Essays on Sugar Taxes, Firm Behavior, and Policy Design

Taxes sur le sucre, comportement des entreprises et élaboration des politiques publiques

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Titre : Taxes sur le sucre, comportement des entreprises et élaboration des politiques publiques
Mots clés : Taxes sur le sucre, reformulation, organisation industrielle, santé publique.

Résumé : Cette thèse analyse le rôle des politiques fiscales dans la réduction de la consommation de sucre et l'amélioration de la santé publique. L'augmentation des taux d'obésité et des maladies liées à l'alimentation a conduit de nombreux gouvernements à travers le monde à mettre en place des taxes ciblant les produits à forte teneur en sucre, en particulier les boissons sucrées. Toutefois, plusieurs questions importantes demeurent quant à l'efficacité de ces politiques, à leur éventuelle extension à d'autres catégories alimentaires et à l'influence des réponses stratégiques des entreprises sur leur efficacité. Cette thèse contribue à ce débat en analysant comment les taxes sur le sucre affectent les choix des consommateurs, le comportement des entreprises et le bien-être issu des biens de consommation alimentaire.
Les résultats montrent que les taxes sur le sucre peuvent réduire de manière significative les achats de sucre, même si leur efficacité varie selon les marchés et les groupes de consommateurs. La reformulation des produits apparaît comme un levier majeur par lequel les taxes réduisent la consommation de sucre, représentant parfois une part importante de la réduction totale observée. Par ailleurs, la conception de la taxe joue un rôle déterminant. L'analyse montre que les taxes par paliers basées sur des seuils de teneur en sucre peuvent générer des gains de bien-être importants, en encourageant à la fois la substitution des consommateurs vers des produits plus sains et l'ajustement de la composition des produits par les entreprises.

Title : Essays on Sugar Taxes, Firm Behavior, and Policy Design
Keywords : Sugar Taxes, Product Reformulation, Industrial Organization, Public Health Policy.

Abstract : This thesis analyzes the role of fiscal policies in reducing sugar consumption and improving public health. Rising obesity rates and diet-related diseases have led many governments to implement taxes targeting products with high sugar content, particularly sugar-sweetened beverages. However, important questions remain regarding the broader effectiveness of such policies, their potential extension to other food categories, and the role played by firms' strategic responses. This thesis contributes to this debate by studying how sugar taxes affect consumer choices, firms' behavior, and welfare in food markets.
The results show that sugar taxes can significantly reduce sugar purchases, although their effectiveness varies across markets and consumer groups. Product reformulation emerges as a key channel through which taxes reduce sugar intake, sometimes accounting for a large share of the overall reduction. At the same time, the design of the tax plays an important role. The analysis shows that tiered taxes based on sugar thresholds can generate larger welfare gains than simpler tax structures by encouraging both consumer substitution toward healthier products and firms' adjustments in product composition.

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Introduction

In 2022, over one billion people aged 5 years and older worldwide were living with obesity (NCD Risk Factor Collaboration, 2024). Obesity is responsible for health issues such as hypertension and diabetes (World Health Organization, 2016b; Guh et al., 2009). In 2019, the European social cost of overweight and obesity was estimated at approximately 464 billion euros, of which 141 billion euros were medical and non-medical direct costs, and 323 billion euros were indirect costs, including those of premature mortality and productivity losses (Okunogbe et al., 2022). The public health literature shows that obesity is associated with an excessive consumption of added sugars, among other nutrients (Te Morenga et al., 2013; Wang et al., 2015). Public authorities have implemented several kinds of policies, such as education campaigns to prevent abuse of added sugar, improvement of product labelling (European Parliament and Council of the European Union, 2011), and enhancement of nutrient consumption through collective agreements with manufacturers (HM Government, 2016). Yet, despite some positive results, these measures have proved insufficiently effective (Brambila-Macias et al., 2011; Public Health England, 2020).

Taxes on sugar-sweetened beverages have become an increasingly adopted policy instrument in efforts to reduce sugar consumption and address rising rates of obesity and diet-related diseases. As soon as in early 2020, more than 50 SSB taxes were already in force worldwide (Cawley et al., 2019a). As a growing number of countries have implemented such policies, a rapidly expanding empirical literature has studied their effects(Aguilar et al., 2021; Cawley et al., 2019b; Griffith et al., 2019a; Silver et al., 2017; Capacci et al., 2019) and motivation (Allcott et al., 2019b).

Ex-post evaluations of consumer reaction to SSB tax suggest positive effects, such as in Mexico where a tax led to a 12% decrease in the consumption of SSB (Colchero et al., 2015), or in Berkeley (California) where a tax led to a 10% decrease (Silver et al., 2017). A systematic review shows that SSB taxes have actually been effective in reducing purchases of the targeted SSBs by an average of -15% through price increases (Andreyeva et al., 2022). A limitation of the existing taxes is the narrowness of their scope, which only allows for small impacts on overall dietary intake (World Health Organization, 2022). Their extension to more unhealthy foods is considered by health authorities (World Health Organization, 2016a; Department for Environment, Food and Rural Affairs, 2020; The Lancet Gastroenterology & Hepatology, 2020). In line with the World Health Organization (WHO), which recommends developing policies to limit the intake of products high in free sugars (World Health Organization, 2015), food taxes have been considered to address this issue more effectively (Roberto et al., 2019; Royo-Bordonada et al., 2019; Cawley et al., 2019a; Lee et al., 2019; Pell et al., 2020, 2021). However, they are less common for other products than SSB, even if they are increasingly adopted (from seven member States of the WHO in 2017 to 29 in 2022, World Health Organization, 2022). For example, non-essential foods with more than 275kcal/100g are taxed in Mexico (World Cancer Research Fund International, 2022), and products high in sugar, salt and/or caffeine are targeted by the "Public Health Product Tax" in Hungary (Biro, 2015; World Cancer Research Fund International, 2022). In 2023, Colombia introduced an excise tax on ultra-processed foods based on unhealthy nutrients (Burki, 2023).

However, little is known about the potential effect of a similar tax for products other than non-alcoholic beverages. One of the main obectives pursue in this thesis is to assess and compare the effects of a hypothetical tax scenario on other markets. Three markets that are major contributors to sugar intake across all age groups (children, adolescents and adults) have been selected.

TABLE 1 – Contribution of non-alcoholic beverages, biscuits, and dairy desserts to added-sugar intakes by age group in France, the UK, and Spain

	France *Sugar* (2014-2015)			**UK** *Added sugar* (2014-2016)			**Spain** *Added sugar* (2013)		
	Non alc. beverages	Biscuits	Dairy desserts	Non alc. beverages	Biscuits	Dairy desserts	Non alc. beverages	Biscuits	Dairy desserts
Children	14.5% (2nd)	16.2% (1st)	13.7% (3rd)	22.2% (2nd)	8.7% (4th)	5.9% (5th)	24.5% (1st)	16.1% (4th)	18.0% (3rd)
Adolescents	20.3% (1st)	16.3% (2nd)	10.5% (3rd)	32.7% (1st)	8.3% (3rd)	2.5% (8th)	36.8% (1st)	13.1% (3rd)	11.1% (5th)
Adults	13.8% (3rd)	13.6% (4th)	9.7% (5th)	21.3% (2nd)	7.1% (4th)	2.8% (8th)	28.4% (1st)	15.1% (3rd)	11.9% (5th)

Notes : This table shows the contribution of non-alcoholic beverages, biscuits, and dairy desserts to added-sugar or sugar intakes for children, adolescents and adults in France, the UK and Spain. The age groups are 1-10, 11-17 and 18-79 for France ; 4-10, 11-18 and 19-64 for the UK ; 9-12, 13-17 and 18-64 for Spain. The number in parentheses indicates the rank of the category. For France, the categories considered are "Soft drinks ; Fruit and vegetables juices", "Pastries, cakes and biscuits", "Yoghurts and fromage frais ; Entremets and dessert creams" (Anses, 2017; Dubuisson et al., 2019). For the UK, the categories considered are "Fruit juices ; Soft drinks", "Biscuits", "Yoghurt, fromage frais and other dairy desserts" (Public Health England, 2018). For Spain, the categories considered are "Sugar soft drinks ; Juices and nectars", "Bakery and pastries", "Yogurt and fermented milks ; Other dairy products" (Ruiz et al., 2017).

To achieve this objective, in the first chapter, we carry out ex-ante evaluations and comparisons of the effects of a sugar tax on the purchased quantity of non-alcoholic beverages, biscuits and dairy desserts by households in the UK, France, and Spain. Specifically, we apply a three-step structural econometric strategy, following Bonnet and Réquillart (2013). In a first step, we use scanner data purchases from France, the UK and Spain, which are nationally representative of their population, to estimate a discrete choice model of demand in each market allowing for substitutions between varieties of products. We represent consumer preferences using a Random Coefficient Logit model (McFadden and Train, 2000), controlling for the endogeneity of prices (Petrin and Train, 2010). This estimation approach identifies household-specific preference parameters and the demand curves for the varieties of biscuits, non-alcoholic beverages or dairy desserts in the three countries. In a second step, we model the supply side as an oligopoly proposing differentiated products and competing *à la Nash* in a Bertrand game, in the spirit of Berry et al. (1995) and Nevo (2001). This step allows for the consideration of the pricing strategy responses of firms facing taxes. As shown by Bonnet and Réquillart (2013), the firms' price response to tax depends on the competitive environment of the market and can influence the effectiveness of such policies in reducing consumption. We use estimated demand curves and the supply model to identify price-cost margins and unit production costs for each product. Using these models, we simulate the effect of a tax on each market by modelling how firms' prices and consumers' purchases would react to the tax. We simulate the impact of a two-tiered, sugar-based tax, as implemented in the UK's non-alcoholic beverage market. Our findings show that, in each market and country, firms generally pass on more than the amount of tax, which results in a reduction in purchases and sugar intake. The tax is most efficient in the non-alcoholic beverage market in the three countries, in the French dairy dessert market, and among households where all the adults are overweight or obese. Reducing sugar intake would impact society as a whole. The introduction of these taxes reduces both consumer surplus and firm profits. However, these losses may be offset by the health-related social benefits they generate. When accounting for consumer surplus, firm profits, fiscal revenue, and the social costs of excessive sugar consumption, we find an overall positive effect on total welfare.

In the second chapter, our objective is to show that extending the tax to foods beyond sodas can effectively reduce sugar purchases. We focus our analysis on a sugar tax on the French dessert market, i.e. compotes, yogurts, fromages blancs/petits suisses (FBPS) and other dairy desserts (ODD).[1] Desserts are important contributors to simple carbohydrate intake. In particular, yogurts and FBPS were the second largest contributors (9.4%) to the sugar intake of French children aged

1. We have decided to tax sugar. Taxing fat in desserts would have been another option. However, a significant proportion of the fat comes from milk, the basic ingredient in yogurt and FBPS, which is also a source of essential minerals (e.g. calcium and magnesium). In contrast, with the exception of sugar from fruit in compotes, most of the sugar in desserts is added sugar.

