approx 0$, this simplifies to:

$$\varepsilon_1(\alpha) = \frac{1}{1-\alpha}\varepsilon_1^h + \frac{\alpha}{1-\alpha}\sum_{i=3}^{m}\varepsilon_{1i}^h - \varepsilon_1^w b_1,$$

where the first two terms provide the compensated elasticity of good 1 as a function of α and the third term provides the income effect.

Non-linear similarity

The inclusion of non-linear similarity is complicated by the additional goods, as this requires that the characteristics space is also m-dimensional, so that we need m measures to span the whole space that lies between B_1 and B_2. As an example, consider the case with 3 goods and 3 characteristics. Then good 2 can become more similar to good 1 by reducing the difference between the goods for any of the three characteristics. Hence, there is a cuboid for which each point is closer to B_1 than the original B_2. As this is a three-dimensional object, we cannot cover all its points with α and λ alone but need a third measure that is not a linear combination of the two. As it happens, it is convenient to add a second non-linear similarity measure (or multiple measures if $m > 3$) by allowing good 2 to move closer to good 3 (good $i \notin \{1, 2\}$) through β_3 (β_i) in a similar fashion as to good 1 through α. This is possible as C is invertible by assumption and thus B_1, B_2 and B_3 cannot lie on the same plane. Moreover, similarly to α that does not affect the price-elasticity of the third (i-th) good, β_3 (β_i) does not affect the price-elasticity of good 1. Hence, the own-price elasticity of good 1 is simply a function of α and λ also in this more general case, and we have:

$$\varepsilon_1(p, \alpha, \lambda) = \frac{1}{1-\alpha}\varepsilon_1^h(p, \lambda) + \frac{\alpha}{1-\alpha}\sum_{i=3}^{m}\varepsilon_{1i}^h(p, \lambda) - \varepsilon_1^w(p, \lambda)b_1.$$

Hence, as long as there is little substitution between good 1 and other goods than good 2 (i.e. $\sum_{i=3}^{m}\varepsilon_{1i}^h(p, \lambda) \approx 0$) and either the budget share of good 1 is small ($b_1 \approx 0$) or the income elasticity of good 1 is small (i.e. $\varepsilon_1^w(p, \lambda) \approx 0$), the own-price elasticity

$\varepsilon_1(p, \alpha, \lambda)$ is well approximated by:

$$\varepsilon_1(p, \alpha, \lambda) = \frac{1}{1-\alpha}\varepsilon_1^h(p, \lambda).$$