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Studying a Sin Tax Scheme with Multiple Reforms Lessons for Consumption Taxation *

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Abstract

This paper studies the relationship between substitutability of taxed and non-taxed goods and the price elasticity of demand. 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 product and store-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 that have intermediate non-taxed substitute: cookies. In a stark contrast, when the tax rate was doubled for sugary soft drinks but not for their close substitute non-sugary soft drinks, consumption elasticity is close to unity. These estimates align well with our theory framework wherein 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 (OECD 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, affects 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 (Gorman (1980) and Lancaster (1966)) 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 to a small degree, the consumers have low willingness to substitute from one good to another, a situation that can be illustrated with steeply sloped indifference curves. On the other hand, if the two goods share much of the same characteristics, consumers have 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 demand elasticity. With low or modest substitutability to the non-taxed good, demand elasticity is close to zero. Instead, with high substitutability between the goods, demand elasticity is very high. Thus, the relationship between substitutability and demand elasticity is such that only when the taxed and non-taxed good are highly substitutable, the demand elasticity is high. When starting from low substitutability between the goods the demand elasticity increases initially slowly with substitutability and rapidly when reaching very close substitutability levels. This yields a highly convex shape between substitutability and demand elasticity.[1] The framework can be extended to having more than two goods, but adding more distant substitutes would not change the main result.

We study these aspects empirically first by utilizing a sweets tax scheme that contains 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 non-sugary soda from the same producer. The reforms in 2011, 2012 and 2017 made the same tax changes across product categories that have very similar goods, but still left fairly similar goods outside of the tax scheme, such as chocolate (taxed) and chocolate-covered cookies (not 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.

We have access to extremely large product-level data for the taxed and non-taxed 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 are sampled randomly, they describe in a meaningful way the 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 with each other, allowing us to determine what the closest non-taxed substitute categories for taxed goods are in each reform. It is an online survey where we ask questions about pairs 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 yields a substitution index, which allows us to predict the demand elasticity based on the theory model. We can then investigate to what extent an average consumption elasticity estimate utilizing the sweets tax scheme is in line with the theory model.

To estimate a consumption tax elasticity, we provide event-studies where products in groups facing sweets tax changes are compared to groups not facing tax changes. We select the comparison groups by taking into account how close substitutes they are to the taxed products based on our survey results. We can study substitution by comparing to what extent sales of products that are not facing tax changes respond to tax changes of close substitutes and establish a more distant comparison group to represent the counterfactual. Otherwise the comparison group consists 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

[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.

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 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 resulting in slight asymmetric tax incidence (see Benzarti et al. (2020)). 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, we estimate quite precise zero change in quantities of sweets, ice cream or soda sold using tax increases that treated similar products the same, for example sugary and sugar-free soda. The same applies to abolishing the tax in 2017 for sweets and ice cream. 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.

These estimates can be used to derive average price elasticities at the average level of prices and demand. The tax changes for sweets and ice-cream that left cookies as the closest substitute not facing tax changes yields the elasticities below 0.1 in absolute value. On the other hand, for sugary soda that had as the closest substitute non-sugary soda we estimate an elasticity close to 1.

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

Our second complimentary approach for studying empirically the link between consumption elasticities and substitutability to non-taxed goods is to develop a substitution index that can be applied to price elasticity estimates from the literature. Our substitution index is based on a product category tree from the TARIC (Integrated Tariff of the European Communities). The index is based on how many nods in the tree one needs to cross to get from one product to the substitute group, and therefore, how many goods are at a comparable level in the tariff tree. The less nods the higher is the substitutability. We complement the TARIC information with information about geographical proximity (in case of cross-border shopping) and other assessments of substitutes for fuel and services.

An increasingly active literature has analyzed the impacts of various consumption taxes on sales or consumption. The literature has found a large range of consumption elasticities. From these we attempt to include all quasi-experimental studies that provide credibly causal evidence relating to the price elasticity of consumption. We then group the estimates from literature into four categories based on the availability of substitutes that do not face tax changes; very low, low, intermediate and high substitutability. We also use the average substitution index of the category to place the category on an ordinal scale.

The result of this exercise is that estimated consumption elasticities in the literature are low when substitution index is low and that consumption elasticities increase in a highly convex shape with the substitution index. The result resembles remarkably well the pattern of elasticities from our sweets tax reforms, and aligns well with the prediction from our theory framework.

In more detail about the literature survey, in the very low substitutability category we include studies on general consumption taxes or very broad based excise taxes (Kosonen

(2015), Harju et al. (2018), and Merker (2023)). In the low substitutability category we include elasticities of driving distance and fuel consumption with respect to fuel price variation (e.g. Levin et al. (2017) and Langer et al. (2017)) as well as the price elasticity of electricity (Hindriks and Serse 2022). The intermediate substitutability category includes price elasticity estimates of less wide excise taxes such as alcohol taxes (Asplund et al. (2007)) and taxes on sweetened beverages (Gonçalves and dos Santos (2020)) when the taxes are applied in a large geographic area (full country). In the high substitutability category we include studies utilizing local sin tax reforms, such as the 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 and Rafkin (2022) and Cotti et al. (2022)).

We did not include some studies in the literature survey due to the lack of estimated elasticities, that nevertheless seem to support our findings. For example, in the high substitutability category would be Harju et al. (2020) who study taxing new cars with CO2 based taxes. The substitutability in this case is high as one can substitute a higher CO2 emissions car with lower CO2 emissions car or a new car with used car, that is, substitute a higher taxed car with lower taxed car. The evidence points that the reform introducing CO2 emissions based car tax dramatically shifted the consumption away from higher taxed and high CO2 emission cars towards lower taxed and lower CO2 emission cars. Johansson et al. (2014) study how a Finnish alcohol tax cut affected outcomes in neighboring Sweden as a function of distance to the Finnish border. They find large changes in alcohol sales close to the border, where alcohol on the Finnish side is a close substitute to alcohol on the Swedish side, but these effects diminish rapidly to zero further off the border. Moreover, Fletcher et al. (2010) 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.

Sin taxes have also been studied extensively using structural estimates (see e.g. Chan (2006), Dubois et al. (2020), Miravete et al. (2020)). Some of these structural papers estimate models that share a feature with our framework in that they include product characteristics as something consumers care about, for example Dubois et al. (2014) develop a theoretical framework, which nests the Gorman-Lancaster model (Gorman (1980) and Lancaster (1966)) used in this paper. The advantage of structural models over our approach is that they allow to estimate the whole demand system, and therefore to also do counterfactual analysis of the effects of different kinds of policy changes. Our estimate does not reveal the curvature of the demand curve, it is instead an average estimate for the elasticity in the existing environment. We think that the advantage of our approach is to provide a credibly causal estimate with transparent event-study evidence supporting the assumptions. Moreover, our study complements the structural literature in providing analytical results and quasi-experimental support for the characteristics based consumption models.

Previous literature has more extensively studied the price incidence of consumption taxes than their effects on consumption. We contribute to this literature by estimating price incidence of excise taxes using very large scanner data yielding precise estimates. 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 (2017) documents over-shifting in the prices as the response to the introduction of a soda tax in Mexico. Similarly, Bergman and Hansen (2019) 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.

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 two goods to their compensated demand elasticities. The idea is that when two similar goods have different prices, e.g due to taxing only one of the goods, the demand elasticity measures to what extent consumers would substitute the higher price good to the lower price good. In Section 5.4 we calibrate the model to our empirical setting using substitution index and see how well the empirical results align with the predictions form the model. The two goods in the model are empirically assumed to be goods coming from different product categories.

The model produces a highly convex relationship between the demand elasticity of a good and the substitutability of the two goods: for low to relatively high levels of substitutability, the elasticity is small, but for highly 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.

The model has two goods, but can be generalized to more goods, which would produce qualitatively similar results when assuming that the two goods analyzed here are the closest substitutes. The model does not have income effects, and adding them would make a the total responsiveness to taxes higher even in the absence of close substitutes.

2.1 Setup

The model is set up to consider the consumption choices of a single agent between two goods containing potentially different set of characteristics. 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 characteristics 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 each good is consumed. 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] 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 lies between 0 and 1, so that an α value of 0 means that the goods are not substitutable at all and an α value of 1 means that identical, so that they are perfect substitutes. α is derived in the model through product characteristics, and the higher α is, the more similar – and hence, more substitutable – the goods are. We next explain how α is formed based on a situation with two goods, which are not substitutable at all with each other, while one of them is replaced by a third good which shares some of the characteristics of the other two goods.

Assume that the characteristics vector of good 1 is c^1 and the characteristics vector

[3] This highlights the connection between a Gorman–Lancaster model and the standard model of consumer choice: if there are as many goods as characteristics and C is the identity matrix, we have the standard model.

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 replaces good 2. Good 3 is a composite of goods 1 and 2 such that it shares a fraction α of good 1's characteristics and a fraction (1-α) of good 2's characteristics. More formally, good 3 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 of our model. We consider three cases: a case where α is initially low, so that the goods are not very close substitutes (the left panel in figure 1), a case where α is initially at a medium level so that the goods are relatively close substitutes (middle panel in 1), and a case where α is high to begin with, so that the goods are close substitutes (right panel in figure 1). A small increase in substitutability, that is, increase in α, by $\Delta\alpha$ straightens out the indifference curve in all cases, so that the two goods become more elastic to price differences. This change is illustrated in the figure as the change from the black indifference curve to the red one.

The figure also illustrates how the change in the responsiveness to price differences translates to how the chosen bundle would react to a tax change. This is outlined by the bundles x_0, which are the original bundles without the tax change, and x_1, which are

[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.

the bundles the consumer would choose after the tax change assuming no change in α. These are marked with black dots in the figure. This can be contrasted with a situation where α changes by $\Delta\alpha$ and the new chosen bundle becomes $x_1(\Delta\alpha)$, which are marked with red dots in the figure. In all cases, the change from x_0 to $x_1(\Delta\alpha)$ is larger than the change from x_0 to x_1. However, when the goods are initially very close substitutes (high α), the change from x_0 to $x_1(\Delta\alpha)$ is *substantially* larger than from x_0 to x_1 compared both to the case when the goods are not very close substitutes (low α) and when they are relatively close substitutes (medium α). Notably, the contrast between how a tax change would affect the chosen bundle in these different cases arises although we assumed that substitutability increases by an equal amount across the three cases.

The main result from the theory framework intuitively derives from the changes in indifference curves when α increases. Because the indifference curves change differently at different original levels of substitutability, 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, which is derived from the theory model, 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:

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

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, because these give essential information about products. The survey shows each time photos of both products, their names and prices, and below these 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 photos for all products, we also set up a photography studio with studio lights to take photos ourselves producing photos of similar quality than the actual marketing photos.

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. Respondents could use a slider bar to provide an answer or type in the number to a box next to the slider bar. The higher the number the more substitutable the products are with each other, which was also each time explained in the survey next to the question. 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. Also these answers can be averaged for a product pair to receive a substitution index, which is this time in money. A challenge here is that different products cost slightly different amounts of money, leading to the fact that the difference in amount of money should be made relative to the base value.

In total, there were 2,500 respondents to the survey, with more than 20,000 product pairs viewed in total.

We also gathered additional information on products data on a subgroup of the whole product universe available in the sales data. These data were 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 typical hyper market) for 2,091 products.

4.3 Substitutability results from the survey and additional product information data

We next describe the results from the product survey. We also provide other substitution indices using different types of information about the products.

Figure 3 shows the distributions of answers to question 2, the main question of interest in the survey, asking on a scale between 0 to 10 how substitutable products are with higher number indicating more substitutable. In the figure 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, that is, substitution product category. The closest substitution categories 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 substitution 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 and reach a 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.

Figure 4 shows a substitution index for the different product-group pairs considered above. The index is constructed by simply taking the mean of the answers to question 2 for which Figure 3 provides the distributions, as well as the 95% confidence intervals of the means. An interesting observation is that the substitution index seems to increase almost linearly across the product-group pairs considered. The substitution index constructed from the survey is the main information we use in the analysis below and when fitting the theory model with the empirical setting.

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.7 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 similarity measures based on store floor locations and nutritional content are simply a Euclidean distance between two products, i.e. the Euclidean distance between store floor coordinates 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 Empirical results and empirical strategy

In this section we first provide our empirical results both on the effects of the different sweets tax reforms on prices and quantities sold. We then describe how our empirical results align with a prediction from our theory framework when using the substitution index to link them.

5.1 Estimation methods

The main interest here is to estimate to what extent tax changes affect consumption of goods that are taxed directly, and to what extent there is substitution to products that do not face tax changes. We examine in the event-study framework changes in the consumption of different product groups: those that face tax changes and those that are potentially close substitutes using as more distant groups as the control group.

Relative to a simple event-study, where one would have a treated and control group, we have a more challenging problem of determining which are the potential substitution groups and which are the product groups that can be used as a control. Choosing the product groups affects also whether they are comparable over time and thus whether the control group establishes a credible counterfactual. Thus, we need to be careful in how we choose the groups. In choosing them, we relied on our results from Section 4.3 on the substitutability of different product groups and implemented the following procedure.

We first compared product groups facing tax reforms with various product groups that did not face tax changes. We selected all products that seemed like close substitutes based on the survey to the substitutable group.