1 to 10 years in 2014-2015, and the fifth-largest (6.7% of total sugar intake) for French adults aged 18 to 79 years (French Agency for Food, Environmental and Occupational Health & Safety, 2017). We evaluate the impact of a sugar-based excise tax with a single threshold. Compared with other fiscal instruments (e.g. VAT, sales taxes, or taxes based only on volume), nutrient-based tiered excise taxes are increasingly recognized as more effective in improving health outcomes, since they directly target the nutrient responsible for health harms (Allcott et al., 2019a; Grummon et al., 2019) and can encourage reformulation. From a theoretical perspective, such a design provides firms with clear incentives to reformulate products : Réquillart et al. (2016) show that when thresholds are not excessively stringent, firms prefer to reduce sugar content rather than pay the tax, generating positive health and welfare outcomes (see also Duvaleix-Tréguer et al. 2012). Empirical evidence supports this mechanism. Several studies show that firms strategically reduced sugar content to fall just below the lower levy threshold (Scarborough et al., 2020; Pell et al., 2021; Allais et al., 2023). This firms' strategic reaction of bunching at the threshold to avoid the policy was also found for warning label policy in Chile (Barahona et al., 2023). Overall, this evidence supports the choice of an excise tax on sugar with a single threshold, as even this straightforward design appears sufficient to encourage reformulation.

To assess the impact of the tax in the French dessert market, we develop and estimate a model of supply and demand for dessert that accounts for consumer food substitution patterns and firms' pricing strategies. We also consider a likely product reformulation response in which firms reformulate their products to avoid the tax, when it is technically and sensorially feasible. On the demand side, consumers care about the price and taste of products. We model consumer preferences using a random coefficient logit model, controlling for endogeneity of prices. It captures heterogeneity in observed and unobserved consumer preferences and allows for flexible substitution patterns between differentiated products in the market. Consumer preferences are estimated using household-level scanner data from a representative panel of French households on dessert purchases describing product and household characteristics. On the supply side, firms compete on prices to maximize profit. We model the supply side as an oligopoly offering differentiated products and competing à la Nash in a Bertrand game, in the spirit of Berry et al. (1995) and Nevo (2001).

Consistent with previous evidence (Scarborough et al., 2020; Pell et al., 2021; Allais et al., 2023), we assume that firms reformulate by lowering added sugar so that the final sugar content of the product is just below the threshold when feasible, while leaving recipes unchanged otherwise.

Our findings highlight that the tax could encourage consumers to switch to categories or products with lower sugar content, thereby steering them away from non-reformulated and high-sugar options. The effect on sugar intake varies widely across the population, but more than a quarter of French households reduce their sugar intake by more than three teaspoons per week. Furthermore, we demonstrate that the taxation scenario combined with our likely reformulation assumptions implies a smaller reduction in sugar intake but reduces the economic costs incurred by consumers and firms, compared to a taxation scenario without reformulation. This study highlights the decisive role of reformulation in the acceptability of the tax : although it mitigates the health impact of the tax, it increases its acceptability by limiting losses for consumers and producers. These results underscore the importance for public policymakers to design taxes that encourage companies to reformulate in order to achieve substantial health benefits while promoting social and economic acceptability.

The third chapter goes further to undertand how strategic reformulation impact sugar taxes. We develops and estimates a structural demand and supply model that integrates firms' price and quality responses to a sugar tax in a differentiated-product market. We consider a two-stage game in which manufacturers compete in prices, while changes in sugar content are infrequent and require paying a fixed reformulation cost. This formulation captures the idea that modifying a recipe involves technological, organizational, and demand-adjustment costs and can be found in Koujianou Goldberg and Hellerstein (2013). Using this decisions process, we recover product-level lower bounds on reformulation costs from observed equilibrium and embed them in a counterfactual analysis of nutrient-based taxation. Our analysis delivers several results. First, we document substantial heterogeneity across product categories in equilibrium markups and in the magnitude of reformulation costs relative to revenues. These differences translate into sharply uneven incentives to adjust sugar content. Second, we show that accounting for endogenous reformulation is crucial for evaluating the effects of a sugar tax. When product characteristics are held fixed, the tax mainly operates through demand reallocation and price adjustments. When reformulation is taken into account, a large share of the reduction in sugar consumption comes from changes in product composition, and the contraction of the market is substantially attenuated. Third, we uncover strong heterogeneity in reformulation behavior across firms and products, reflecting differences in baseline sugar content, demand elasticities, and the magnitude of fixed costs.

A particular policy that receive a lot of scrutiny is the Soft Drinks Industry Levy (SDIL). In April 2018, the United Kingdom introduced the SDIL, a tiered tax applied to soft drinks according to their sugar concentration. Beverages containing less than 5 grams of sugar per 100 millilitres are exempt, drinks containing between 5 and 8 grams face a lower tax rate, and products exceeding 8 grams per 100 millilitres are subject to a higher rate. In the same way, most designs implemented by regulators in the last 20 years include some tiered aspect (*e.g.*, France, UK, Spain, Chile). There has not been a sugar tax implemented that is strictly proportional to sugar content, [2] although it was theoretically and empirically shown to be the optimal design (Allcott et al., 2019a; O'Connell and Smith, 2024).

This raises the central question of whether tiered sugar taxes can be welfare-optimal, and if so, how their structure should be designed. Specifically, should the tax apply only to products exceeding certain sugar content levels ? How many thresholds should be introduced, where should they be placed, and what should be the corresponding tax rates ?

We aims to address the questions by analyzing how tax design affect welfare in the chapter 4. Specifically, we provide a regulatory framework that accounts for total welfare, measured as consumer surplus, firm profits, tax revenues, and the costs of externalities resulting from excessive sugar consumption. These sugar costs are associated with treating conditions, such as weight gain, type 2 diabetes, and cardiovascular disease (Allcott et al., 2019b; Bhattacharya and Sood, 2011). Including the cost of externalities allows for a comprehensive measure of welfare that accounts for heterogeneous effects on consumers, firms, the government, and health. Three components of the tax design can vary in our framework : the number of thresholds, the location of these thresholds (in grams of sugar per 100 mL), and the tax rate for each threshold (in euro cents per liter). This setting enables us to cover a large variety of tax designs, from taxes proportional to sugar content to tiered tax designs with varying numbers of thresholds.

Our findings reveal that tiered tax designs, when incorporating strategic responses from firms, can lead to significantly greater welfare improvements than linear taxation or the implemented Soft Drinks Industry Levy in the UK. Specifically, the optimal design features higher taxes on high-sugar products, prompting firms to reduce prices on lower-sugar alternatives. This adjustment not only enhances public health outcomes but also increases consumer surplus and preserves firm

2. Quasi-linear sugar taxes have been implemented but all have a threshold. For example, taxes at a rate of approximately 0.15 and 0.40 US cents for each gram of sugar over an initial threshold of 4 g/100 mL have been implemented in South Africa and Sri Lanka, respectively.

profitability. These results suggest that tiered sugar taxes can serve as welfare-enhancing policy tools when designed to reflect both consumer heterogeneity and market competition.

Unlike standard excise taxes that aims to operate primarily through prices, the SDIL was explicitly designed and publicized with the objective of inducing product reformulation by manufacturers. Because tax liability depends directly on the sugar concentration of beverages, firms can reduce or entirely avoid the tax by lowering the sugar content of their products. This feature places firms' product design decisions at the center of the policy.

In the final chapter of the thesis, I study manufacturers' reformulation responses to the Soft Drinks Industry Levy in the UK soft drink market. The demand system allows consumers to have heterogeneous preferences for both prices and sugar content, capturing realistic substitution patterns across beverages. Modeling such heterogeneity is crucial for evaluating taxation policies in soft drink markets Etilé et al. (2021). The empirical framework is then extended to incorporate endogenous reformulation decisions by manufacturers. Firms are modeled as choosing the sugar content of their products in a first stage, before competing in prices in a second stage. Changing a product's formulation requires paying a fixed reformulation cost, while observed reformulation decisions therefore reveal information about the magnitude of these costs. Following Koujianou Goldberg and Hellerstein (2013) these estimates allow to recovers bounds on product-level reformulation costs from observed and unobserved reformulation decisions.

I show that the implied reformulation costs vary systematically across products and are larger for products located at the extremes of the sugar distribution. Using the estimated model, I simulate counterfactual equilibria under the SDIL and show that observed reformulation patterns can be partly predicted by the structural model using ex ante information on demand and cost conditions.

Contribution to the litterature

The writing of this thesis contributes to the growing literature on fiscal policies targeting nutrient by providing a comprehensive structural analysis of sugar taxation in food markets. While a large empirical literature has examined taxes on sugar-sweetened beverages (SSB), most studies focus on reduced-form evaluations of price and consumption responses, often treating product characteristics as fixed and considering a single market or tax design (Griffith et al., 2019b; Cawley et al., 2019a; Allcott et al., 2019b). In contrast, this thesis develops a unified structural framework that jointly models consumer demand, firms' strategic behavior including endogenous product reformulation across several food markets, and tax design.

First, it contributes to the empirical literature on food taxation by providing structural evaluations of nutrient-based taxes beyond the traditional focus on soft drinks. While SSB taxes have been widely implemented and studied, much less is known about the potential effects of extending such fiscal instruments to other food categories that contribute significantly to sugar intake. Using detailed household scanner data and product-level nutritional information, the thesis evaluates the impact of sugar taxes in several markets, including non-alcoholic beverages, biscuits, and dairy desserts across multiple countries. By comparing policy outcomes across these markets and institutional contexts, the thesis provides new evidence on how the effectiveness of fiscal policies depends on market structure, product differentiation, and consumer substitution patterns.

Second, it contributes to the literature on taxation in imperfectly competitive markets by integrating strategic firm behavior into the evaluation of food taxes. Building on the structural industrial organization framework of Berry et al. (1995), Nevo (2001), and Berry et al. (2004), the empirical analysis combines a random-coefficient logit demand system with an oligopolistic supply model in which multiproduct firms compete in prices *à la* Bertrand. This framework allows the recovery of substitution patterns, markups, and marginal costs, and enables counterfactual simulations of tax policies while accounting for firms' pricing responses. By explicitly modeling the strategic interaction between firms, all chapters add to the litterature that shows how market power and pass-through shape the welfare effects of nutrient-based taxation (Bonnet and Réquillart, 2013; Dubois et al., 2020; O'Connell and Smith, 2024).

Third, it contributes to the literature on optimal sin taxation by studying how tax design affects welfare in markets with heterogeneous consumers and strategic firms. Theoretical work suggests that taxes proportional to the harmful nutrient content are optimal under standard Pigouvian principles (Pigou, 1934; Diamond, 1975; Allcott et al., 2019a). However, most real-world policies rely on tiered tax schedules with thresholds, such as the UK Soft Drinks Industry Levy. On chapter 4 it develops a regulatory framework that allows the number of thresholds, their location, and their associated tax rates to vary, and evaluates their welfare implications using structural counterfactual analysis. By accounting for heterogeneous demand, market power, and strategic pricing, the results show that tiered tax structures can outperform both volumetric taxes and linear sugar taxes in equilibrium. The analysis therefore provides new insights into the welfare-optimal design of nutrient-based taxation.

Finally, the thesis contributes more broadly to the empirical literature on product design and endogenous product characteristics in differentiated-product markets. While many structural demand models treat product attributes as fixed, firms often adjust product characteristics in response to regulation, technological constraints, and consumer preferences. By modeling product reformulation as a discrete investment decision involving fixed costs, chapter 3 and 5 provide a tractable framework to analyze firms' quality-adjustment strategies in response to fiscal policies build on Koujianou Goldberg and Hellerstein (2013). This approach highlights the importance of accounting for endogenous product design when evaluating regulatory interventions in food markets.

Taken together, the contributions of this thesis show that the evaluation of nutrient-based taxes requires an integrated analysis of consumer behavior, firm competition, product reformulation, and policy design. By combining rich micro-level data with structural industrial organization methods, the thesis provides new empirical evidence and policy insights on how fiscal instruments can be designed to reduce sugar consumption.

Références

Aguilar, A., E. Gutierrez, and E. Seira (2021) : "The effectiveness of sin food taxes : Evidence from Mexico," *Journal of Health Economics*, 77, 102455.

Allais, O., G. Enderli, F. Sassi, and L.-G. Soler (2023) : "Effective policies to promote sugar reduction in soft drinks : lessons from a comparison of six European countries," *European Journal of Public Health*, ckad157.

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

——— (2019b) : "Should We Tax Sugar-Sweetened Beverages ? An Overview of Theory and Evidence," *Journal of Economic Perspectives*, 33, 202–227.

Andreyeva, T., K. Marple, S. Marinello, T. E. Moore, and L. M. Powell

(2022) : “Outcomes following taxation of sugar-sweetened beverages : a systematic review and meta-analysis,” *JAMA Network Open*, 5, e2215276–e2215276.

Anses (2017) : “Étude individuelle nationale des consommations alimentaires 3 (INCA 3),” *Rapport d'expertise collective, Édition scientifique*.

Barahona, N., C. Otero, and S. Otero (2023) : “Equilibrium effects of food labeling policies,” *Econometrica*, 91, 839–868.

Bercholz, M., S. W. Ng, N. Stacey, and E. C. Swart (2022) : “Decomposing consumer and producer effects on sugar from beverage purchases after a sugar-based tax on beverages in South Africa,” *Economics & Human Biology*, 46, 101136.

Berry, S., J. Levinsohn, and A. Pakes (1995) : “Automobile Prices in Market Equilibrium,” *Econometrica*, 63, 841–890.

——— (2004) : “Differentiated products demand systems from a combination of micro and macro data : The new car market,” *Journal of political Economy*, 112, 68–105.

Bhattacharya, J. and N. Sood (2011) : “Who Pays for Obesity ?” *Journal of Economic Perspectives*, 2, 139–158.

Biro, A. (2015) : “Did the junk food tax make the Hungarians eat healthier ?” *Food Policy*, 54, 107–115.

Bonnet, C. and V. Réquillart (2013) : “Tax incidence with strategic firms in the soft drink market,” *Journal of Public Economics*, 77–88.

Brambila-Macias, J., B. Shankar, S. Capacci, M. Mazzocchi, F. J. Perez-Cueto, W. Verbeke, and W. B. Traill (2011) : “Policy interventions to promote healthy eating : a review of what works, what does not, and what is promising,” *Food and Nutrition Bulletin*, 32, 365–375.

Burki, T. (2023) : “New junk food legislation in Colombia,” *The Lancet Oncology*, 24.

Capacci, S., O. Allais, C. Bonnet, and M. Mazzocchi (2019) : “The impact of the French soda tax on prices and purchases. An ex post evaluation,” *PLOS ONE*, 14, e0223196.

Cawley, J., D. Frisvold, A. Hill, and D. Jones (2019a) : "The impact of the Philadelphia beverage tax on purchases and consumption by adults and children," *Journal of Health Economics*, 67, 102225.

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

Colchero, M. A., B. M. Popkin, J. A. Rivera, and S. W. Ng (2015) : "Beverage purchases from stores in Mexico under the excise tax on sugar sweetened beverages : Observational study," *British Medical Journal*, 352, h6704.

Department for Environment, Food and Rural Affairs (2020) : "National Food Strategy : Part Two," Tech. rep.

Diamond, P. A. (1975) : "A many-person Ramsey tax rule," *Journal of Public Economics*, 4, 335–342.

Dubois, P., R. Griffith, and M. O. Connell (2018) : "The Effects of Banning Advertising in Junk Food Markets," *The Review of Economic Studies*, 85, 396–436.

Dubois, P., R. Griffith, and M. O'Connell (2020) : "How well targeted are soda taxes ?" *American Economic Review*, 110, 3661–3704.

Dubuisson, C., A. Dufour, S. Carrillo, P. Drouillet-Pinard, S. Havard, and J.-L. Volatier (2019) : "The Third French Individual and National Food Consumption (INCA3) Survey 2014–2015 : method, design and participation rate in the framework of a European harmonization process," *Public Health Nutrition*, 22, 584–600.

Duvaleix-Tréguer, S., A. Hammoudi, L. Rouached, and L.-G. Soler (2012) : "Firms' responses to nutritional policies," *European Review of Agricultural Economics*, 39, 843–877.

Etilé, F., S. Lecocq, and C. Boizot-Szantai (2021) : "Market heterogeneity and the distributional incidence of soft-drink taxes : evidence from France," *European Review of Agricultural Economics*, 48, 915–939.

European Parliament and Council of the European Union (2011) : "Regulation (EU) No 1169/2011 on the Provision of Food Information to Consumers," Official Journal of the European Union, L304, adopted 25 October 2011.

French Agency for Food, Environmental and Occupational Health & Safety (2017) : *Étude individuelle nationale des consommations alimentaires 3 (INCA 3) : avis de l'Anses : rapport d'expertise collective*, Anses.

Griffith, R., M. O'Connell, and K. Smith (2017) : "Corrective taxation and internalities from food consumption," *CESifo Economic Studies*, 1–14.

Griffith, R., M. O'Connell, K. Smith, and R. Stroud (2019a) : *The evidence on the effects of soft drink taxes*, IFS.

Griffith, R., M. O'Connell, and K. Smith (2019b) : "Tax design in the alcohol market," *Journal of Public Economics*, 172, 20–35.

Grummon, A. H., B. B. Lockwood, D. Taubinsky, and H. Allcott (2019) : "Designing better sugary drink taxes," *Science*, 365, 989–990.

Guh, D. P., W. Zhang, N. Bansback, Z. Amarsi, C. L. Birmingham, and A. H. Anis (2009) : "The incidence of co-morbidities related to obesity and overweight : a systematic review and meta-analysis," *BMC Public Health*, 9, 1–20.

HM Government (2016) : "Childhood Obesity : A Plan for Action," Tech. rep., HM Government, London.

Koujianou Goldberg, P. and R. Hellerstein (2013) : "A Structural Approach to Identifying the Sources of Local Currency Price Stability," *The Review of Economic Studies*, 80, 175–210.

Lee, M. M., J. Falbe, D. Schillinger, S. Basu, C. E. McCulloch, and K. A. Madsen (2019) : "Sugar-sweetened beverage consumption 3 years after the Berkeley, California, sugar-sweetened beverage tax," *American Journal of Public Health*, 109, 637–639.

McFadden, D. and K. Train (2000) : "Mixed MNL models for discrete response," *Journal of Applied Econometrics*, 15, 447–470.

NCD Risk Factor Collaboration (2024) : "Worldwide trends in underweight and obesity from 1990 to 2022 : a pooled analysis of 3663 population-representative studies with 222 million children, adolescents, and adults," *The Lancet*, 403, 1027–1050.

Nevo, A. (2001) : "Measuring market power in the ready-to-eat cereal industry," *Econometrica*, 69, 307–342.

O'Connell, M. and K. Smith (2024) : "Optimal Sin Taxation and Market Power," *American Economic Journal : Applied Economics*, 34—-70.

Okunogbe, A., R. Nugent, G. Spencer, J. Powis, J. Ralston, and J. Wilding (2022) : "Economic impacts of overweight and obesity : current and future estimates for 161 countries," *BMJ Global Health*.

Pell, D., O. Mytton, T. L. Penney, A. Briggs, S. Cummins, C. Penn-Jones, M. Rayner, H. Rutter, P. Scarborough, S. J. Sharp, et al. (2021) : "Changes in soft drinks purchased by British households associated with the UK soft drinks industry levy : controlled interrupted time series analysis," *British Medical Journal*, 372.

Pell, D., T. L. Penney, O. Mytton, A. Briggs, S. Cummins, M. Rayner, H. Rutter, P. Scarborough, S. J. Sharp, R. D. Smith, et al. (2020) : "Anticipatory changes in British household purchases of soft drinks associated with the announcement of the Soft Drinks Industry Levy : A controlled interrupted time series analysis," *PLoS medicine*, 17, e1003269.

Petrin, A. and K. Train (2010) : "A Control Function Approach to Endogeneity in Consumer Choice Models," *Journal of Marketing Research*, 47, 3–13.

Pigou, A. (1934) : *The economics of welfare*, Macmillan, 4th ed.

Public Health England (2018) : "Results of the National Diet and Nutrition Survey (NDNS) rolling programme for 2014 to 2015 and 2015 to 2016," Tech. rep.

——— (2020) : "Sugar reduction : report on progress between 2015 and 2019," Tech. rep.

Réquillart, V., L.-G. Soler, and Y. Zang (2016) : "Quality standards versus nutritional taxes : Health and welfare impacts with strategic firms," *Journal of Health Economics*, 50, 268 – 285.

Roberto, C. A., H. G. Lawman, M. T. LeVasseur, N. Mitra, A. Peterhans, B. Herring, and S. N. Bleich (2019) : "Association of a beverage tax on sugar-sweetened and artificially sweetened beverages with changes in beverage prices and sales at chain retailers in a large urban setting," *Journal of the American Medical Association*, 321, 1799–1810.

Royo-Bordonada, M. Á., C. Fernández-Escobar, L. Simón, B. Sanz-Barbero, and J. Padilla (2019) : "Impact of an excise tax on the consumption of sugar-sweetened beverages in young people living in poorer neighbourhoods of Catalonia, Spain : a difference in differences study," *BMC Public Health*, 19, 1–11.

Ruiz, E., P. Rodriguez, T. Valero, J. M. Ávila, J. Aranceta-Bartrina, Á. Gil, M. González-Gross, R. M. Ortega, L. Serra-Majem, and G. Varela-Moreiras (2017) : "Dietary Intake of Individual (Free and Intrinsic) Sugars and Food Sources in the Spanish Population : Findings from the ANIBES Study," *Nutrients*, 9, 275.

Scarborough, P., V. Adhikari, R. A. Harrington, A. Elhussein, A. Briggs, M. Rayner, J. Adams, S. Cummins, T. Penney, and M. White (2020) : "Impact of the announcement and implementation of the UK Soft Drinks Industry Levy on sugar content, price, product size and number of available soft drinks in the UK, 2015-19 : A controlled interrupted time series analysis," *PLoS medicine*, 17, e1003025.

Silver, L. D., S. W. Ng, S. Ryan-Ibarra, L. S. Taillie, M. Induni, D. R. Miles, J. M. Poti, and B. M. Popkin (2017) : "Changes in prices, sales, consumer spending, and beverage consumption one year after a tax on sugar-sweetened beverages in Berkeley, California, US : A before-and-after study," *PLOS Medicine*, 14, e1002283.

Te Morenga, L., S. Mallard, and J. Mann (2013) : "Dietary sugars and body weight : systematic review and meta-analyses of randomised controlled trials and cohort studies," *British Medical Journal*, 346.

The Lancet Gastroenterology & Hepatology (2020) : "Voluntary agreements with industry : no sweet success," *The Lancet Gastroenterology & Hepatology*, 5.

Wang, M., M. Yu, L. Fang, and R. Hu (2015) : "Association between sugar-sweetened beverages and type 2 diabetes : A meta-analysis," *Journal of Diabetes Investigation*, 6, 360–366.