We then selected a control group for both the tax group and the substitution group from products that are fairly similar for them to credibly represent a counterfactual, but that were not very close substitutes to the taxed or substitute group. In the latter case we selected only product groups for which we managed to establish parallel pre-trend with the taxed or substitute groups. Fortunately, our data included suitable products that both had parallel pre-trends and that were not very close substitutes, such as, snacks, yoghurts and pastries.

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

We present the event-study graphs both such that different groups described above are shown separately or that their difference in each time period is shown, whichever method produces a more transparent description of the results. We estimate the following equation:

$$y_{it} = \sum_{\tau=-T,\tau\neq-1}^{T} \beta_\tau[t=\tau]g_i + \gamma_t + \mu_i + \epsilon_{it} \tag{3}$$

where i refers to a product sold in particular outlet and τ refers to time periods (either week or month, depending on the setup) and g_i to the group identifier, either one facing tax change, likely substitute group or control group. The event-study specification is such that the g_i is interacted with event time τ, and when we estimate just the time-series for the groups separately we do not include this interaction. μ_i refers to product-outlet i fixed effects and γ_t refers to a set of time fixed effects. ϵ_{it} is the residual error term. The outcome variables y_{it} consist of volume of each product sold or their log price (euros). The standard errors are clustered at the product-outlet level.

We also quantify the impact of the sweets tax reforms with a DiD framework. We estimate the following equation:

$$y_{it} = \gamma_t + \mu_i + \beta_{DD} a_t \times g_i + \epsilon_{it}, \tag{4}$$

where a_t is an indicator taking value one for after the reform period, g_i is the same group indicator as above, $a_t * g_i$ is the interaction of the two indicator terms and thus β_{DD} is the main coefficient of interest. y_{it} is the outcome variable, either unit price or the volumes or items sold. We include in the estimation also product-outlet level fixed effects μ_i. ϵ_{it} is the error term, which is clustered at the product-outlet level.

We also provide an estimate for the consumption elasticities. We do this in two-stage least squares, where we first estimate the impact of a reform on log prices and use this variation to explain the change in log quantities.

$$\begin{aligned} \log p_{it} &= \gamma_t + \mu_i + \beta_{DD} a_t \times g_i + \epsilon_{it}, \\ \log q_{it} &= \gamma_t + \mu_i + \hat{\log} p_{it} + \varepsilon_{it} \end{aligned} \tag{5}$$

Where we first estimate the impact of the reform on log prices $\log p_{it}$ and in the second equation explain the change in log quantities $\log q_{it}$ with the estimated change in log prices $\hat{\log} p_{it}$. Both equations include the product by store fixed effects μ_i as well as time fixed effects γ_t .

5.2 Graphical evidence

Here we provide graphical evidence on how reforms impacted quantities sold or the price of products. We estimate equation (3) either separately for different groups or event-study specification and plot the coefficients and their confidence intervals in the presented graphs.

The sales of the products in our sample exhibit strong seasonal fluctuation as exemplified in Figure 5, which is produced estimating equation 3. The figure compares the development of the amount of taxable products (excluding soft drinks) around the 2011 and 2012 reforms (mainly sweets, chocolate and ice cream) with a set of non-taxable products (mainly cookies, sweet and savoury pastry, pudding and yogurt). The extent of seasonality is high in that sales vary 20% around the annual average sales. We consider seasonality as something naturally arising from consumption varying with season, for example, influenced by seasonal temperature. A concern is that 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, which is fortunately possible using multiyear detailed dataset in our disposal. 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 procedure successfully removes the high seasonal variation but leaves the changes in the trends across years intact that the reforms would potentially cause. This highlights the value of having observations for each month over many years over having only couple of points in time, for example, from a survey, because then producing de-seasonalizing the data would be impossible.

Figure 6 presents the over time development of the amount of products sold with seasonal adjustment for the 2011/2012 reforms. The figure presents three groups (g_i), those facing the tax change, which are sweets and ice cream here, their closest substitute group, which is cookies, and a control group consisting of similar but more distant products, mainly sweet and savoury pastries, puddings and yoghurt, in panel (a). In panel (b) the figure present event-study graph that compares the monthly level difference of taxable group relative to the control group. Panel (b) also include a solid line depicting how the event study graph would develop if the consumption elasticity would be unity, which clearly differs from actual development. The figure excludes soft drinks, because in order to find parallel pre-trends, we needed to construct a different control group for them. The figure shows that the three groups develop on the same trend before the 2011 reform. However, the groups develop similarly also after the two reforms in 2011 and 2012. Thus, the figure shows quite convincingly that the two reforms had no large impact on the sales of the taxable group, and no substitution effect to the closest substitution group.

Figure 7 presents the development of sales for the three groups over the 2017 reform that abolished the tax for sweets and ice cream, but left the tax for soft drinks in place. The sales of the three groups presented in panel (a) develop again quite smoothly over the 2017 reform without any clear and systematic differences between the groups after the reform. Although there are some noise in the series, the figure does not depict any large changes like the one depicted with a solid line in panel (b) indicating how the series would evolve if consumption elasticity would be unity. Thus, the figure indicates that abolishing the tax had at most a small effect on sales of sweets or ice cream for which the tax was abolished.

Figure 8 shows the development of sales of sugary versus sugar-free drinks (including all drinks that faced the tax reform in the taxable group) as well as a control group (comprising ice cream, sweets and chocolates), and Figure A.4 the same comparison between the sugary and sugar-free sodas in the 2014 reform. The 2014 reform doubled the tax rate for sugared liquids from 0.11 €/l to 0.22 €/l, while it left the tax on sugar-free drinks unchanged at 0.11 €/l. The figures show that the three groups are on a parallel trend prior to the 2014 reform and that there is a clear separation between the sales of the taxable and substitution groups precisely at the time of the reform. The control group illustrates that at the 2014 reform the consumption of sugary soda declined and the consumption of sugar-free soda increased. Furthermore, Figure 9 depicts the total soda sales (adding sugary and sugar-free soda together) relative to the control group. Here we do not observe any decline in total soda sales. These results suggest that there was a substitution effect from sugary soda to sugar-free soda.

Turning to the analysis of price incidence, Figure 11 presents the development of prices at weekly level around the 2011 and 2012 reforms for all taxed and non-taxed products pooled. The figure shows that the prices of taxed and non-taxed products follow on average 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 would indicate. 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 full pass-through is calculated by adding the mechanical price effect due to taxes to the control group prices, and is marked to the figure with the horizontal purple line. For the 2011 reform the purple line overlaps the line of the taxable group after the three months period, indicating the full pass-through to prices.

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, although the tax increase itself was smaller. After these two reforms the taxed group is at around 10% higher level than the control group, indicating the effect of the two reforms combined on prices on average.

To provide some estimates for different subcategories Figure A.6 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. The tax burden on ice cream is higher because the tax is based on weight of the product and ice cream tends to weigh more relative to price than other solid products. Soft drinks had the opposite feature to ice creams in that the pass-through was less than full, and for drinks the tax increase due to the reform was smaller because there was an pre-existing tax that was just increased to the same level with other products in the 2011 reform.

We also analyze the price incidence for abolishing the sweets tax for sweets and ice cream from the beginning of 2017 in Figure A.5. The figure indicates 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.6 show that for sweets the pass-through seems to be full for the the reform abolishing the tax for sweets and ice cream, but for the other categories slightly less.

Figure 10 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.

5.3 The effects of different reforms on quantities, prices and the implied consumption tax elasticities

In this subsection, we provide differences-in-differences estimates of the impacts of the sweets tax on quantities sold, prices and the estimated consumption elasticities these changes in consumption and prices imply. In addition to standard comparison of products facing tax changes with other products we want to identify substitution effects as the methods section above explained.

Table 2 collects our differences-in-differences (DiD) estimates (equation (4)) for log sales and prices as well as our elasticity estimate for the 2011 and 2012 reforms. The outcome variable is log volume of products sold within a month in a store. Products facing the tax change are compared with the pure control group. We do not include the estimates for the substitution group here, but Figures 6 and 7 indicate that the substitution effect for the 2011 and 2017 reforms will be zero. With product by store fixed effects the estimate is interpretable as relative changes in the number of products sold. 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.

The preferred estimate is in column (2), which combines reforms 2011 and 2012 and adds product-level fixed effects. The estimate for change in quantities is -0.004. The estimated change in log prices is 0.14 suggesting about 14% increase in prices due to the two tax increases. The elasticity estimate (estimating equation (5)) is -0.028, indicating estimated elasticity fairly close to zero. The standard errors are clustered at product-outlet level. The estimates are nevertheless quite precise due to number of observations exceeding 20 millions.

Table 3 show the DiD and elasticity estimates for the same outcomes in the 2017 reform. The estimate for change quantities in our preferred estimate in column (2) is -0.002. Note that although the estimate is very close to zero, it is of wrong sign give the reduction in taxes in the 2017 reform. The change in log prices is -0.074. The elasticity estimate for the 2017 reform is 0.026, again a small estimated elasticity.

Table 4 shows the corresponding estimates for the 2014 reform. Columns (1) and (2) use as the control group ice-creams and columns (3) and (4) solid sweets. Columns (2) and (4) present the preferred estimates and include product by outlet fixed effects. The choice of the control group does not affect the estimates very much. The log quantity change in column (2) is -0.049 and in column (4) -0.042. The corresponding price log price changes are 0.045 and 0.041, respectively. This leads to an estimated elasticity of -1.008 presented in column (2). Thus, a similar or smaller tax induced price increase led to a significantly larger change in consumption captured by much larger elasticity than in the other reforms for sweets and ice cream.

Table 5 collects our preferred quantity, price and elasticity estimates for different product categories facing tax changes, that also have varying products as the closest substitutes not facing tax changes. The table shows a pattern where the elasticity estimates are close to zero for sweets (0.044), ice-cream (-0.007) and chocolate (0.097), while the estimate is close to unity for sugary soda (-1.008). The main difference for these product groups is how close substitute the closest product group is that is not facing tax changes. This seems to give support for our theory framework. We investigate the support for our theory framework more formally in the next Subsection.

5.4 Fitting the empirical estimates with our theory framework

We have presented above in Section 2 a theoretical framework according to which we organize the discussion of empirical estimates. Here we review how the empirical results align with the theory framework matched with the substitution index from our survey. We use the substitution index to see how our estimated elasticities develop when ordered according to their distance to closest substitution group. We also use the substitution index to draw a prediction from our model suggesting how large the consumption elasticity would be. We then examine whether the pattern of quasi-experimental estimates organized according to their substitutability to closest non-taxed goods align with the prediction from the theory model.

We present both the prediction from the theory framework and our quasi-experimental estimates in a two-dimensional graph. On the horizontal axis of this graph is our Substitution index derived using our survey and referring to how close substitute for a product group is found that does not face tax changes. The substitution index and how it is constructed is described in subsection 4.3. On the vertical axis of the graph is the consumption elasticity.

Figure 12 presents the resulting relationship between the substitution index both from our theory model in shaded grey area and our quasi-experimental estimates for the consumption elasticities for different product groups marked in blue dots. The theory predicts that the demand elasticity of the taxed products increases in highly non-linear fashion in substitution index. The grey line in the figure shows exactly this. The shaded area corresponds to varying the parameter values of the model. To examine whether our quasi-experimental estimates yield a similar pattern, the figure presents the consumption elasticity estimates organized according to the substitution index. The figure shows that the quasi-experimental estimates presented in blue dots line up well with the model presented in the grey line. We estimate a demand elasticity of close to zero for the other pairs than soft drinks. The effect is dramatically different for sub-groups of soft drinks for which we estimate high demand elasticities and which also lie on the high end of our substitution index.

6 Evidence from previous literature

To find further evidence for the relationship between substitutability to non-taxed goods and consumption elasticities, we conducted a review of past elasticity estimates and related these to an empirical measure of substitution possibilities based on EU tariff-categories.

We included 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

29 different estimates from 22 studies. The studies are reported in Table 6.

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 product exports and imports. With the goods-tree, we measure substitution possibilities as a function of the shortest distance to a substitute good for which tax treatment does not change. We apply the goods-tree with 3-levels of categories (6 digits), which are in the order of descending generality.[9]

The main rule we use to construct the index is as follows: for a given good in a given setting (i.e. sugary soda in 042202), 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 042202). 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 four leading figures of the code are the same (e.g. for sweetened soda in 042202, non-sweetened soda is in category 042201), 3) the closest substitute may only share the first two digits (e.g. for sweetened soda in category 042202, this might be some candy in category 041704), or 4) the closest substitute may not share any categories. Finally, for each of these cases, we assign an index number between 0 and 1 as follows: we compute the shortest distance from a taxed good to a non-taxed good in the tariff tree (e.g. for sweetened soda in 042202, one has to go through two edges to get to non-sweetened soda in 042201) this distance is then normalized to be between 0 and 1 by dividing by the longest possible route (with three levels, this means six edges, so 1/3 for sweetened soda). Next, we turn this normalized distance (d) into a measure of substitution possibilities $s = 1 - d^2$. The

[9] For example, for sugary soda, the code is 042202, where 04 stands for "Prepared foodstuffs; beverages, spirits, and vinegar; tobacco and manufactured tobacco substitutes", 22 stands for "Beverages, spirits and vinegar", and 02 stands for "Waters, including mineral waters and aerated waters, containing added sugar or other sweetening matter or flavoured, and other non-alcoholic beverages, not including fruit, nut or vegetable juices of heading 2009".

idea here is that the number of goods increases approximately to the power of two with distance[10] An example of this is illustrated in Figure 7.