World Cancer Research Fund International (2022) : "NOURISHING and MOVING Policy Databases," Tech. rep.

World Health Organization (2015) : "Guideline : Sugars intake for adults and children," Tech. rep.

——— (2016a) : "Fiscal policies for diet and the prevention of noncommunicable diseases," Tech. rep.

——— (2016b) : "Report of the commission on ending childhood obesity," Tech. rep.

——— (2022) : "Fiscal policies to promote healthy diets : policy brief," Tech. rep.

1 - Cross-country comparison of ex-ante sugar tax evaluations : Evidence from the biscuit, non-alcoholic beverage, and dairy dessert markets in France, Spain, and the United Kingdom

Cross-country comparison of ex-ante sugar tax evaluations: Evidence from the biscuit, non-alcoholic beverage, and dairy dessert markets in France, Spain, and the United Kingdom *

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Abstract

Background: Obesity represents a growing global challenge, with significant health and economic consequences. One of the main drivers of this epidemic is excessive sugar intake. Public policies such as education campaigns and product labelling have shown limited effectiveness, leading to increasing interest in fiscal measures like sugar taxes. While taxes on sugar-sweetened beverages have demonstrated reductions in consumption, evidence remains limited regarding their extension to other high-sugar products.
Objective: This study assesses the potential impacts of sugar taxation policies in France, the United Kingdom, and Spain on three key product categories that contribute substantially to sugar intake: non-alcoholic beverages, biscuits, and dairy desserts.
Method: Using nationally representative scanner data and a structural econometric model, we estimate demand, model firm pricing behavior under oligopolistic competition, and simulate the effects of a two-tiered sugar-based tax.
Results: Results indicate that firms generally over-shift the tax to prices, leading to significant reductions in purchases and sugar intake, with the largest impacts observed in non-alcoholic beverages and French dairy desserts. The tax is particularly effective among households with overweight or obese adults. Although consumer surplus and firm profits decline, these losses are outweighed by fiscal revenues and reductions in the social costs of excessive sugar intake. **Conclusions:** Overall, our findings suggest that extending sugar taxes to other food and drink products can reduce sugar consumption and generate positive welfare effects. We then provide valuable evidence for policymakers considering broader fiscal measures to address diet-related health challenges.

Contents

1 Introduction

The food sector has a crucial role in food security, but also weights major stakes such as ensuring healthy nutrition and managing the environmental impact of food production. In 2022, over one billion people aged 5 years and older worldwide were living with obesity (NCD Risk Factor Collaboration, 2024). Obesity is responsible for health issues such as hypertension and diabetes (World Health Organization, 2016b; Guh et al., 2009). In 2019, the European social cost of overweight and obesity was estimated at approximately 464 billion euros, of which 141 billion euros were medical and non-medical direct costs, and 323 billion euros were indirect costs, including those of premature mortality and productivity losses (Okunogbe et al., 2022). The public health literature shows that obesity is associated with an excessive consumption of added sugars, among other nutrients (Te Morenga et al., 2013; Wang et al., 2015). Public authorities have implemented several kinds of policies, such as education campaigns to prevent abuse of added sugar, improvement of product labelling, and enhancement of nutrient consumption through collective agreements with manufacturers. Yet, despite some positive results, these measures have proved insufficiently effective (Brambila-Macias et al., 2011; Public Health England, 2020). In line with the World Health Organization (WHO), which recommends developing policies to limit the intake of products high in free sugars (World Health Organization, 2015), food taxes have been considered to address this issue more effectively (Roberto et al., 2019; Royo-Bordonada et al., 2019; Cawley et al., 2019; Lee et al., 2019; Pell et al., 2020, 2021). They have already been widely implemented for sugar-sweetened beverages (SSB), as they are one of the most important contributors to added sugar intake. In early 2020, more than 50 SSB taxes were already in force worldwide (Cawley et al., 2019). A systematic review shows that SSB taxes have actually been effective in reducing purchases of the targeted SSBs by an average of -15% through price increases (Andreyeva et al., 2022). A limitation of the existing measures is the narrowness of their scope, which only allows for small impacts on overall dietary intake (World Health Organization, 2022). Therefore, their extension to more unhealthy foods is considered by health authorities (World Health Organization, 2016a; Department for Environment, Food and Rural Affairs, 2020; The Lancet Gastroenterology & Hepatology, 2020). However, they are less common for other products than SSB, even if they are increasingly adopted (from seven member States of the WHO in 2017 to 29 in 2022, World Health Organization, 2022). For example, non-essential foods with more than 275kcal/100g are taxed in Mexico (World Cancer Research Fund International, 2022), and products high in sugar, salt and/or caffeine are targeted by the "Public Health Product Tax" in Hungary (Biro, 2015; World Cancer Research Fund International, 2022). In 2023, Colombia introduced an excise tax on ultra-processed foods based on unhealthy nutrients (Burki, 2023).

However, little is known about the potential effect of a similar tax for products other than non-alcoholic beverages. The main objective of this study is to assess and compare the effects of a hypothetical tax scenario based on the UK's existing soda tax on variations in purchases and sugar consumption in the non-alcoholic beverage market, as well as in the biscuit and fresh dairy dessert markets. These three markets are major contributors to sugar intake across all age groups (children, adolescents and adults) (see Table 1). The study will be conducted in three different countries: Spain, France, and the United Kingdom (UK).

Table 1: Contribution of non-alcoholic beverages, biscuits, and dairy desserts to added-sugar intakes by age group in France, the UK, and Spain

	France *Sugar* (2014-2015)			**UK** *Added sugar* (2014-2016)			**Spain** *Added sugar* (2013)		
	Non alc. beverages	Biscuits	Dairy desserts	Non alc. beverages	Biscuits	Dairy desserts	Non alc. beverages	Biscuits	Dairy desserts
Children	14.5%	16.2%	13.7%	22.2%	8.7%	5.9%	24.5%	16.1%	18.0%
	(2nd)	(1st)	(3rd)	(2nd)	(4th)	(5th)	(1st)	(4th)	(3rd)
Adolescents	20.3%	16.3%	10.5%	32.7%	8.3%	2.5%	36.8%	13.1%	11.1%
	(1st)	(2nd)	(3rd)	(1st)	(3rd)	(8th)	(1st)	(3rd)	(5th)
Adults	13.8%	13.6%	9.7%	21.3%	7.1%	2.8%	28.4%	15.1%	11.9%
	(3rd)	(4th)	(5th)	(2nd)	(4th)	(8th)	(1st)	(3rd)	(5th)

Notes: This table shows the contribution of non-alcoholic beverages, biscuits, and dairy desserts to added-sugar or sugar intakes for children, adolescents and adults in France, the UK and Spain. The age groups are 1-10, 11-17 and 18-79 for France; 4-10, 11-18 and 19-64 for the UK; 9-12, 13-17 and 18-64 for Spain. The number in parentheses indicates the rank of the category. For France, the categories considered are "Soft drinks; Fruit and vegetables juices", "Pastries, cakes and biscuits", "Yoghurts and fromage frais; Entremets and dessert creams" (Anses, 2017; Dubuisson et al., 2019). For the UK, the categories considered are "Fruit juices; Soft drinks", "Biscuits", "Yoghurt, fromage frais and other dairy desserts" (Public Health England, 2018). For Spain, the categories considered are "Sugar soft drinks; Juices and nectars", "Bakery and pastries", "Yogurt and fermented milks; Other dairy products" (Ruiz et al., 2017).

To achieve this objective, we carry out ex-ante evaluations and comparisons of the effects of a sugar tax on the purchased quantity of non-alcoholic beverages, biscuits and dairy desserts by households in the UK, France, and Spain. Specifically, we apply a three-step structural econometric strategy, following Bonnet and Réquillart (2013). In a first step, we use scanner data purchases from France, the UK and Spain, which are nationally representative of their population, to estimate a discrete choice model of demand in each market allowing for substitutions between varieties of products. We represent consumer preferences using a Random Coefficient Logit model (McFadden and Train, 2000), controlling for the endogeneity of prices (Petrin and Train, 2010). This estimation approach identifies household-specific preference parameters and the demand curves for the varieties of biscuits, non-alcoholic beverages or dairy desserts in the three countries. In a second step, we model the supply side as an oligopoly proposing differentiated products and competing *à la Nash* in a Bertrand game, in the spirit of Berry et al. (1995) and Nevo (2001). This step allows for the consideration of the pricing strategy responses of firms facing taxes. As shown by Bonnet and Réquillart (2013), the firms' price response to tax depends on the competitive environment of the market and can influence the effectiveness of such policies in reducing consumption. We use estimated demand curves and the supply model to identify price-cost margins and unit production costs for each product. Using these models, we simulate the effect of a tax on each market by modelling how firms' prices and consumers' purchases would react to the tax. Here, we simulate the impact of a two-tiered, sugar-based tax, as implemented in the UK's non-alcoholic beverage market. Our findings show that, in each market and country, firms generally pass on more than the amount of tax, which results in a reduction in purchases and sugar intake. The tax is most efficient in the non-alcoholic beverage market in the three countries, in the French dairy dessert market, and among households where all the adults are overweight or obese. Reducing sugar intake would impact society as a whole. The introduction of these taxes reduces both consumer surplus and firm profits. However, these losses may be offset by the health-related social benefits they generate. When accounting for consumer surplus, firm profits, fiscal revenue, and the social costs of excessive sugar consumption, we find an overall positive effect on total welfare.

Our analysis contributes to the current debate on food taxes by assessing the impact of a sugar tax on three different food markets in three different countries. We provide a global welfare analysis of this fiscal tool, taking into account its social costs and benefits, which could be useful for policymakers.

The paper is organised as follows. Section 2 provides a brief overview of the method, covering the data that was used and the empirical strategy. Section 3 presents the results of the demand and supply model, while Section 4 presents the results of the counterfactual analysis. Finally, Section 5 discusses the policy implications of the study, and Section 6 concludes.

2 Methods

2.1 Data

We use representative consumer panel data from Kantar Worldpanel from 2017 for France, the UK and Spain. The consumer panels of Kantar Worldpanel comprise 19,679 households in France, 24,586 households in the UK, and 7,887 households in Spain. Households in Catalonia, where a regional soft drink tax was introduced in May 2017, are excluded from the analysis to ensure a homogeneous sample of Spanish households with respect to tax exposure. The data contains daily home-scan records of food purchases from three distinct markets: non-alcoholic beverages, biscuits, and dairy desserts. The datasets contain household information such as income, household composition, and the height and weight of each household member, as well as product characteristics such as brand, size, quantity, price, sugar and fat content.

Market definitions. Table A.1 provides a description of the products included in each market.

Non-alcoholic beverages markets: We include sugar-sweetened beverages, fruit juices and flavoured waters in the three countries. In the UK market, we also include milk-based drinks (e.g., flavoured milk) because they form part of children's diets. We exclude water and products that are not ready to drink (e.g., syrup, powdered drinks and cocktail mixers).

Biscuits markets: Following the Kantar food classification, we exclude sweets, chocolate tablets and chocolate bars from our analysis for the three countries. They are not close substitutes for biscuits, as illustrated by their location in supermarkets, where they are generally not found in the same aisle as biscuits. The only exception is UK chocolate bars smaller than two fingers, which are categorised as biscuits in the UK's childhood obesity plan (Public Health England, 2016).

Desserts markets: This includes yoghurts and other dairy desserts (ODDs) for the three countries, as well as fromage blanc and petits suisses (FBPSs) for France and the UK. The latter items are categorised as ODD in Spain, as they account for only a very small proportion of the Spanish dairy desserts market.

Demographics characteristics. Households are categorised according to three criteria. First, we create dummy variables to indicate whether there are children under six or between seven and 16 years old in the household. Secondly, we define the household's obesity status using the proportion of obese or overweight adults in the household. Adults with a body mass index (BMI) above 30 are considered obese, while those with a BMI between 25 and 30 are considered overweight. Thirdly, we define the socio-economic class of the household. The definition of the socio-economic class variable differs across the three databases. In France, it is based on monthly income and household size; in the UK, it is based on socio-professional categories; and in Spain, it is based on level of education and employment situation. However, we assume that the ranking of households within a country remains consistent regardless of the socio-economic class criteria used. Descriptive statistics of the sample are provided in Table A.2.

Product definition. We define the range of products available to households in each market and country as a combination of product attributes. We split each market into sub-categories (detailed in Tables A.3, A.4 and A.5). We have information on the firm and the brand of the product (see Table A.6 for details about the market structure). We also use the sugar content information provided in the British and Spanish panels. For France, due to the unavailability of this information in the dataset, nutritional data were obtained from the French Food Observatory (Oqali) and supplemented with additional information on product composition from brand websites and the Open Food Facts database (Open Food Facts, 2012). In all three countries, we identify products containing added sugar.

Non-alcoholic beverages markets: The definition of the differentiated products is based on information such as the firm and brand name, the drinks subcategory and other product characteristics (e.g., whether the SSB is diet or regular and whether the fruit juice contains added sugar and its flavour). Following this product differentiation, we obtain 319, 402 and 285 distinct beverage varieties (hereafter referred to as "alternatives") in France, the UK and Spain, respectively.

Biscuits: We define an alternative based on the subcategory, firm and brand names, and the flavour of the biscuit (e.g. chocolate or vanilla). Combining these characteristics results in 407 alternatives in France, 500 in the UK, and 309 in Spain.

Desserts: The definition of differentiated products is based on information relating to subcategories, firm and brand names, and other product characteristics (e.g., plant-based ingredients instead of dairy milk, fat content, and the presence of sweeteners). This yields 266 alternatives in France, 171 in the UK, and 281 in Spain.

Further information on the definition of subcategories, the identification of the presence of added sugars in products, and the construction of the differentiated products and prices is provided in Appendix A.1. We also present some descriptive statistics on the market structure and prices for each market and each country in this appendix.

2.2 Descriptive statistics

Figure 1 displays the distribution of household purchases in panel A and the distribution of sugar content in panel B for the three countries and three markets.

We can see that the proportion of households with high non-alcoholic beverage consumption is substantially higher in the UK than in other countries. In the UK, 14.5% of households consume more than 330 ml per capita per day (the equivalent of one can), compared to 6.7% in France and 5.3% in Spain. Household distribution seems more homogeneous between countries in the biscuit market, where 4.2% of French households, 5.6% of UK households, and 3.3% of Spanish households consume more than 40 g of biscuits per capita per day (roughly equivalent to one biscuit). The proportion of French households purchasing more than 125 g of dairy desserts per capita per day (the equivalent of a standard-size yogurt) is 17.8%, which is much higher than the corresponding proportion of UK households (1.6%) and Spanish households (4.5%).

The distribution of sugar content in beverages is denser around 10 grams of sugar per 100 grams of product, especially in the French market. The British and Spanish beverage markets offer more products with a low sugar content than the French market. Biscuits are mainly distributed at around 30 g of sugar per 100 g of product, although biscuits on the Spanish market are substantially less concentrated than in the other two countries. Dairy desserts are mainly distributed at around 13 g of sugar per 100 g of product in France and Spain and at around 11–12 g per 100 g in the UK. However, the distribution is also quite dense around 4–6 g of sugar per 100 g of product in France and Spain and to a lesser extent in the UK. This part of the distribution corresponds to products without added sugar, such as plain yogurts.

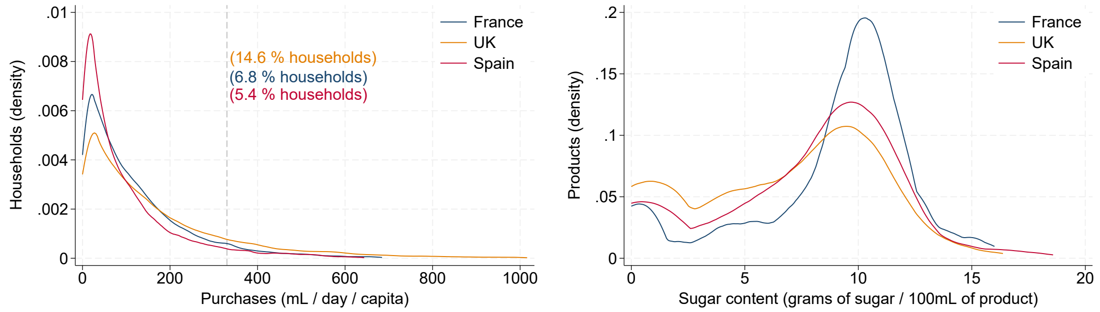
Table A.7 provides information on sugar consumption of non-alcoholic beverages, biscuits and dairy desserts, overall and by household characteristics. Our dataset reveals that non-alcoholic beverages account for the greatest sugar intake, which justifies the introduction of a sugar tax in this market: France (since 2012), Catalonia (since 2017) and the UK (since 2018). Of these three markets, France has the highest sugar intake from non-alcoholic beverages and dairy desserts. Although UK households purchase larger quantities of beverages than French households (Figure 1, Panel A), the higher sugar content of products in France (Figure 1, Panel B) offsets this difference, resulting in a higher sugar intake from this sector in France. We also observe high sugar consumption from dairy desserts in France. This is due to high consumption of these products, as well as their high sugar content (Figure 1).

Disaggregating sugar consumption by household characteristics reveals that poor households consume more sugar from non-alcoholic beverages in all three countries and from biscuits in France and the UK, and from dairy desserts in Spain (see Table A.7). Households in which all members are overweight or obese have the highest sugar consumption in all nine markets. Households with children aged 7–16 consume more sugar from non-alcoholic beverages and biscuits in all countries. However, the results are more mixed in the dairy desserts market, depending on the age of the children in the household.

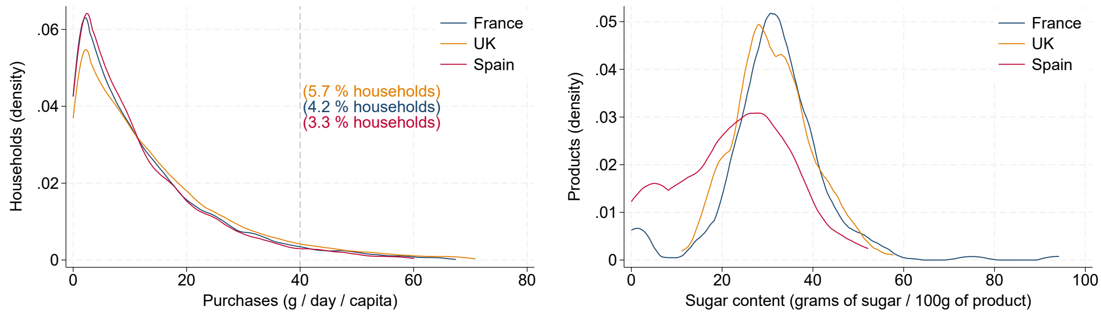
Figure 1: Descriptive statistics

Purchases across households	Sugar content across products
Panel A	Panel B

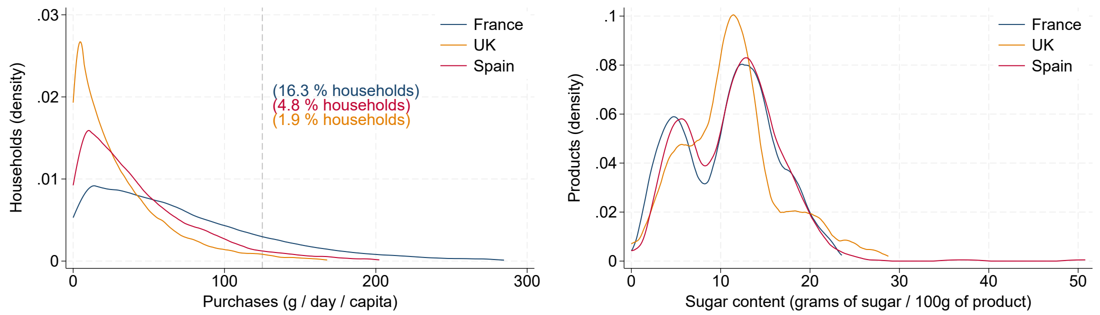
Beverages



Biscuits



Dairy desserts



Notes: Panel A: Distribution of quantities purchased by households in France, the UK and Spain. For the non-alcoholic market (first panel), quantities are expressed in millilitres (mL) per day per capita, and the 330 mL threshold corresponds to the size of a standard can. For the biscuit market (second panel), quantities are expressed in grams per day per capita and the 40-gram threshold corresponds to one standard biscuit. For the fresh dessert market (third panel), quantities are expressed in grams per day per capita and the 125-gram threshold corresponds to a standard yogurt. The 99th percentile is excluded when plotting the graphs. Panel B: Distribution of the sugar content across defined alternatives that represent the products available on each market in France, the UK and Spain. The x-axis is expressed in grams of sugar per 100 grams of product.

2.3 Empirical strategy

We develop a structural econometric model of demand and supply to analyse consumer choices and firm pricing strategies in response to taxation. We use a flexible discrete-choice framework combined with a supply model that assumes oligopolistic competition between firms. The estimation of the impact of the tax involves three steps, as described in Bonnet and Réquillart (2013).

First, separate demand models are estimated for non-alcoholic beverages, biscuits and dairy desserts, in order to analyse household purchases for each country. Using a random coefficient logit framework, we estimate preferences for product characteristics and derive price elasticities, i.e., how households adjust their purchases in response to a price change (see Appendix B.1 for details).

Second, using the estimated consumer substitution parameters, we model the supply side to analyse strategic pricing decisions, i.e., how firms set their prices, and determine the marginal costs of alternatives (see Appendix B.2 for details).

Lastly, we use the estimated demand and supply model to conduct a counterfactual simulation and assess the impact of a two-tiered sugar tax, equivalent to the Soft Drinks Industry Levy (SDIL) design, in each market and country. The SDIL was introduced by the UK government in 2018 and has two sugar thresholds and two tax amounts (see Appendix C.1 for details). Table 2 summarises, for the nine scenarios, the location of the two sugar content thresholds (in grams of sugar per 100 g or mL of products), and the two tax amounts applied at these thresholds (see Appendix C.2 and Appendix C.3 for details on how we determine them based on the characteristics and the tax design of the UK beverage market). For example, in the French biscuit market, products containing less than 29 g of sugar per 100 g are exempt from the tax; those containing 29–33 g are taxed at 1.94€/kg; and those with more than 33 g are taxed at 2.59€/kg. Implementing a tax affects the marginal cost of products. We estimate the resulting new price equilibrium from this additional marginal cost based on the supply and demand model (see Appendix C.4 for details). Depending on the behavior of households and the level of competition, firms can pass on more or less of the tax. The pass-through rate of the tax is crucial, as it affects the change in consumption. This methodology allows us to study the impact of taxes on the market, including the transmission of taxes and changes in prices, as well as its consequences for diet, such as changes in consumption and sugar intake.