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 travelled by a 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.

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

Using the procedure described above we categorize into four groups the studies that we were able to find and that provide an elasticity estimate estimated using quasi-experimental framework. The substitution index allocated to each group is the average of the substitution indices of individual estimates. We describe the result from this exercise, the relationship between the average elasticities and average substitution indices in Figure A.8. The figure shows that the relationship between average consumption elasticities and the substitution index is a convex shape. Thus, when organizing the results in the

[10] Using two is only an approximation and could in practice be a higher number as there tend to be more than two sub categories within each higher level category.

literature according to our substitution index, the result aligns well with the prediction from our theory framework, which is presented with a stylized grey curve behind the average elasticities from the literature.

Table 6 gives the details of the studies used. Different columns in the table give the product-group that is taxed in the study, the closest substitute product-group, which one of the four substitution groups the estimate falls to, the substitution index we derived for the substitution group on average, and the consumption elasticity estimated in the study.

As the table describes, in the highest substitution group are studies on taxing sugar-sweetened beverages with artificially flavored products as the closest substitution group and where the reform occurs in a narrow geographical area. Also in the highest substitution group are studies on taxing cigarettes or e-cigarettes with other tobacco products as the closest substitution group. In the second highest substitution group are studies where the taxed group is various alcohol products with possibility to import alcohol from neighboring countries, or studies on sweetened beverages where the tax is applied to a wide geographical area. In the third group are studies on taxing gasoline, electricity or mile of travel by car, the we deem have as the closest substitution group other forms of transport. In the lowest substitution group are studies on value added taxes or a broad tax on all sweets and beverages in Norway that has as the closest substitution products other groceries.

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. To more formally describe this mechanism, we present a theory framework which is in the Gorman–Lancaster tradition, where goods contain varying amounts of the same characteristics. The framework allows to derive analytical results for how demand elasticity depends on how similar they are, that is, how substitutable they are with each other. 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 and medium levels of substitution the demand elasticity can be close to zero, but increase rapidly when substitutability between the taxed and non-taxed good reaches a high level.

To provide empirical support for the theory framework, we studied the sweets tax introduced in Finland in 2011 and subsequent tax increases in 2012 and 2014 and abolishing the tax in 2017 for sweets and ice cream.

We find as our main empirical result that the tax increases in 2011 and 2012 or abolishing the tax in 2017 affected the consumption of sweets, ice creams or very little. In contrast, we find that the 2014 tax increase for sugary soft drinks did reduce their consumption and at the same time increased the consumption of sugar-free soft drinks, which did not directly face any tax changes themselves. The consumption of soft drinks as a total did not respond to the reform relative to a more distant control group. Thus, the effects of the 2014 reform seem to have occurred through substitution from sugary soft drinks to non-sugary soft drinks.

For prices we see that the combined 2011 and 2012 tax increases, the 2014 tax increase for sugary soft drinks and 2017 tax reduction for sweets and ice cream all led to about 10% change in prices on average in absolute value. Thus, differential price impact across different reforms cannot explain the very differential impacts on consumption. Abolishing the tax was under shifted to prices while tax increases were fully or even over shifted to prices indicating asymmetry to some degree, consistent with Benzarti et al. (2020) for VAT.

In order to link the theory model with the empirical results we provide a substitution index describing how close substitutes the products facing tax changes are with products not facing tax changes. Our main index is based on a survey that We designed for this purpose. The survey is an online survey that asks how substitutable pairs of products are with each other, and then repeats the same question from subsequent pairs of products presented in random order. The results indicate that the substitution index is increasing close to linearly across pairs of product groups. The survey indicates that sugary and non-sugary soft drinks have the highest substitutability, while for sweets, chocolate and ice cream all have cookies as the closest substitute group, but that have a slightly lower substitution index than different soft drinks with each other.

We derive predictions from our theory model on consumption elasticity based on the substitution index. When aligning our quasi-experimental elasticity estimates utilizing tax changes within the sweets tax scheme, we find a very similar pattern of consumption elasticities than those predicted by the theory framework. We estimate a substantial demand elasticity close to unity for the soft drinks and low demand elasticities close to zero for the other taxed product groups.

We also provide a literature survey to consumption elasticities estimated in quasi-experimental settings. We develop a substitution index for these studies based on EU tariff-goods tree and augmented with geographical proximity and other considerations of proximity for services not found in the tree. The substitution index developed in this way is useful for ex ante policy considerations of what would happen following a particular consumption tax, when combined with our theory framework. First, it is good to check whether the theory framework aligns with the elasticities from the literature. Indeed, when organizing the average elasticities found in the literature into four categories based on the substitution index, we find a convex relationship such that the large demand elasticities are found only in the highest substitution category. Many other elasticity estimates are close to zero. Thus, the theory framework seems to be able to explain how large an elasticity various consumption tax changes will create through how close non-taxed substitutes exist.

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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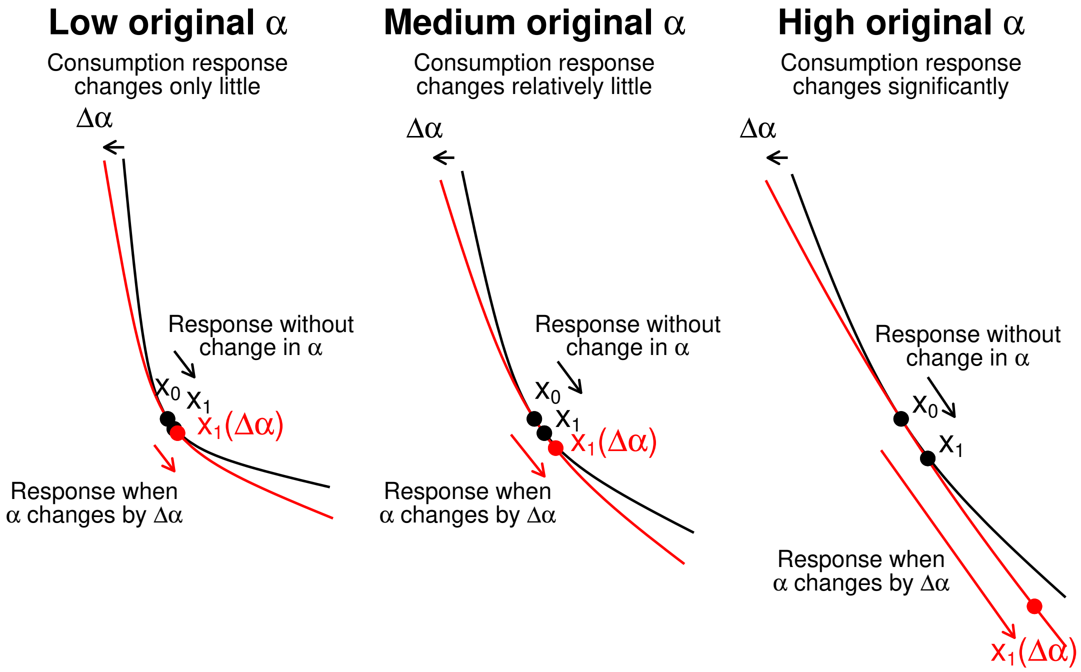
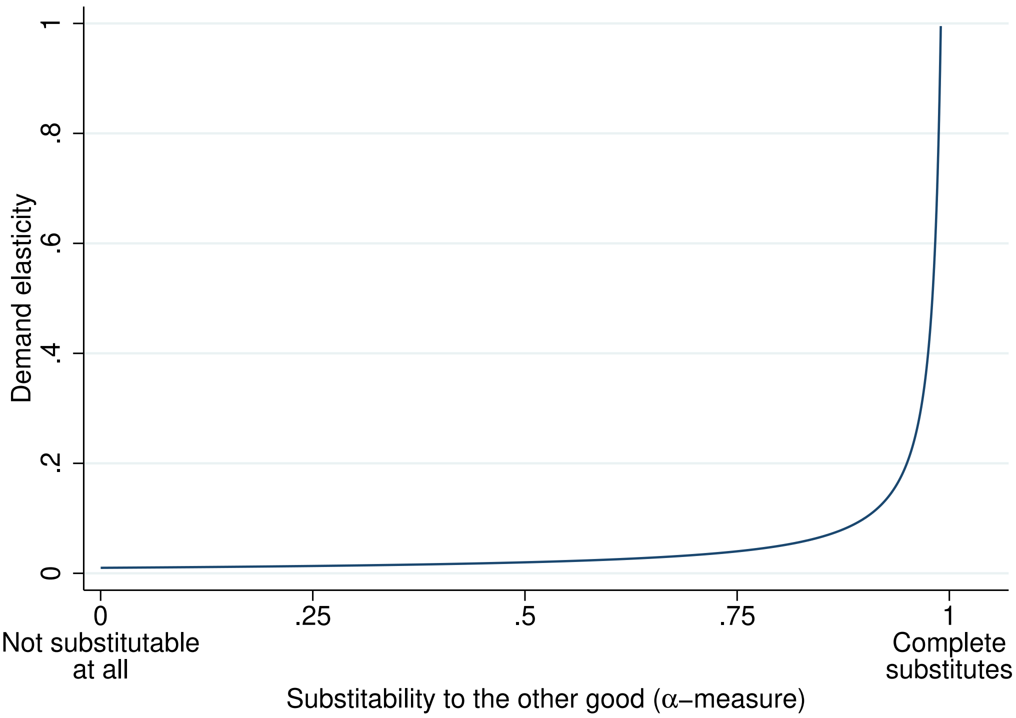
Figures

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



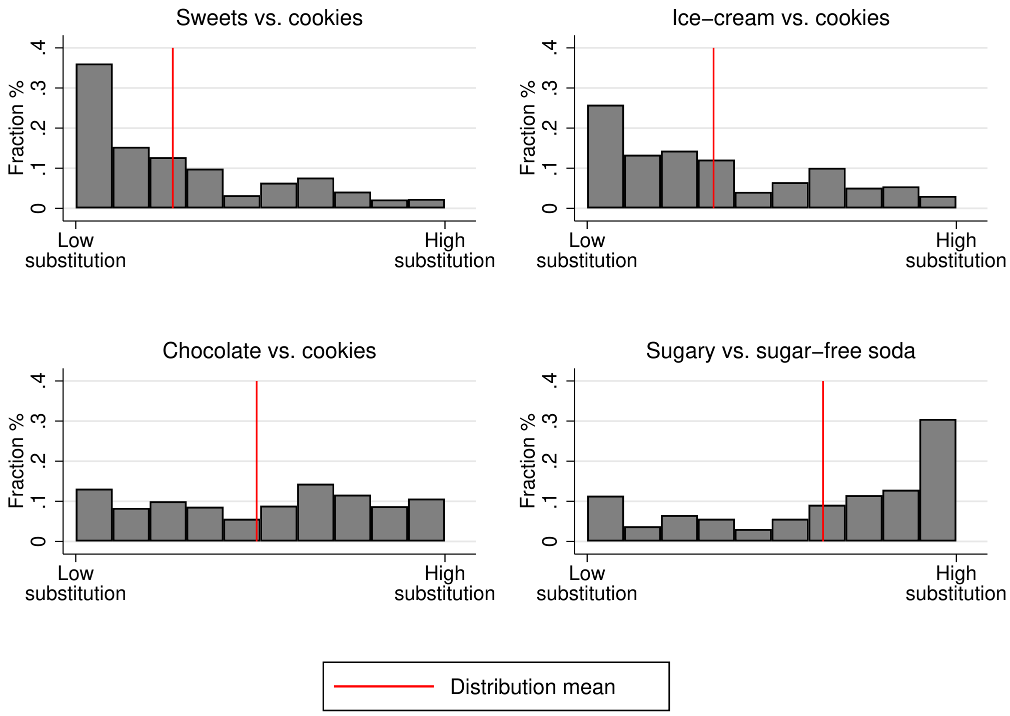
Note: The figure illustrates how increasing substitutability (labeled α) between goods in a stylized two-good Gorman–Lancaster (Gorman 1980, Lancaster 1966) model impacts the indifference curves between the two goods. This is measured by how similar the characteristics vectors of the goods are as outlined 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. The left panel depicts a situation with low original substitutability between the two goods (low α), whereas the middle panel depicts a situation with medium initial substitutability, and the right panel a situation with high initial substitutability. Increasing substitutability by $\Delta\alpha$ in all panels moves the indifference curves from the black indifference curves to the red ones. 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 the increase in α by $\Delta\alpha$), 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 either not close (left panel) or intermediately close substitutes (middle 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