To provide a welfare analysis of the tax scenario, we compute the variation in consumer surplus, firm profit, fiscal revenue and social cost of excessive sugar consumption in all markets and countries. We refer to the expressions described in Appendix C.5.

Table 2: Tax scenarios

	Sugar thresholds (g / 100 g or ml)	Tax amount (€ / kg or L)
Non-alcoholic beverages		
UK	[5 ; 8]	[0.21 ; 0.28]
France	[8 ; 10]	[0.33 ; 0.43]
Spain	[8 ; 10]	[0.26 ; 0.35]
Biscuits		
UK	[27 ; 33]	[1.38 ; 1.84]
France	[29 ; 33]	[1.94 ; 2.59]
Spain	[20 ; 28]	[1.05 ; 1.41]
Dairy desserts		
UK	[11 ; 13]	[0.96 ; 1.28]
France	[12 ; 14]	[0.79 ; 1.05]
Spain	[11 ; 13]	[0.69 ; 0.92]

Notes: This table presents the two-tiered taxes implemented in the counterfactual analyses for each market and each country. The first column shows the location of the two thresholds (in grams of sugar per 100 g or mL). The second column displays the tax amount (in euros per kg or L) at each threshold. Details on the counterfactual calibrations are provided in Appendices C.2 and C.3.

3 Results of the demand and supply model

3.1 Demand estimates

The estimates from the demand model on the non-alcoholic beverage, biscuit and dairy dessert markets are presented in Tables B.5, B.6 and B.7, respectively. In every market, country and population, price has a significant negative impact on utility. Unobserved heterogeneity in price disutility is also substantial in every case. We found that obesity status plays a role. When households are composed of overweight or obese adults, they are more price sensitive in the non-alcoholic beverage market, except when all Spanish adults are overweight or obese where there is no additional effect on price sensitivity. Conversely, a weak difference in price sensitivity in the biscuit and dairy dessert markets is observed according to the obesity status. Households in lower socio-economic classes are more price-sensitive than those in higher classes in every market and country, except for the French dairy dessert market. The presence of children also affects price sensitivity, but this varies by market and country.

In terms of product characteristics, British households, especially those with children, display a stronger preference for diet products in the non-alcoholic beverage market. This is not the case for Spanish and French households. In all three markets, households prefer products with more sugar, except for French households in the non-alcoholic beverage market. Households with children have a stronger preference for sugary products in all three countries. In the biscuit and dairy dessert markets, households prefer fatty products.

The brand fixed effect parameter estimates (not displayed in the tables) are larger than the other preference parameter estimates, suggesting high brand loyalty. The positive and significant error terms of the price equation (see subsection B.1.2) indicate that the unobserved factors influencing prices encourage the purchase of alternatives.

3.2 Elasticities and margins

Table B.11 shows the own-price elasticities of non-alcoholic beverages, biscuits, and dairy desserts, categorised by household composition, obesity status, and socio-economic class. We find that demand for non-alcoholic beverages is the most elastic, whereas demand for dairy desserts is the least elastic, in all three countries. We also observe some heterogeneity across demographics. Household composition and obesity status affect own-price elasticity, but there is no common trend. As expected, we observe that poor households have the most price-elastic demand, while rich households have the least. However, no heterogeneity is observed according to socio-economic class in the French dairy dessert market.

Tables B.8, B.9 and B.10 show the own-price elasticities and firm margins by category for beverages and dairy desserts, and by sugar content level for biscuits. We observe that the heterogeneity across product categories is more important than the heterogeneity across household demographics. Margins for firms are highly heterogeneous between categories of non-alcoholic beverages in every country, ranging from 15.9% of the price for energy drinks to 53.2% for lemonades in the UK, for example. Substantial heterogeneity is also displayed in the biscuit market, ranging from 26.9% of the price for biscuits with a sugar content below 10 g per 100 g of product to 60.1% of the price for biscuits with a sugar content between 31 and 37 g per 100 g of product in France. In the dairy desserts market, however, firm margins are less heterogeneous between categories, ranging from 34.8% for ODD to 55.7% for plain yogurts in France. Within the same market, firm margins also vary between countries. Margins in the UK market are, on average, lower than in France and Spain.

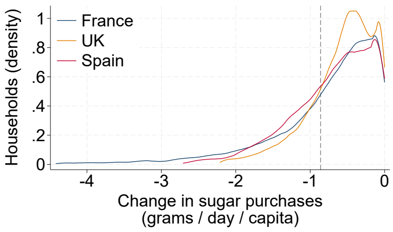
4 Counterfactual experiment

Using the model of consumers' and firms' behaviors, we assess the impact of a sugar tax on each market and country. The tax scenarios are presented in Table 2 for each market and each country.

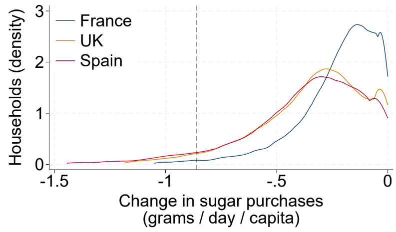
Figure 2 illustrates the impact of the tax on sugar purchases across households. When we compare markets, we can see that the tax on non-alcoholic beverages has led to a greater decrease in sugar consumption than in the other markets, with the French dairy dessert market following closely behind. This is primarily due to higher initial sugar intake from non-alcoholic beverages in the three countries (Table A.7) and higher elasticities (Table B.11). The results for dairy desserts in France are mainly due to large initial purchases. When comparing countries, taxes are more efficient in France, except for the biscuit market, where taxes in Spain and the UK appear to reduce sugar consumption more effectively. On average, the daily effect on sugar intake is small. The average reduction ranges from 0.24 g/day/capita in the UK dairy desserts market (a 7% reduction) to 0.86 g/day/capita in the French non-alcoholic beverages market (a 9% reduction) (Table 3). The largest variation in sugar intake is observed in the Spanish biscuit market, where the average reduction is 0.40 g/day/capita, corresponding to a 15% decrease from an initial consumption of 2.65 g/day/capita. However, the distribution depicted in Figure 2 shows that the proportion of the population reducing their sugar intake by one teaspoon, equivalent to 6 grams of sugar per week, is 1.3%, 11.3% and 26.2% for the British, Spanish and French dairy dessert markets, 3.8%, 5.9% and 1.0% for the British, Spanish and French biscuit markets, and 21.6%, 32.2% and 32.6% for the British, Spanish and French non-alcoholic beverage markets, respectively.

Figure 2: Variation in sugar purchases across households

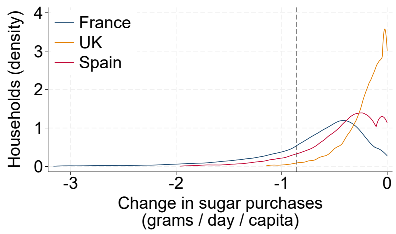
(a) Beverages



(b) Biscuits



(c) Dairy desserts

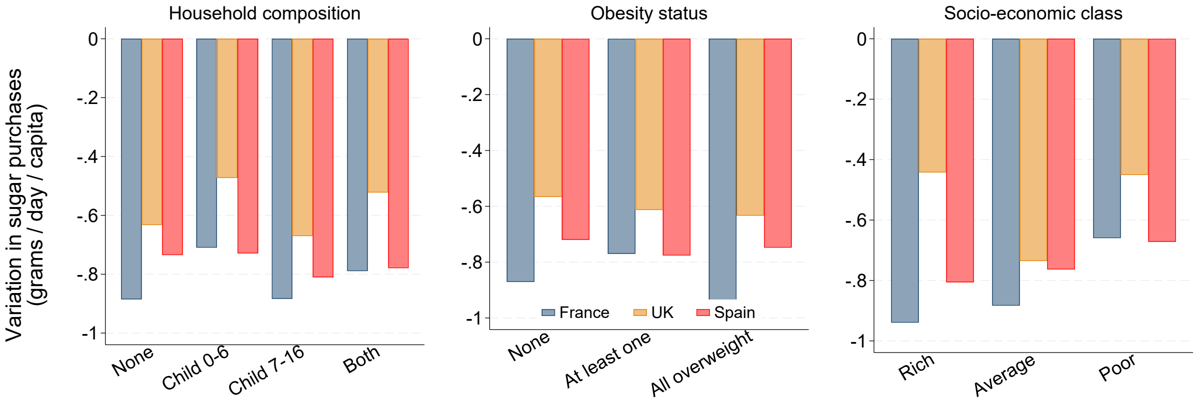


Notes: These figures plot the distributions of the variation in sugar purchases across households in the panel following the implementation of the tax. The distribution is computed across households in the panel. The variation (x-axis) is expressed in grams of sugar per day per capita. The vertical dashed line indicates the equivalent of one sugar cube per week per capita (= 0.86 grams per day per capita). The first and last percentiles have been dropped for each distribution.

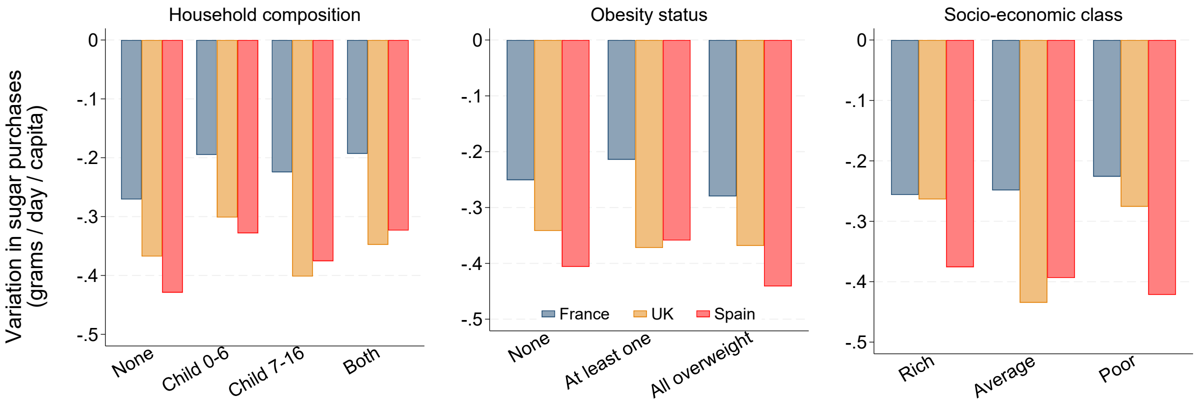
Figure 3 shows how sugar purchases vary by demographic group. Since the differences in own-price elasticities by demographic group are quite small (Table B.11), variations in sugar purchases largely depend on the initial sugar purchases of each group. The greatest variation in sugar purchases is seen among households without children in all markets in France. In the UK and Spain (except for the biscuit market), the variation is greater for households with a child aged 7–16. In France, the variations are higher for wealthy households and lower for poorer households, which can be explained by differences in price elasticity and initial purchase levels. In the UK, households in the middle socio-economic class depict the highest reduction. In Spain, the results according to socio-economic class are more mixed, with rich households reducing their sugar purchases more from the beverage and dairy dessert markets and less from the biscuit market. We also observe that, globally, households comprising all overweight or obese adults reduce their sugar purchases the most, regardless of the market or country. However, there is an exception in the Spanish beverage market, where the difference according to obesity status is weak.