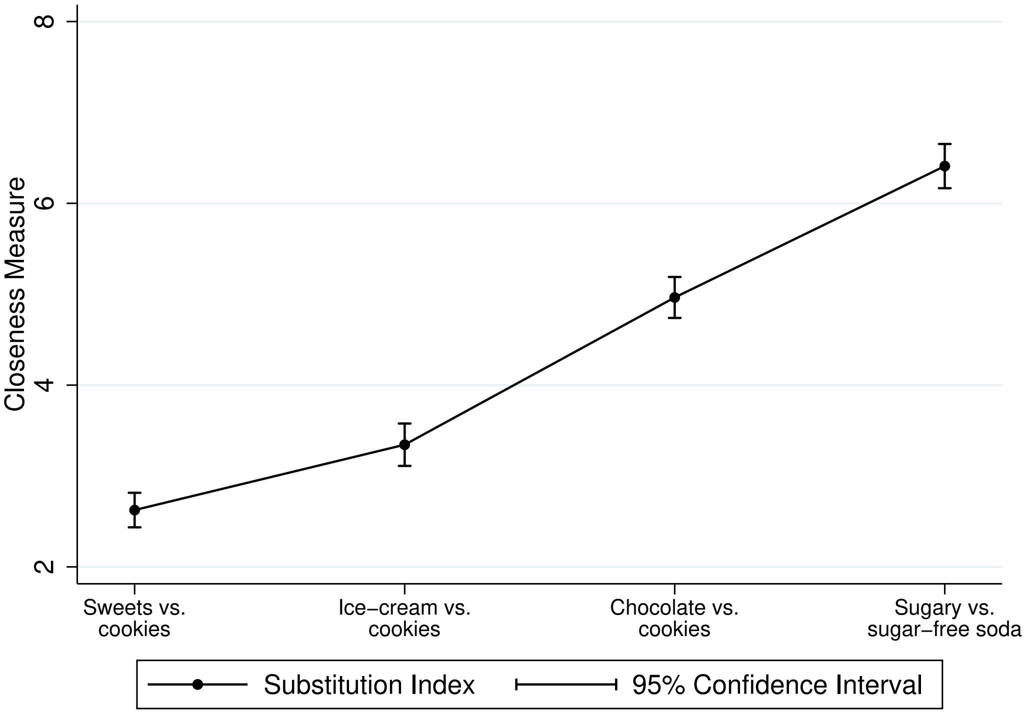
Note: The figure shows the (compensated) own-price demand elasticity of a good in a two-good, two-characteristics Gorman-Lancaster model as a function of how substitutable the goods are with each other. This is measured by how similar the characteristics vectors of the goods are as outlined in section 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: Distributions of substitution preferences



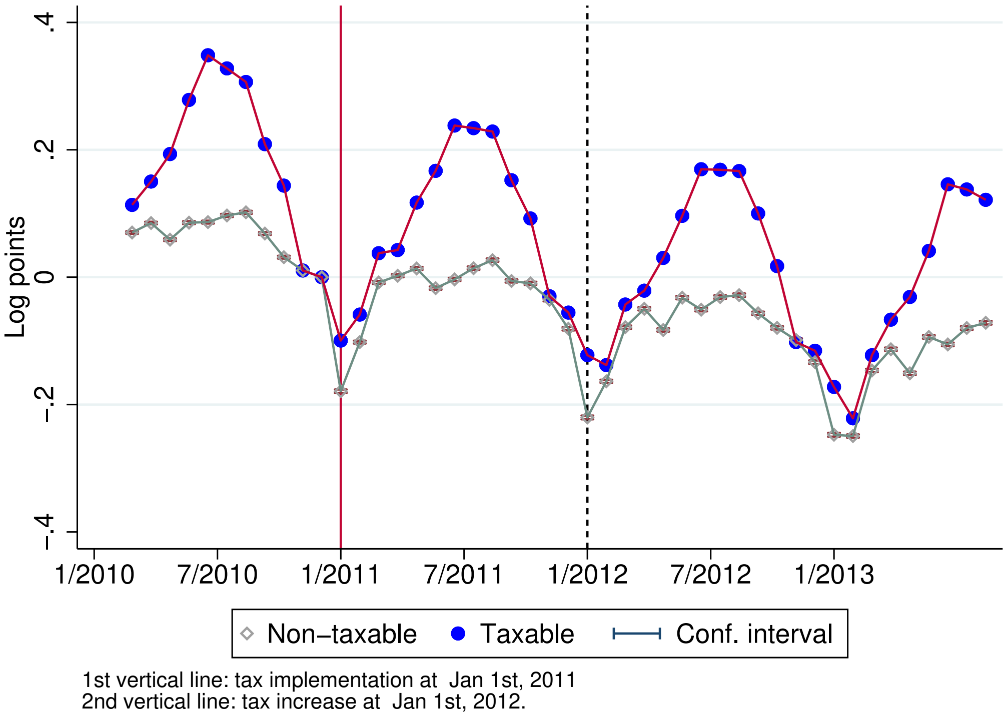
Note: The figure shows distributions of the answers to the survey question "On a scale from 0 to 10, how substitutable are these products for you?" for taxed product categories compared to their closest non-tax category. The closest non-tax category is chosen by the same index. The more the distribution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

Figure 4: 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.

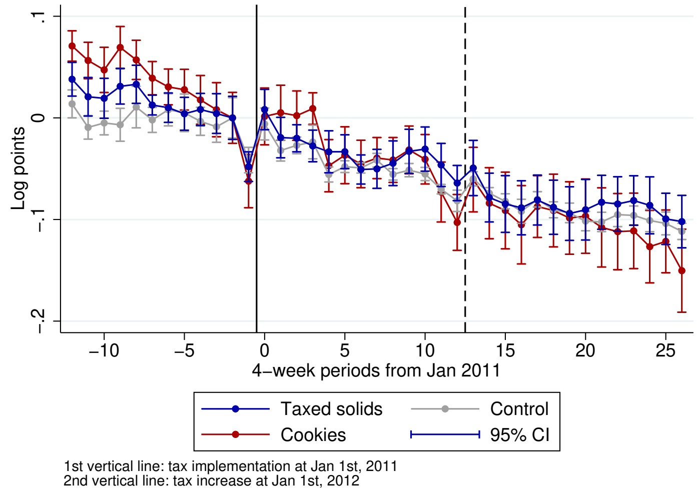
Figure 5: Development of quantities, solid products in the 2011 and 2012 reforms, not de-seasonalized



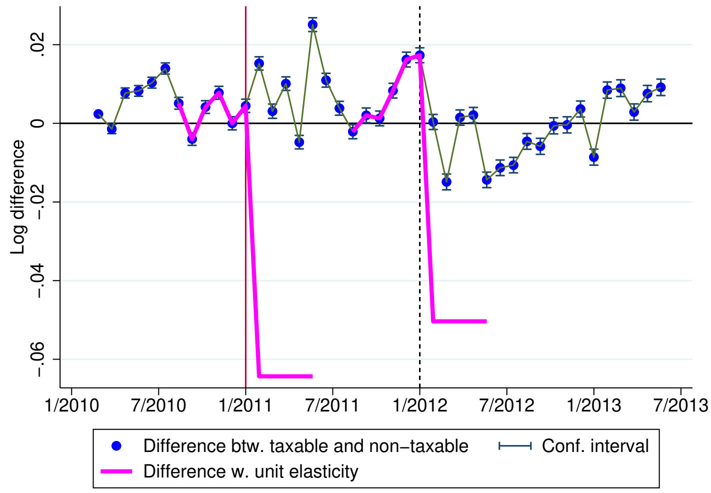
Note: The figure shows regression coefficients for month dummies from regressions of log number of products sold with product-outlet fixed effects (estimates of equation (3)). The graph displays strong within year seasonality, such that the difference between the peak in summer months to the lowest point in winter is close to 0.4 log points. 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 6: Development of de-seasonalized quantities, solid products in the 2011 and 2012 reforms

(a) Trends: taxed solids, versus control group and cookies



(b) Comparison to unit elasticity case

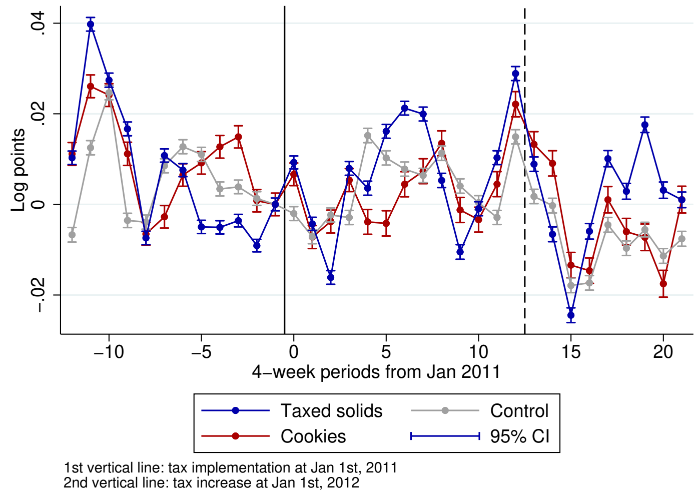


Note: Panel (a) shows regression coefficients for month dummies from regressions of log number of products sold with product-outlet fixed effects (estimates of equation (3)) for three groups: taxed solids, a control group, and cookies which constitute a substitution group. The three series move similarly around the 2011 and 2012 reforms. Taxable solids include all solid taxable products in the 2011 and 2012 reforms: mainly sweets, chocolate and ice cream. The control group include solid products that were not included in the 2011 and 2012 reforms excluding cookies: mainly 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. The series' are normalized to zero two months before the 2011 reform.

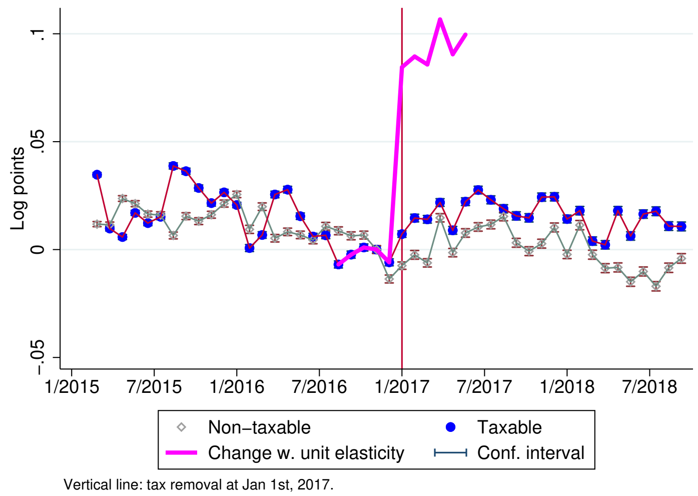
Panel b) shows the difference in log number of products sold between taxable and non-taxable solids around the 2011 and 2012 reforms. The difference fluctuates around zero showing non systematic effect of the reform for quantities. Taxable products include all solid taxable products in the 2011 and 2012 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 7: Development of de-seasonalized quantities, solid products in the 2017 reform

(a) Trends: taxed solids, versus control group and cookies



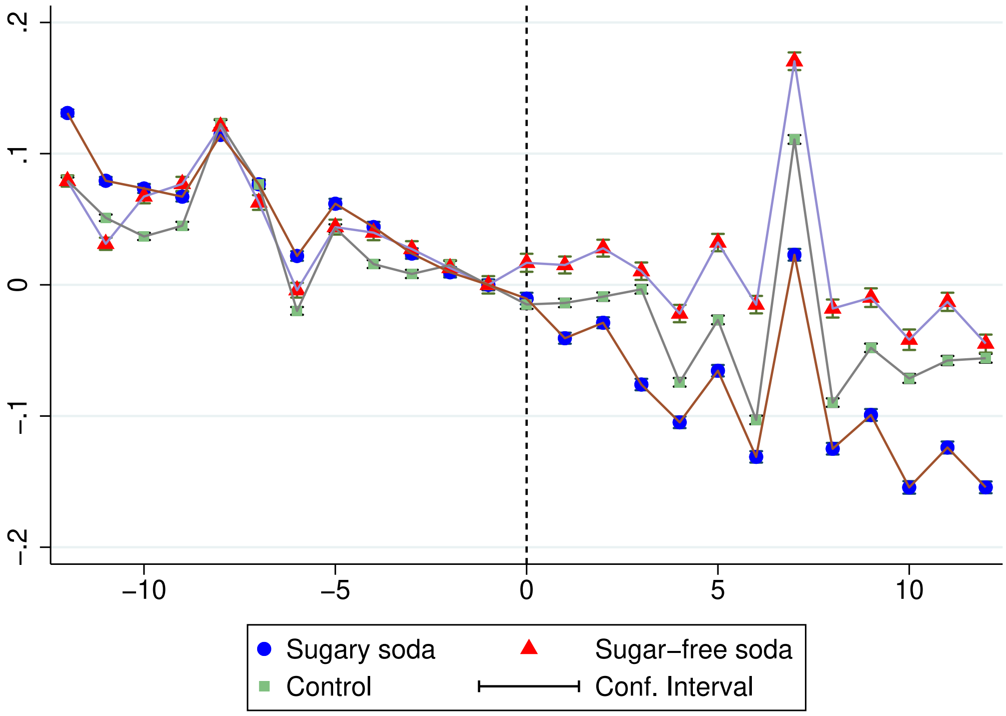
(b) Comparison to unit elasticity case



Note: Panel (a) shows regression coefficients for month dummies from regressions of log number of products sold with product-outlet fixed effects (estimates of equation (3)) for three groups: taxed solids, a control group, and cookies which constitute a substitution group. The three series move similarly around the 2017 reform with some idiosyncratic variation across months. Taxable solids include all solid taxable products in the 2017 reform: mainly sweets, chocolate and ice cream. The control group include solid products that were not included in the 2017 reforms excluding cookies: mainly 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. The series' are normalized to zero one month before the 2017 reform.

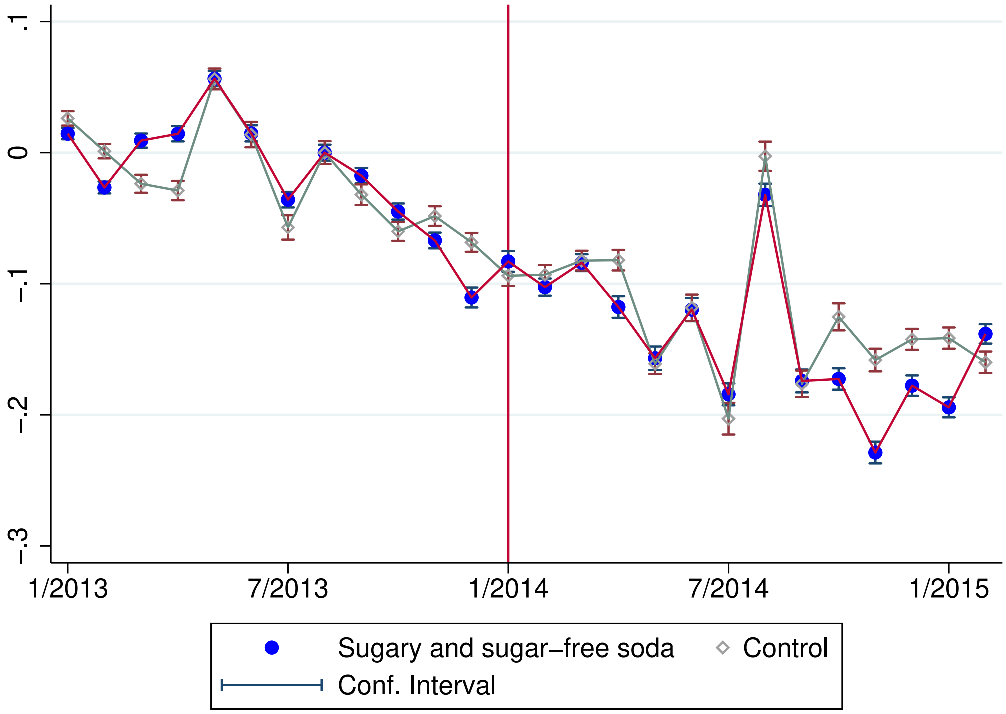
Panel b) shows regression coefficients for month dummies from regressions of log number of products sold with product-outlet fixed effects (estimates of equation (3)). Taxable products include all solid taxable products in the 2017 reform: mainly sweets, chocolate and ice cream. Non-taxable products include solid products that were not included in the 2017: 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. The vertical line indicates the 2017 removal of the sweets tax for solid products. The series are normalized to zero at the last month prior to the 2017 reform and are seasonally corrected.

Figure 8: Development of sugary vs sugar-free soda vs common control group sales in the 2014 reform



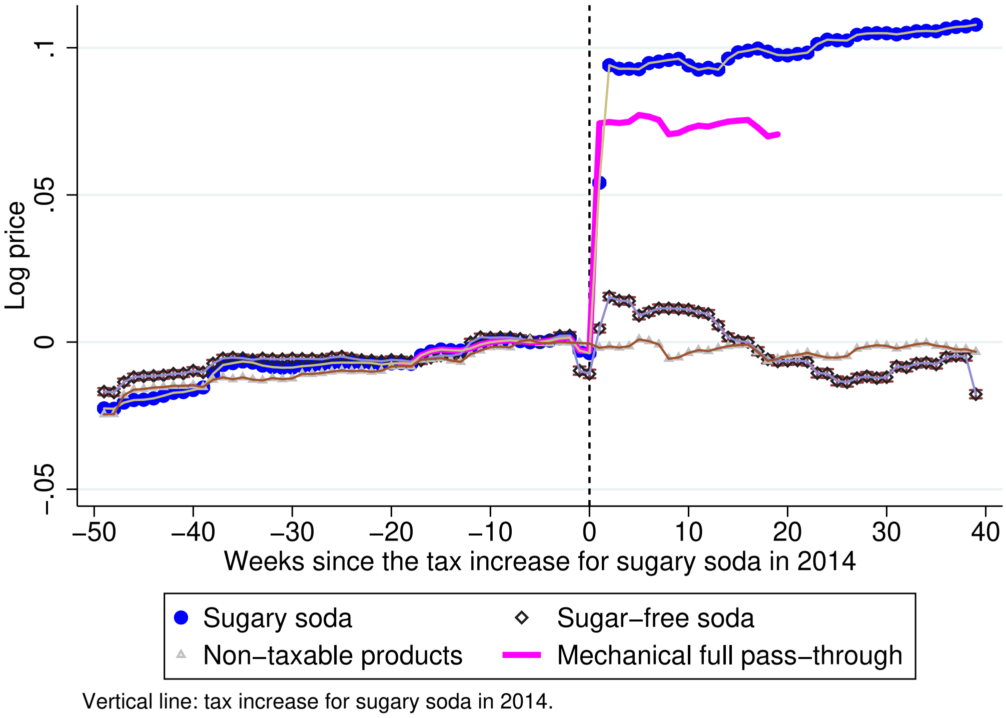
Note: The figure shows regression coefficients for month dummies from regressions of log volume of products sold with product-outlet fixed effects (estimates of equation (3)) for sugary (subject to reform) and sugar-free soda (not subject to reform) and a control group of ice-cream (not subject to reform). The figure shows that the three series develop in parallel prior to the reform and deviate from each other at the time of the reform such that the sales of sugary soda decline and sugar-free soda increase relative to the control group. 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 9: Development of total soda sales in the 2014 reform



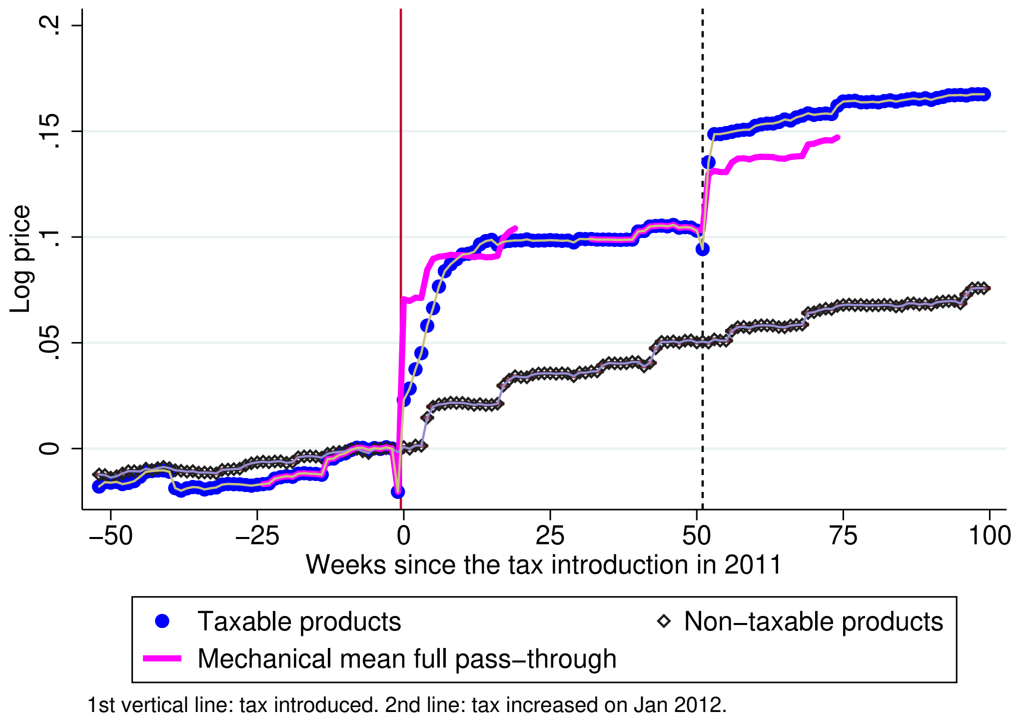
Note: The figure shows regression coefficients for month dummies from regressions of log volume of products sold with product-outlet fixed effects (estimates of equation (3)). The figure shows that the two groups develop in parallel both before and after the reform such that the sales of soda sales in total do not decline after the reform relative to the control group. 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 10: Development of log soda price by sugar content and comparison prices in the 2014 reform



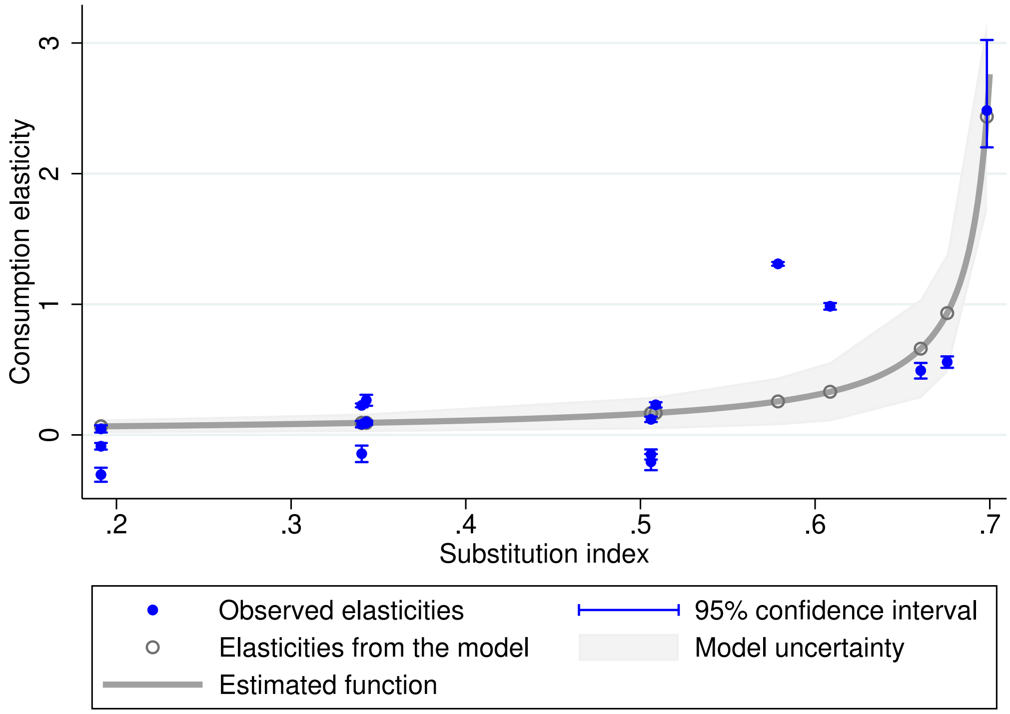
Note: The figure shows regression coefficients for week dummies from regressions of log volume-based prices with product-outlet fixed effects (estimates of equation (3)) for sugary (subject to reform) and sugar-free soda (not subject to reform) and a comparison group of non-taxable products. The figure shows that log prices of sugary soda products jump to a higher level of about 0.1 log points right at the reform and relative to sugar-free soda or the control group. 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 11: Development of log unit prices in the 2011 and 2012 reforms



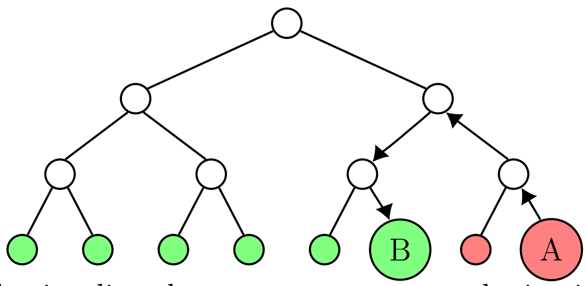
Note: The figure shows regression coefficients for week dummies from regressions of log unit prices with product-outlet fixed effects (estimates of equation (3)). The figure shows that prices of taxable products increase after the reform, and that there is a general increase in the prices of non-taxable products as well. The prices of taxable products end up at about 0.1 log points higher level than the prices of non taxable products after the 2012 reform. 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 12: Fitted values of the model