Figure 3: Variation in sugar purchases by demographics

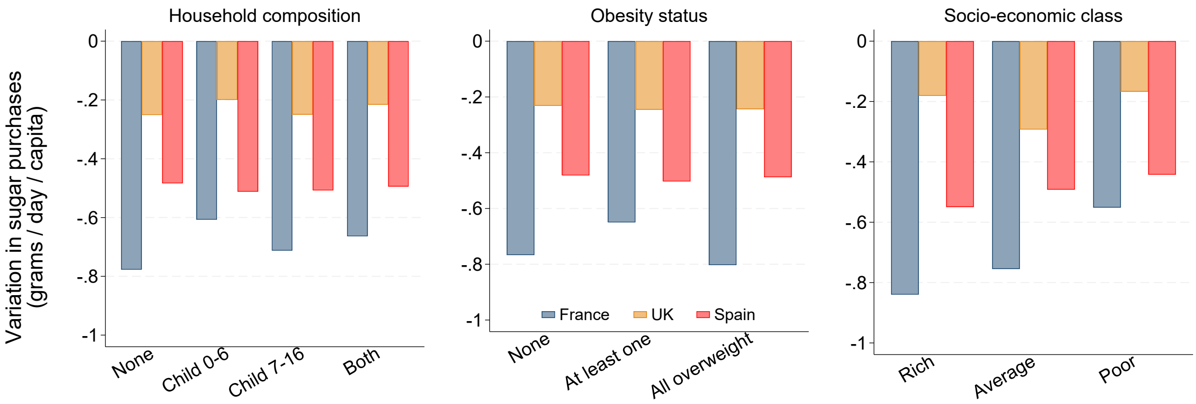
(a) Beverages



(b) Biscuits



(c) Dairy desserts



Notes: These figures plot the average variation in sugar purchases by demographics following the implementation of the tax. The variation is expressed in grams of sugar per day per capita. The left panel represents the household composition and the categories are "no children", "at least one child between 0 and 6 years old", "at least one child between 7 and 16 years old", "at least one child between 0 and 6 years old and one child between 7 and 16 years old". The middle panel represents the obesity status of the household and the categories are "no overweight nor obese adult ", "at least one overweight or obese adult", "all overweight or obese adults". The right panel represents the socio-economic class of the household and the categories are "rich", "middle" and "poor".

Table 3: Summary of the sugar tax simulations

	France	UK	Spain
Beverages			
Outside option (pp)	+1.05	+0.16	+1.67
	+49.5%	+11.3%	+60.6%
Pass-through (mean)	1.08	1.01	1.11
[p5;p95]	[0.99;1.15]	[1.00;1.01]	[0.99;1.39]
Sugar intake (in g/day/capita)	-0.86	-0.61	-0.75
Variations (in million €)			
Consumer surplus	-39.2	-9.6	-9.8
Profit	-0.2	-0.7	-0.1
Tax revenue	+23.5	+5.8	+4.1
Sugar social cost	-49.3	-62.1	-39.2
Total welfare			
without health benefits	-15.9	-4.5	-5.8
with health benefits	+33.4	+57.5	+33.5
Biscuits			
Outside option (pp)	+7.69	+8.33	+10.16
	+75.9%	+99.1%	+43.0%
Pass-through (mean)	1.09	1.00	1.04
[p5;p95]	[0.97;1.17]	[0.99;1.01]	[0.92;1.07]
Sugar intake (in g/day/capita)	-0.25	-0.36	-0.40
Variations (in million €)			
Consumer surplus	-48.0	-20.3	-9.7
Profit	-11.7	-1.8	-4.0
Tax Revenue	+35.4	+9.4	+6.4
Sugar social cost	-24.2	-31.3	-14.8
Total welfare			
without health benefits	-24.3	-12.7	-7.2
with health benefits	-0.1	+18.6	+7.6
Dairy desserts			
Outside option (pp)	+0.91	+1.45	+0.66
	+78.82	+73.9%	+121.1%
Pass-through (mean)	1.01	1.01	1.03
[p5;p95]	[0.98;1.03]	[0.96;1.04]	[0.91;1.12]
Sugar intake (in g/day/capita)	-0.74	-0.24	-0.49
Variations (in million €)			
Consumer surplus	-79.4	-28.9	-17.2
Profit	-2.4	-1.7	-2.9
Tax revenue	+54.4	+17.5	+7.6
Sugar social cost	-87.6	-19.9	-34.6
Total welfare			
without health benefits	-27.4	-13.0	-12.5
with health benefits	+60.2	+6.9	+22.1

Notes: This table summarizes the results of the sugar tax simulations: variation of the outside option (in percentage points and in percentage); average pass-through (and 5th and 95th percentiles); variation in sugar intake (in grams per day per capita); variations in million € of the consumer surplus, profit, rax revenue, sugar social cost and total welfare (which is the sum of profit, consumer surplus and fiscal revenue variations). Health benefits are computed with the social cost of sugar estimated at 12.833 € per kg of sugar consumed by Seidel et al. (2023), using data from Institute for Health Metrics and Evaluation (2022), Lara Castor et al. (2024), and von Philipsborn et al. (2023). Formulas are provided in Appendix C.5.

Table 3 shows the impact of the tax on various market indicators. The outside option, representing non-purchase behavior by households, increases significantly in all countries and markets. This ranges from +11% in the UK's non-alcoholic beverages market to +99.1% in the UK's biscuits market. This indicates a significant reduction in the total market share of the alternatives considered in each market and country. This decrease is explained by the increase in price due to the full passing on of the tax, as well as the price sensitivity of consumers. Indeed, the pass-through is greater than one on average for all markets and countries. However, there is some heterogeneity, with the pass-through being below one for certain products, meaning that firms can absorb some of the tax to avoid excessive losses.

5 Discussion

Our analysis shows that introducing a sugar tax in France, Spain and the UK would reduce sugar intake from non-alcoholic beverages, biscuits and dairy desserts. However, this reduction would not be without impact on society. Firstly, governments could earn fiscal revenue to cover health costs due to excess sugar consumption, or implement additional policies to help reduce sugar consumption further. According to Table 3, the simulated increases in tax revenues amount to 4.1, 5.8 and 23.5 million euros for non-alcoholic beverages; 6.4, 9.4 and 35.4 million euros for biscuits; and 7.6, 17.5 and 54.4 million euros for dairy desserts, in Spain, the UK and France, respectively.

However, consumers and firms would be affected by the introduction of these taxes. We estimate that the annual variation in consumer surplus ranges from -9.6 million euros in the UK non-alcoholic beverage market to -79.4 million euros in the French dairy desserts market. Our results also suggest that firms' annual losses are smaller and could range from 0.1 million euros in the Spanish non-alcoholic beverage market to 11.7 million euros in the French biscuit market. These decreases in economic welfare could be offset by reductions in social costs resulting from health benefits associated with the tax. Assuming a value of 12.8 € per kg for the social cost of sugar, estimated by Seidel et al. (2023) using data from Institute for Health Metrics and Evaluation (2022), Lara Castor et al. (2024), and von Philipsborn et al. (2023), we estimate the economic gain due to health benefits to be on the order of tens of millions of euros. After summing all the costs and benefits induced by the tax, we observe positive total welfare for all markets and countries except the French biscuit market (-100,000 euros). This total welfare analysis is important for policymakers as it shows that the health benefits can more than compensate for the losses of consumers and firms.

6 Conclusions

This paper presents a three-step approach for evaluating the nutritional and economic effects of a two-tier sugar tax on the non-alcoholic beverages, biscuits, and dairy desserts markets in France, Spain, and the UK. Our findings suggest that such a tax would reduce sugar intake across these three markets, particularly in the non-alcoholic beverages sector, but also in the French dairy desserts sector. This reduction comes at an economic cost to consumers and firms. However, the reduction in social costs due to the health benefits of reduced sugar intake can offset these costs for society as a whole.

The study is subject to some limitations. Firstly, we overlooked the fact that supply can respond to tax policies by reformulating products to reduce their sugar content. There is evidence of beverage reformulation and a reduction in sugar content when the tax is designed as an excise tax with sugar thresholds (Andreyeva et al., 2022). This strategic price response enables firms to avoid or reduce the cost of the tax. Secondly, we only considered three sectors of sugary products, ignoring potential effects of the tax on other markets. Consumers facing price increases in these categories may substitute toward untaxed sugary products in different categories. For example, Oddo et al. (2021) demonstrate how the soda tax could impact sales of untaxed sweets in Seattle. Therefore, such cross-category substitution could offset the expected reduction in sugar consumption, highlighting the potential relevance of implementing a more comprehensive tax on all sugary products. Modelling the entire diet would be challenging, given the need to consider demand and supply reactions in all relevant markets. This would require modelling the structure of all markets and considering a large number of products in the choice set. Furthermore, more complex demand models are required to account for multiple choices (Hendel, 1999; Bhat, 2005; Gentzkow, 2007; Bhat, 2018). Finally, introducing taxes and public communication around this policy instrument could change consumer preferences for sugary products. In this analysis, however, we assume that preferences remain unaffected.

References

Allais, O., F. Etilé, and S. Lecocq (2015): "Mandatory labels, taxes and market forces: An empirical evaluation of fat policies," *Journal of Health Economics*, 43, 27–44.

Andreyeva, T., K. Marple, S. Marinello, T. E. Moore, and L. M. Powell (2022): "Outcomes following taxation of sugar-sweetened beverages: a systematic review and meta-analysis," *JAMA Network Open*, 5, e2215276–e2215276.

Anses (2017): "Étude individuelle nationale des consommations alimentaires 3 (INCA 3)," *Rapport d'expertise collective, Édition scientifique*.

Berry, S. (1994): "Estimating discrete-choice models of product differentiation," *RAND Journal of Economics*, 25, 242–262.

Berry, S., J. Levinsohn, and A. Pakes (1995): "Automobile Prices in Market Equilibrium," *Econometrica*, 63, 841–890.

Bhat, C. R. (2005): "A Multiple Discrete–Continuous Extreme Value Model: Formulation and Application to Discretionary Time-Use Decisions," *Transportation Research Part B: Methodological*, 39, 679–707.

——— (2018): "A New Flexible Multiple Discrete–Continuous Extreme Value (MDCEV) Choice Model," *Transportation Research Part B: Methodological*, 110, 261–279.

Biro, A. (2015): "Did the junk food tax make the Hungarians eat healthier?" *Food Policy*, 54, 107–115.

Bonnet, C. and V. Réquillart (2013): "Tax incidence with strategic firms in the soft drink market," *Journal of Public Economics*, 77–88.

Brambila-Macias, J., B. Shankar, S. Capacci, M. Mazzocchi, F. J. Perez-Cueto, W. Verbeke, and W. B. Traill (2011): "Policy interventions to promote healthy eating: a review of what works, what does not, and what is promising," *Food and Nutrition Bulletin*, 32, 365–375.

Burki, T. (2023): "New junk food legislation in Colombia," *The Lancet Oncology*, 24.

Cawley, J., D. Frisvold, A. Hill, and D. Jones (2019): "The impact of the Philadelphia beverage tax on purchases and consumption by adults and children," *Journal of Health Economics*, 67, 102225.

Department for Environment, Food and Rural Affairs (2020): "National Food Strategy: Part Two," Tech. rep.