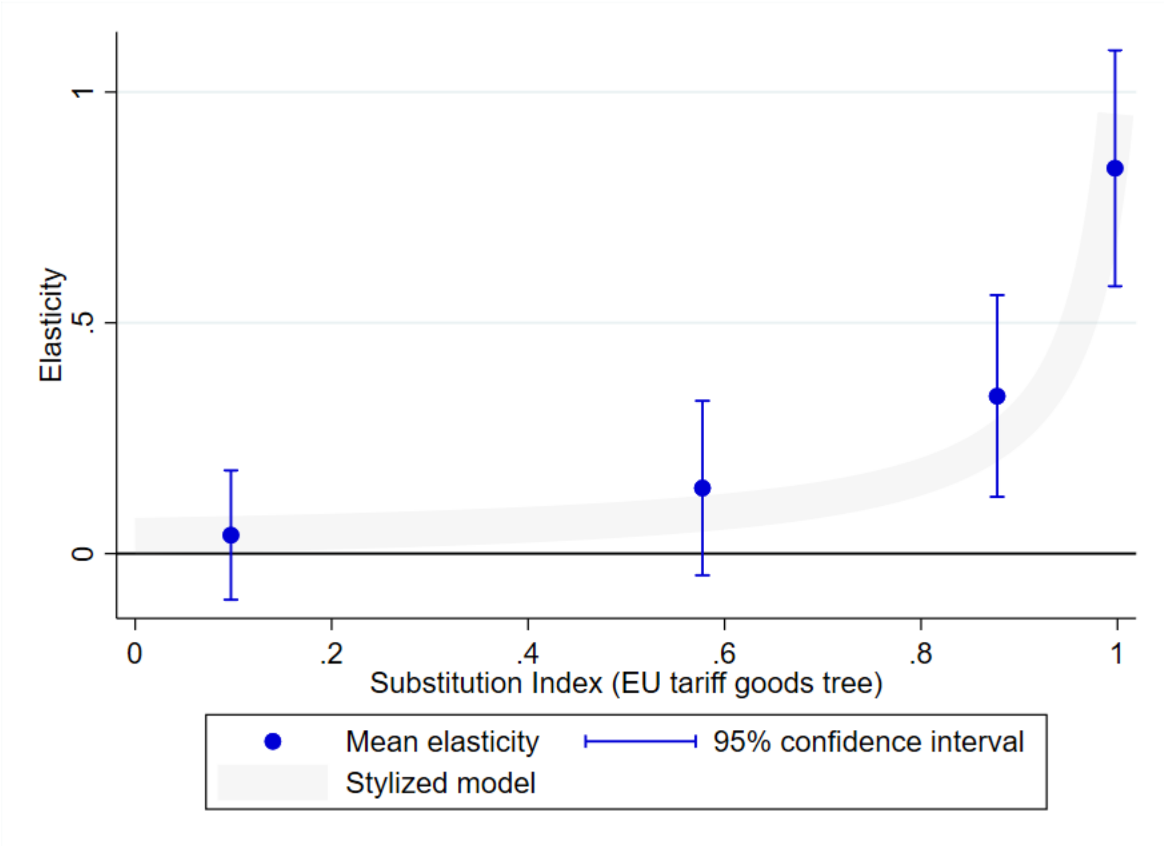
Note: The figure shows estimates of consumption elasticities for various sub-groups of products, and fitted values from an empirically applicable version of our model organized by the substitution index of the product group facing tax changes and the closest product-group not facing tax changes in the horizontal axis. The figure shows that the consumption elasticity grows non-linearly and reach significantly higher than zero level only when the substitution index reaches level of about 0.6 with the highest level being 1. This highly convex pattern holds for botht the estimated elasticities and the prediction from the theory model.

Figure 13: Illustration of a substitution index based on the EU-tariff tree



Notes: This graph visualizes how we construct a substitution index from the EU-tariff goods tree. Each level in the tree here represents a two-digit category level, with the highest node corresponding to a category encompassing all goods in the tree. Here, we note taxed categories by red and non-taxed categories by green. As an example, when we construct the substitution index for goods in the category A, then B is a closest non-taxed category. The shortest route from A to B goes through two levels of categories. The longest possible route goes through three levels, the length of which we normalize to 1. Hence, the normalized distance (d) from A to B is $2/3$. We define the substitution index as $1 - d^2$, where the square comes from the idea that the number of plausible substitution categories at a similar distance increases approximately to the power of two.

Figure 14: Elasticities from the literature versus the substitution index from the EU tariff goods tree



Note: This figure plots meta-analysis estimates of elasticities from previous literature in four categories using a DerSimonian-Laird random-effects model. The figure shows a highly convex pattern similar to our estimates from the sweets tax scheme and aligns well witht the prediction from our theory model presented in a shaded grey curve underneath the estimated elasticities from the literature. The 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

	Stat	Price	Pieces	Prices: Sweets	Prices: Ice	Prices: 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: Quantity and price changes and elasticities in the 2011-2012 reforms, Taxed solids

	(1)	(2)
Quantity change	-0.003	-0.004
	(0.001)	(0.001)
Price change	0.154	0.143
	(0.001)	(0.001)
Elasticity		-0.028
		(0.001)
N	23,195,177	23,186,261
4-week FE's	X	X
Product–outlet FE's		X

Notes: This table provides difference-in-differences estimates of the quantity and price responses and associated elasticities of taxed solids in the 2011-2012 reforms. Estimate for quantities is -0.004, estimate for prices is 0.143, and estimate for elasticity is -0.028. The control group is non-taxed solids without cookies. The estimates compare seasonalized log outcomes pre-reform (2010) to post-reform (2012). There are two specifications: (1) controls for 4-week fixed effects, while (2) adds product–outlet fixed effects. Outcomes are seasonalized, and standard errors are clustered at the product–outlet level.

Table 3: Quantity and price changes and elasticities in the 2017 reforms, Taxed solids

	(1)	(2)
Quantity change	0.002	-0.002
	(0.001)	(0.001)
Price change	-0.091	-0.074
	(0.001)	(0.001)
Elasticity		0.026
		(0.009)
N	21,431,086	21,418,727
4-week FE's	X	X
Product–outlet FE's		X

Notes: This table provides difference-in-differences estimates of the quantity and price responses and associated elasticities of taxed solids in the 2017 tax removal for solids. Estimate for quantities is -0.002, estimate for prices is -0.074, and estimate for elasticity is 0.028, which would imply a slight decrease in quantity sold due to removal of the tax. The control group is non-taxed solids without cookies. The estimates compare seasonalized log outcomes pre-reform (2016) to post-reform (2017). There are two specifications: (1) controls for 4-week fixed effects, while (2) adds product–outlet fixed effects. Outcomes are seasonalized, and standard errors are clustered at the product–outlet level.

Table 4: Quantity and price changes and elasticities in the 2014 reforms, Taxed soft drinks

	(1)	(2)	(3)	(4)
Quantity change	-0.061	-0.049	-0.049	-0.042
	(0.001)	(0.001)	(0.001)	(0.001)
Price change	-0.001	0.045	0.043	0.041
	(0.001)	(0.001)	(0.001)	(0.001)
Elasticity		-1.008		-1.028
		(0.036)		(0.040)
N	5,349,212	5,345,110	27,276,290	27,265,710
Control group	Ice-cream	Ice-cream	Solids	Solids
4-week FE's	X	X	X	X
Product–outlet FE's		X		X

Notes: This table provides difference-in-differences estimates of the quantity and price responses and associated elasticities of taxed (sugary) sodas in the 2014 tax increase for sugary liquids. Estimate for quantities is -0.049, estimate for prices is 0.045, and estimate for elasticity is -1.008. The control group is ice-creams. The estimates compare de-seasonalized log outcomes pre-reform (2013) to post-reform (2014). There are two specifications: (1) controls for 4-week fixed effects, while (2) adds product–outlet fixed effects. Columns (3) and (4) present similar estimates but use solid products as the control group. Outcomes are de-seasonalized, and standard errors are clustered at the product–outlet level.

Table 5: Quantity and price changes and elasticities by sub-groups, preferred estimates

	Sweets	Ice-cream	Chocolate	Sugary soda
Quantity change	0.004	-0.001	0.008	-0.049
	(0.001)	(0.001)	(0.001)	(0.001)
Price change	0.082	0.136	0.086	0.045
	(0.001)	(0.001)	(0.001)	(0.001)
Elasticity	0.044	-0.007	0.097	-1.008
	(0.006)	(0.004)	(0.008)	(0.036)
N	11,311,024	9,828,089	8,720,756	5,345,110
Control group	Non-taxed solids w/o cookies	Non-taxed solids w/o cookies	Non-taxed solids w/o cookies	Ice-cream
Tax reform	2011	2011	2011	2014

Notes: This table provides our preferred difference-in-differences estimates of the quantity and price responses and associated elasticities of taxed product categories. The sub-groups are: sweets, ice-cream, chocolate and sugary soda. Elasticity estimates are -0.060, 0.0, , and -1.008, respectively. The estimates compare de-seasonalized log outcomes one year before a given reform to one year post-reform. Outcomes are de-seasonalized, and standard errors are clustered at the product–outlet level. Estimates from the 2011 reform compare outcomes of the last six months of 2011 to outcomes of 2012 due to noise in the data during the first six months of 2011.

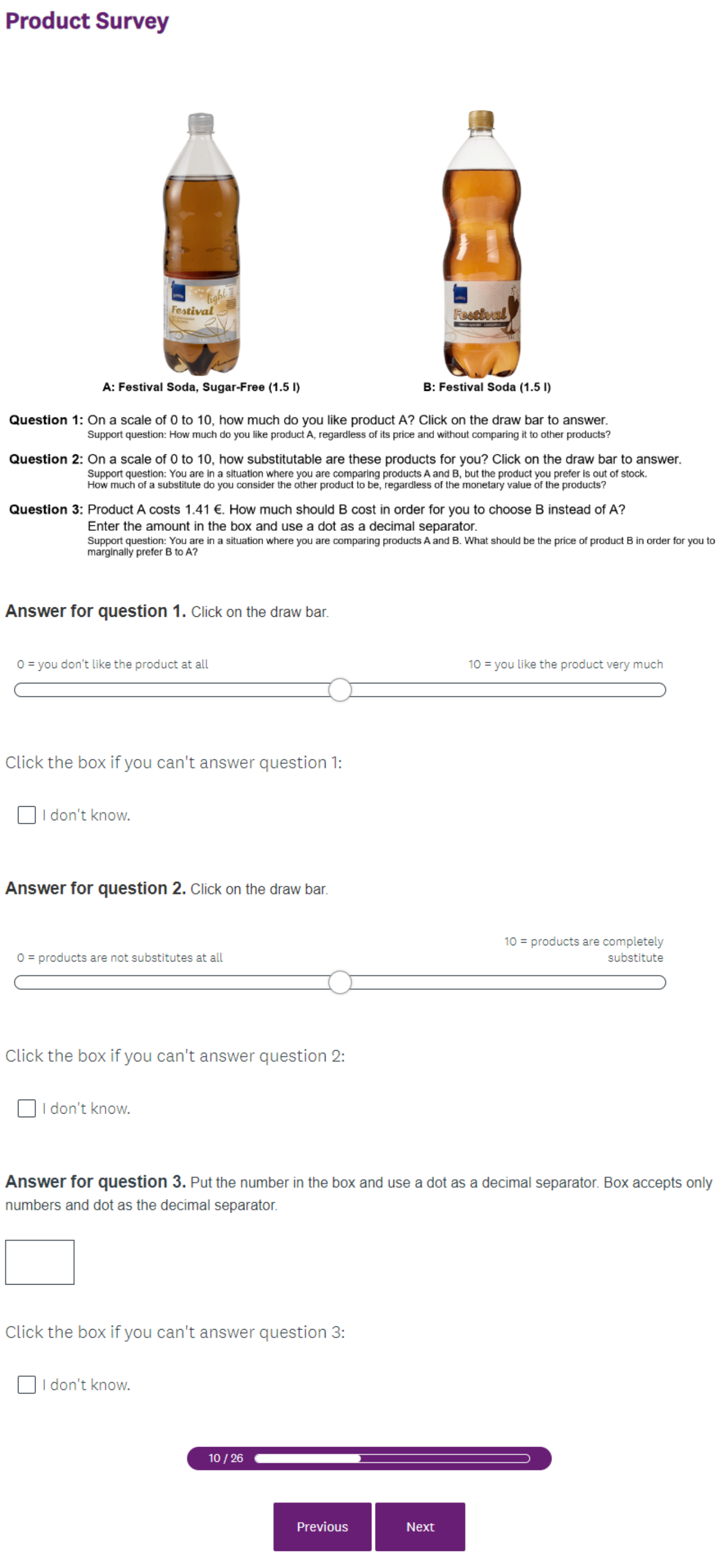
Table 6: Studies included in the meta-analysis

Study	Good	Closest substitute	Cat.	SI	Elasticity
Allcott and Rafkin (2022)	Cigarettes	Other tobacco prod.	0	0.9975	1.908
Allcott and Rafkin (2022)	E-cigarettes	Other nicotine prod.	0	0.9975	1.318
Cawley et al. (2020)	Sweetened beverages	Non-sweetened beverages	0*	0.9975	1.300
Chiou and Muehlegger (2014)	Cigarettes	Other tobacco prod.	0	0.9975	0.355
Colantuoni and Rojas (2015)	Sweetened beverages	Non-sweetened beverages	0*	0.9975	0.250
Colantuoni and Rojas (2015)	Sweetened beverages	Non-sweetened beverages	0*	0.9975	0.154
Cotti et al. (2016)	Chewing tobacco	Other tobacco prod.	0	0.9975	0.206
Cotti et al. (2016)	Snuff	Other tobacco prod.	0	0.9975	0.849
Cotti et al. (2016)	Cigarettes	Other tobacco prod.	0	0.9975	2.200
Cotti et al. (2016)	E-cigarettes	Other nicotine prod.	0	0.9975	0.440
Evans et al. (1999)	Cigarettes	Other tobacco prod.	0	0.9975	0.294
Gruber et al. (2003)	Cigarettes	Other tobacco prod.	0	0.9975	0.450
Harding et al. (2012)	Cigarettes	Other tobacco prod.	0	0.9975	0.369
Lovenheim (2008)	Cigarettes	Other tobacco prod.	0	0.9975	0.457
Powell et al. (2020)	Sweetened beverages	Non-sweetened beverages	0*	0.9975	1.100
Roberto et al. (2019)	Sweetened beverages	Non-sweetened beverages	0*	0.9975	1.700
Rojas and Wang (2021)	Carbonated drinks	Non-carbonated drinks	0*	0.9975	0.970
Seiler et al. (2021)	Sweetened beverages	Non-sweetened beverages	0*	0.9975	0.650
Asplund et al. (2007)	Beer	Non-alcoholic drinks	1*	0.8775	0.467
Asplund et al. (2007)	Spirits	Non-alcoholic drinks	1*	0.8775	0.321
Asplund et al. (2007)	Wine	Non-alcoholic drinks	1*	0.8775	1.720
Gonçalves and dos Santos (2020)	Sweetened beverages	Non-sweetened beverages	1	0.8775	0.570
Gillingham et al. (2015)	Gasoline	Other forms of transport	2	0.5775	0.099
Hindriks and Serse (2022)	Electricity	Other forms of energy	2	0.5775	0.017
Langer et al. (2017)	Mile of travel by car	Other forms of transport	2	0.5775	0.150
Levin et al. (2017)	Gasoline	Other forms of transport	2	0.5775	0.301
Harju and Kosonen (2010)	Restaurant meals	Home-made meals	3	0.0975	-0.045
Kosonen (2015)	Haircuts	Home haircuts	3	0.0975	0.082
Merker (2023)	Sweets and beverages	Other food	3	0.0975	0.083

Note: Cat. refers to number of categories between taxed good and closest substitute good in the EU tariff tree. Category values with an asterisk (*) are reduced by one due to substantial possibilities for cross-border shopping. SI refers to a EU tariff goods tree based substitution index.

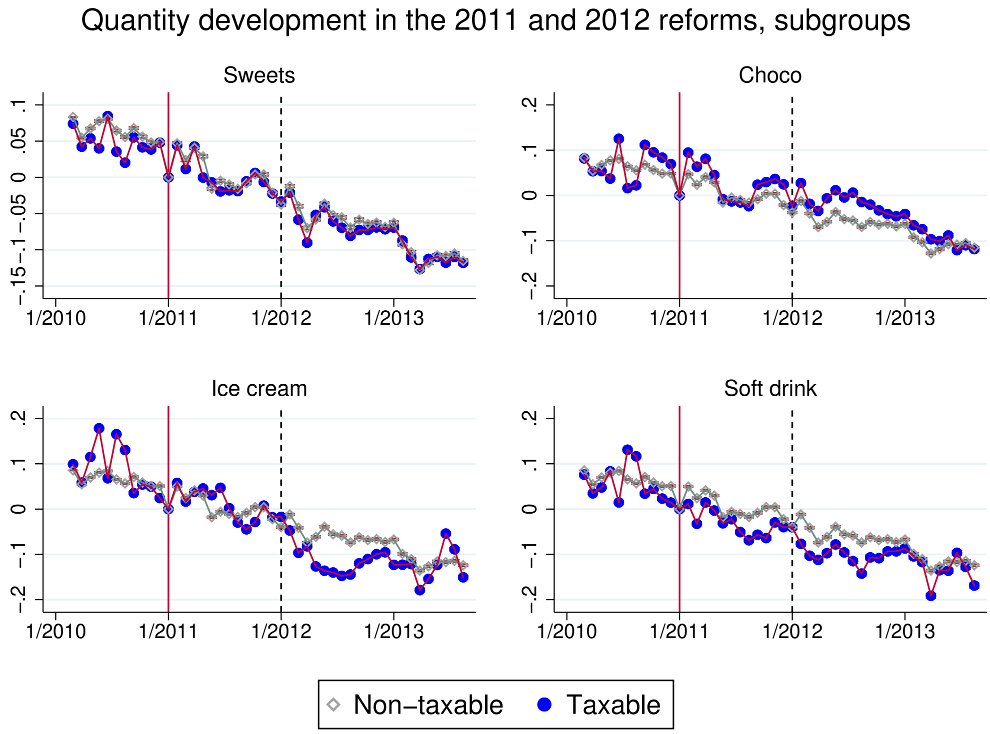
A APPENDIX

Figure A.1: Example of the substitution survey



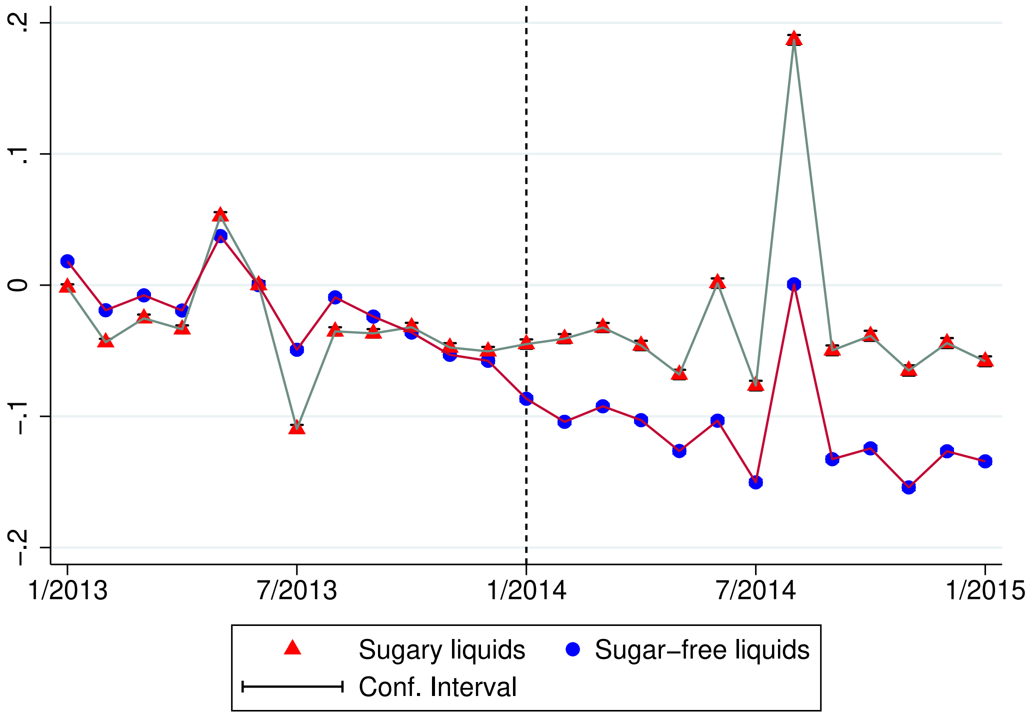
B APPENDIX - Additional figures and tables

Figure A.2: Development of quantities, various sub-categories of taxable products in the 2011 and 2012 reforms



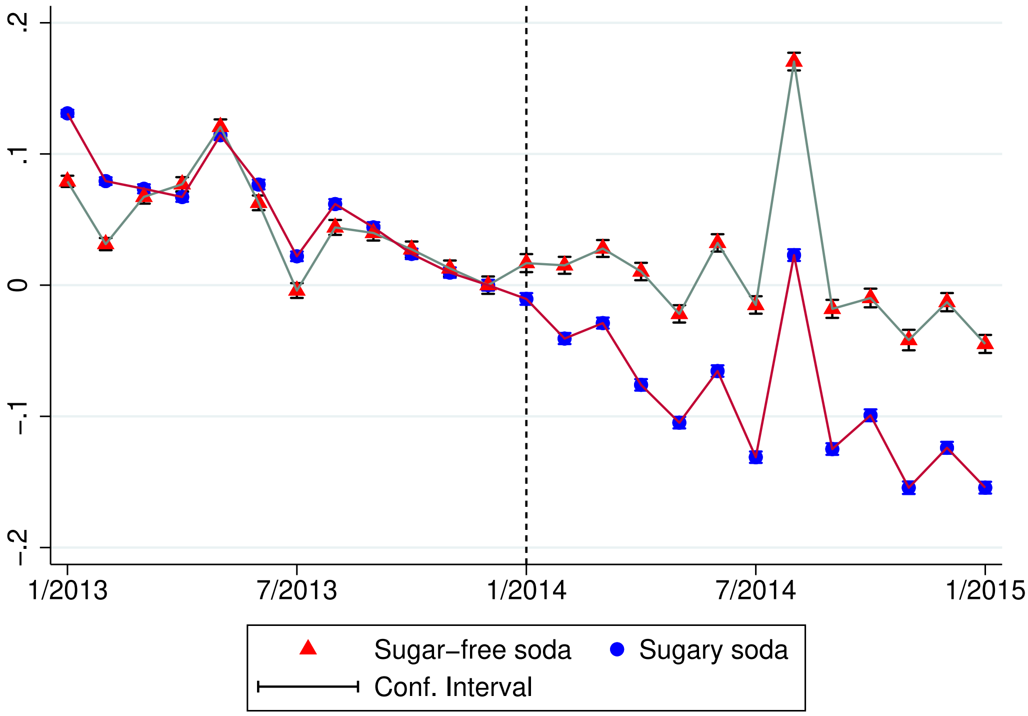
Note: The figure shows regression coefficients for month dummies from regressions of log volume of products sold with product-outlet fixed effects (estimates of equation (3)). Taxable products include sweets, chocolate, ice cream, and soft drinks, respectively. Non-taxable products include solid products 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.3: Development of sugary vs sugar-free liquids sales in the 2014 reform



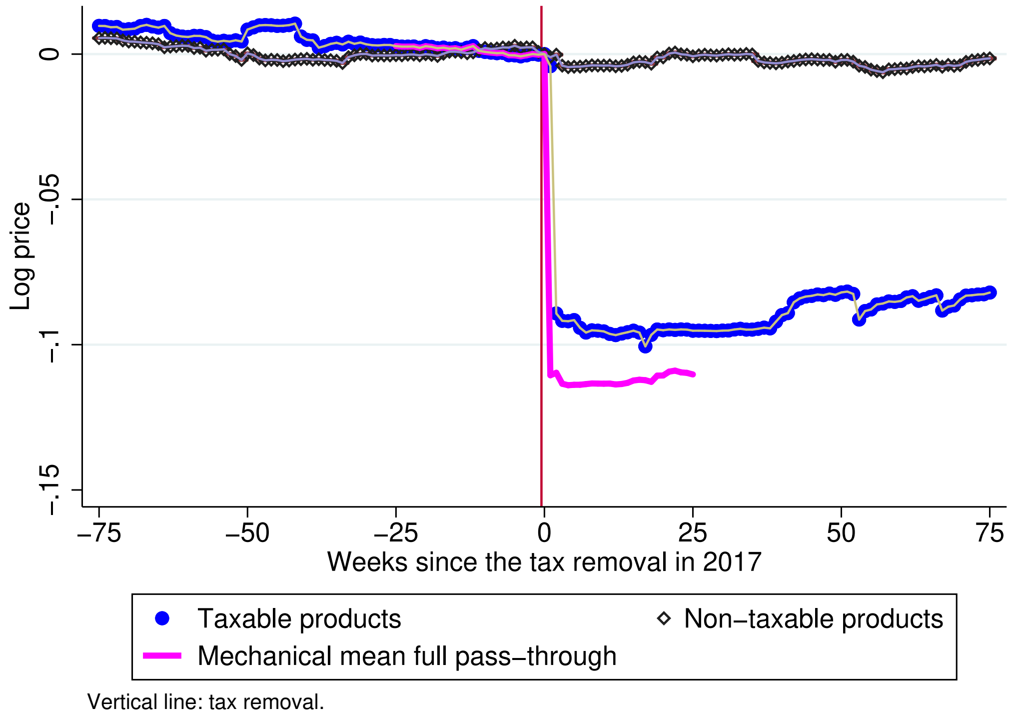
Note: The figure shows regression coefficients for month dummies from regressions of log volume of products sold with product-outlet fixed effects (estimates of equation (3)) for sugary (subject to reform) and sugar-free liquids (not subject to reform). The figure includes 95% confidence intervals surrounding 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.4: Development of sugary vs sugar-free soda sales in the 2014 reform



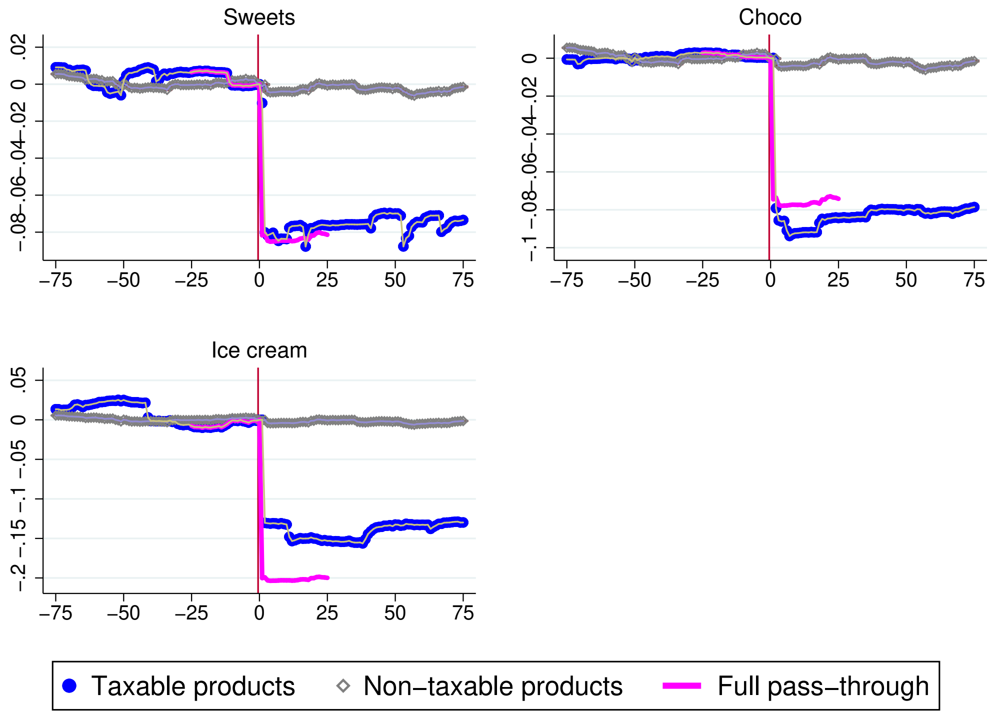
Note: The figure shows regression coefficients for month dummies from regressions of log volume of products sold with product-outlet fixed effects (estimates of equation (3)) for sugary (subject to reform) and sugar-free soda (not subject to reform). The figure includes 95% confidence intervals surrounding 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.5: Development of log unit prices in the 2017 reform



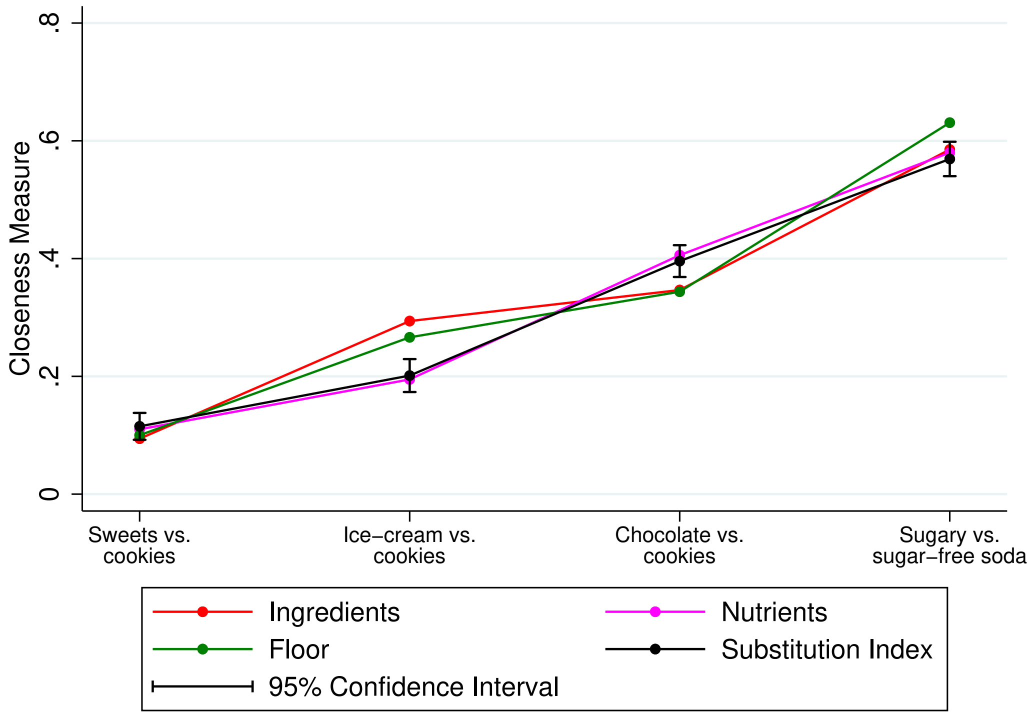
Note: The figure shows regression coefficients for week dummies from regressions of log unit prices with product-outlet fixed effects (estimates of equation (3)). Taxable products include all taxable products in the 2017 tax removal: mainly sweets, chocolate and ice cream, but no liquids. Non-taxable 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.6: Development of log unit prices, various sub-categories of taxable products in the 2017 reform



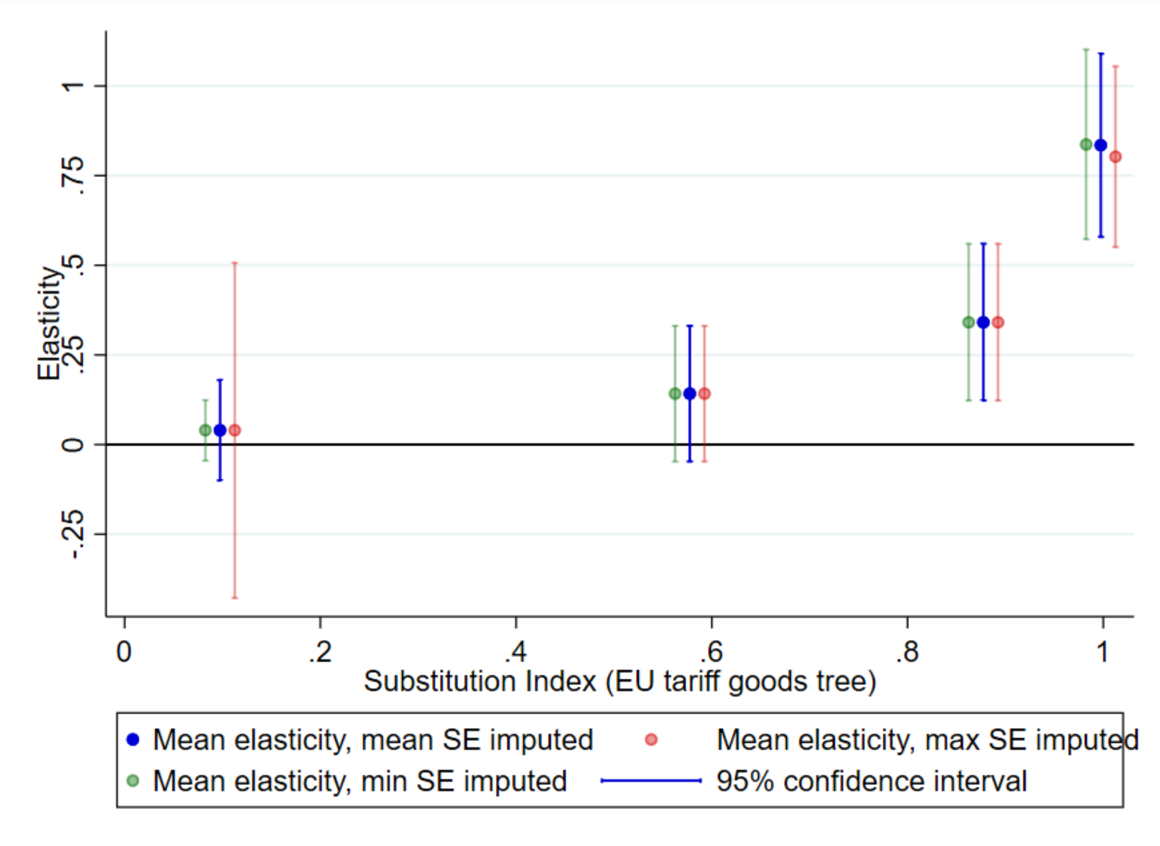
Note: The figures show regression coefficients for week dummies from regressions of log unit prices with product-outlet fixed effects (estimates of equation (3)). Taxable products include sweets, chocolate and ice cream, respectively. Non-taxable products include all products in our data that were not 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.7: 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.

Figure A.8: Elasticities from the literature versus the substitution index from the EU tariff goods tree



Note: This figure plots meta-analysis results for elasticities from previous literature in four categories using a DerSimonian-Laird random-effects model. The 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). Different series represent different meta-analysis estimates of elasticities for the groups based on different assumptions made on missing standard error values. These are either imputed to match the minimum, mean or maximum standardized standard errors of the sample of estimates that report standard errors.

Table A.1: Quantity and price changes and elasticities in the 2014 reforms, Taxed liquids

	(1)	(2)
Quantity change	-0.036	-0.013
	(0.001)	(0.001)
Price change	0.000	0.026
	(0.001)	(0.001)
Elasticity		-0.507
		(0.038)
N	12,899,354	12,896,760
4-week FE's	X	X
Product–outlet FE's		X

Notes: This table provides difference-in-differences estimates of the quantity and price responses and associated elasticities of taxed (sugary) sodas in the 2014 tax increase for sugary liquids. Estimate for quantities is -0.049, estimate for prices is 0.045, and estimate for elasticity is -1.008. The control group is ice-creams. The estimates compare seasonalized log outcomes pre-reform (2013) to post-reform (2014). There are two specifications: (1) controls for 4-week fixed effects, while (2) adds product–outlet fixed effects. Outcomes are seasonalized, and standard errors are clustered at the product–outlet level.

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[11], we have:

$$x = C^{-1}c. \tag{6}$$

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.

[11] 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 $(\alpha rc_{11} + (1-\alpha)c_{12}, ..., \alpha rc_{m1} + (1-\alpha)c_{m2})$ 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:

$$\frac{\partial x(\alpha)}{\partial \alpha} = -C(\alpha)^{-1}\frac{\partial C(\alpha)}{\partial \alpha}x(\alpha). \tag{7}$$

Note here that $\frac{\partial C(\alpha)}{\partial \alpha} = \begin{bmatrix} 0 & rc_{11} - c_{12} & 0 & \cdots & 0 \\ 0 & rc_{21} - c_{22} & 0 & \cdots & 0 \\ 0 & rc_{31} - c_{32} & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & 0 \\ 0 & rc_{m1} - c_{m2} & 0 & \cdots & 0 \end{bmatrix} = r[0_{m\times1}, C_{(1)}(\alpha), 0_{m\times1}, ..., 0_{m\times1}] - [0_{m\times1}, C_{(2)}, 0_{m\times1}, ..., 0_{m\times1}]$ 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:

$$\begin{aligned} C(\alpha)^{-1}\frac{\partial C(\alpha)}{\partial \alpha} &= r[C(\alpha)^{-1}0_{m\times1}, C(\alpha)^{-1}C_{(1)}(\alpha), C(\alpha)^{-1}0_{m\times1}, ..., C(\alpha)^{-1}0_{m\times1}] \\ &- [C(\alpha)^{-1}0_{m\times1}, C(\alpha)^{-1}C_{(2)}, C(\alpha)^{-1}0_{m\times1}, ..., C(\alpha)^{-1}0_{m\times1}]. \end{aligned}$$

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:

$$C(\alpha)^{-1}\frac{\partial C(\alpha)}{\partial \alpha} = \begin{bmatrix} 0 & r & \cdots & 0 \\ 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \cdots & 0 \end{bmatrix} - [0_{m\times 1}, C(\alpha)^{-1}C_{(2)}, 0_{m\times 1}, ..., 0_{m\times 1}]. \tag{8}$$

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 8, 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 7 we have:

$$\frac{\partial x(\alpha)}{\partial \alpha} = \begin{bmatrix} 0 & -\frac{1}{1-\alpha}r & \cdots & 0 \\ 0 & \frac{1}{1-\alpha} & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \cdots & 0 \end{bmatrix} x(\alpha) = \begin{bmatrix} -\frac{1}{1-\alpha}rx_2(\alpha) \\ \frac{1}{1-\alpha}x_2(\alpha) \\ 0 \\ \vdots \\ 0 \end{bmatrix}. \tag{9}$$

Note that, by 6, $x_2(\alpha) = C(\alpha)_2^{-1}c$ where $C(\alpha)_2^{-1}$ is the second row of $C(\alpha)^{-1}$. Using Cramer's rule, we have that:

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

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 10 depend on the second column of $C(\alpha)$. As only the second column of $C(\alpha)$ depends on α, none of the cofactors in 10 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 10 that:

$$\begin{aligned} x_2(\alpha) &= C(\alpha)_2^{-1}c \\ &= \frac{1}{detC(\alpha)}[D_{12}(\alpha), D_{22}(\alpha), ..., D_{m2}(\alpha)]c \\ &= \frac{1}{1-\alpha}\frac{1}{detC}[D_{12}, D_{22}, ..., D_{m2}]c \\ &= \frac{1}{1-\alpha}C(\alpha|\alpha = 0)_2^{-1}c \\ &= \frac{1}{1-\alpha}x_2(\alpha|\alpha = 0) \\ &= \frac{1}{1-\alpha}x_2. \end{aligned} \tag{11}$$

Combining 11 with 9, 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 $\alpha = 0$:

$$\frac{\partial x(\alpha)}{\partial \alpha} = \begin{bmatrix} -\frac{1}{(1-\alpha)^2} r x_2 \\ \frac{1}{(1-\alpha)^2} x_2 \\ 0 \\ \vdots \\ 0 \end{bmatrix}. \tag{12}$$

Expression for $x(\alpha)$

Note that, by 12, 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 12, 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 11 and, as the demand for other goods is not affected by α, we have:

$$x(\alpha) = \begin{bmatrix} x_1 - \frac{\alpha}{1-\alpha} r x_2 \\ \frac{1}{1-\alpha} x_2 \\ x_3 \\ \vdots \\ x_m \end{bmatrix} \tag{13}$$

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

From 13 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 13, 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:

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