Dubuisson, C., A. Dufour, S. Carrillo, P. Drouillet-Pinard, S. Havard, and J.-L. Volatier (2019): "The Third French Individual and National Food Consumption (INCA3) Survey 2014–2015: method, design and participation rate in the framework of a European harmonization process," *Public Health Nutrition*, 22, 584–600.

Gentzkow, M. (2007): "Valuing New Goods in a Model with Complementarity: Online Newspapers," *American Economic Review*, 97, 713–744.

Griffith, R., M. O'Connell, and L. Nesheim (2010): "Sin taxes in differentiated product oligopoly: an application to the butter and margarine market," *CeMMAP working papers 37/10*.

Guh, D. P., W. Zhang, N. Bansback, Z. Amarsi, C. L. Birmingham, and A. H. Anis (2009): "The incidence of co-morbidities related to obesity and overweight: a systematic review and meta-analysis," *BMC Public Health*, 9, 1–20.

Heiss, F. and V. Winschel (2008): "Likelihood approximation by numerical integration on sparse grids," *Journal of Econometrics*, 144, 62–80.

Hendel, I. (1999): "Estimating Multiple-Discrete Choice Models: An Application to Computerization Returns," *Review of Economic Studies*, 66, 423–446.

Institute for Health Metrics and Evaluation (2022): "Global Burden of Disease Study 2019 (GBD 2019) Results," Tech. rep., available at https://vizhub.healthdata.org/gbd-results and https://vizhub.healthdata.org/gbd-compare.

Lara Castor, L., R. Micha, F. Cudhea, V. Miller, P. Shi, J. Zhang, J. Sharib, J. Erndt-Marino, S. Cash, S. Barquera, D. Mozaffarian, and A. Memon (2024): "Intake of sugar sweetened beverages among children and adolescents in 185 countries between 1990 and 2018: population based study," *British Medical Journal*, 386.

Lee, M. M., J. Falbe, D. Schillinger, S. Basu, C. E. McCulloch, and K. A. Madsen (2019): "Sugar-sweetened beverage consumption 3 years after the Berkeley, California, sugar-sweetened beverage tax," *American Journal of Public Health*, 109, 637–639.

McFadden, D. and K. Train (2000): "Mixed MNL models for discrete response," *Journal of Applied Econometrics*, 15, 447–470.

NCD Risk Factor Collaboration (2024): "Worldwide trends in underweight and obesity from 1990 to 2022: a pooled analysis of 3663 population-representative studies with 222 million children, adolescents, and adults," *The Lancet*, 403, 1027–1050.

Nevo, A. (2001): "Measuring market power in the ready-to-eat cereal industry," *Econometrica*, 69, 307–342.

Oddo, V. M., J. Leider, and L. M. Powell (2021): "The Impact of Seattle's Sugar-Sweetened Beverage Tax on Substitution to Sweets and Salty Snacks," *The Journal of Nutrition*, 151, 3232–3239.

Okunogbe, A., R. Nugent, G. Spencer, J. Powis, J. Ralston, and J. Wilding (2022): "Economic impacts of overweight and obesity: current and future estimates for 161 countries," *BMJ Global Health*.

Open Food Facts (2012): "Food products database," Tech. rep.

Pell, D., O. Mytton, T. L. Penney, A. Briggs, S. Cummins, C. Penn-Jones, M. Rayner, H. Rutter, P. Scarborough, S. J. Sharp, et al. (2021): "Changes in soft drinks purchased by British households associated with the UK soft drinks industry levy: controlled interrupted time series analysis," *British Medical Journal*, 372.

Pell, D., T. L. Penney, O. Mytton, A. Briggs, S. Cummins, M. Rayner, H. Rutter, P. Scarborough, S. J. Sharp, R. D. Smith, et al. (2020): "Anticipatory changes in British household purchases of soft drinks associated with the announcement of the Soft Drinks Industry Levy: A controlled interrupted time series analysis," *PLoS medicine*, 17, e1003269.

Petrin, A. and K. Train (2010): "A Control Function Approach to Endogeneity in Consumer Choice Models," *Journal of Marketing Research*, 47, 3–13.

Public Health England (2016): "The childhood obesity plan," Tech. rep.

——— (2018): "Results of the National Diet and Nutrition Survey (NDNS) rolling programme for 2014 to 2015 and 2015 to 2016," Tech. rep.

——— (2020): "Sugar reduction: report on progress between 2015 and 2019," Tech. rep.

Revelt, D. and K. Train (1998): "Mixed Logit with Repeated Choices: Households' Choices of Appliance Efficiency Level," *Review of Economics and Statistics*, 80, 647–657.

Roberto, C. A., H. G. Lawman, M. T. LeVasseur, N. Mitra, A. Peterhans, B. Herring, and S. N. Bleich (2019): "Association of a beverage tax on sugar-sweetened and artificially sweetened beverages with changes in beverage prices and sales at chain retailers in a large urban setting," *Journal of the American Medical Association*, 321, 1799–1810.

Royo-Bordonada, M. Á., C. Fernández-Escobar, L. Simón, B. Sanz-Barbero, and J. Padilla (2019): "Impact of an excise tax on the consumption of sugar-sweetened beverages in young people living in poorer neighbourhoods of Catalonia, Spain: a difference in differences study," *BMC Public Health*, 19, 1–11.

Ruiz, E., P. Rodriguez, T. Valero, J. M. Ávila, J. Aranceta-Bartrina, Á. Gil, M. González-Gross, R. M. Ortega, L. Serra-Majem, and G. Varela-Moreiras (2017): "Dietary Intake of Individual (Free and Intrinsic) Sugars and Food Sources in the Spanish Population: Findings from the ANIBES Study," *Nutrients*, 9, 275.

Seidel, F., B. Oebel, L. Stein, A. Michalke, and T. Gaugler (2023): "The True Price of External Health Effects from Food Consumption," *Nutrients*, 15, 3386.

Te Morenga, L., S. Mallard, and J. Mann (2013): "Dietary sugars and body weight: systematic review and meta-analyses of randomised controlled trials and cohort studies," *British Medical Journal*, 346.

The Lancet Gastroenterology & Hepatology (2020): "Voluntary agreements with industry: no sweet success," *The Lancet Gastroenterology & Hepatology*, 5.

von Philipsborn, P., O. Huizinga, A. Leibinger, D. Rubin, J. Burns, K. Emmert-Fees, S. Pedron, M. Laxy, and E. Rehfuess (2023): "Interim Evaluation of Germany's Sugar Reduction Strategy for Soft Drinks: Commitments versus Actual Trends in Sugar Content and Sugar Sales from Soft Drinks," *Annals of Nutrition and Metabolism*, 79.

Wang, M., M. Yu, L. Fang, and R. Hu (2015): "Association between sugar-sweetened beverages and type 2 diabetes: A meta-analysis," *Journal of Diabetes Investigation*, 6, 360–366.

World Cancer Research Fund International (2022): "NOURISHING and MOVING Policy Databases," Tech. rep.

World Health Organization (2015): "Guideline: Sugars intake for adults and children," Tech. rep.

——— (2016a): "Fiscal policies for diet and the prevention of noncommunicable diseases," Tech. rep.

——— (2016b): "Report of the commission on ending childhood obesity," Tech. rep.

——— (2022): "Fiscal policies to promote healthy diets: policy brief," Tech. rep.

A Data

A.1 Market definition

The preliminary data cleaning excludes the products that do not enter the market definition and products considered as price outliers.[1] Purchases from households with sample weight equal to 0 are also excluded, that is we consider purchases of households who are fully active in the period.

Table A.1: Summary of the market definition

Non-alcoholic beverages	**France**	**UK**	**Spain**
Sugar-sweetened beverages (cola, iced tea, lemonade, fruit-flavoured drink, sport and energy drink, tonic, other)	yes	yes	yes
Fruit juice (pure fruit juice, nectar, smoothie, fruit juice with milk)	yes	yes	yes
Flavoured water	yes	yes	yes
Milk-based drinks	no	yes	no
Water	no	no	no
Syrup, powdered drink, cocktail mixer	no	no	no
Biscuits	**France**	**UK**	**Spain**
Biscuits	yes	yes	yes
Biscuits coated with chocolate	yes	yes	yes
Chocolate bar $<$ 2 fingers	no	yes	no
Chocolate bar $>$ 2 fingers	no	no	no
Chocolate tablet	no	no	no
Sweets	no	no	no
Desserts	**France**	**UK**	**Spain**
Yogurts	yes	yes	yes
Other Dairy Desserts	yes	yes	yes
Fresh Cheese and Petits Suisses	yes	yes	no

Notes: This table presents the products included in each market for the three countries.

[1] We also exclude products with price outliers because they might be errors or they are not a direct substitute for standard non-alcoholic beverages or biscuits. Products with a price higher than 10 euros per litre in the non-alcoholic beverages market and 50 euros per kg in the biscuits markets are considered as price outliers.

A.2 Demographic characteristics

Table A.2: Household characteristics in Kantar panel

	France		UK		Spain	
	N	%	N	%	N	%
Household composition						
Without children	12,055	61	16,093	65	4,624	59
With children below 6 years old	1,881	10	2,960	12	1,092	14
With children 7-16 years old	3,838	19	3,668	15	1,586	20
With children both below 6 and 7-16 years old	1,905	10	1,865	8	585	7
Obesity status						
No overweight or obese adults	7,317	37	5,972	24	2,083	27
Some overweight or obese adults	6,674	34	8,184	33	3,423	43
All overweight or obese adults	5,688	29	10,430	43	2,381	30
Socio-economic class						
Rich	2,719	14	5,262	21	1,529	19
Average	14,136	72	13,912	57	4,772	61
Poor	2,824	14	5,412	22	1,586	20
All	**19,679**		**24,586**		**7,887**	

Notes: This table presents the distribution of households for each national consumer panel, overall and by household composition, obesity status, and socioeconomic class.

A.3 Product definition

Sub-categories

Non-alcoholic beverages market: We create 14 different sub-categories of non-alcoholic beverages, reported in Table A.3. The sugar-sweetened beverage category is made up of colas, iced tea, fruit-flavoured drinks, flavoured water, tonic water, lemonade, energy drinks, and other SSBs. The fruit juice category includes nectar, fruit juice made from concentrate, pure fruit juices, fruit juice with milk, and smoothies. Milk-based drinks are made up of flavoured milk. The sub-categories may be different between countries because Kantar does not use the same drinks classification between countries (e.g., flavoured milk is considered as a SSBs by Kantar in the UK market) and because consumption levels are different and so grouped in the "Other SSBs", "pure fruit juice" or "nectar" sub-category to avoid having too much noise in the estimation process.

Table A.3: Non-alcoholic beverages sub-categories

	France	UK	Spain
Sugar sweetened beverages (SSB)			
Colas	✓	✓	✓
Iced teas	✓	with Other SSBs	✓
Fruit-flavoured drinks	✓	✓	✓
Flavoured waters	✓	✓	with Other SSBs
Tonic waters	with Other SSBs	✓	with Other SSBs
Lemonades	with Other SSBs	✓	✓
Energy drinks	with Other SSBs	✓	✓
Other SSBs	✓	✓	✓
Fruit juice			
Nectars	✓	✓	✓
Fruit juice (from concentrate)	✓	with Pure fruit juice	with Pure fruit juice
Pure fruit juice	✓	✓	✓
Fruit juice with milk			✓
Smoothies	with Nectar	✓	
Milk-based drinks			
Flavoured milks		✓	

Notes: This table describes the sub-categories in the non-alcoholic beverage market. A sub-category specified as "with X" means that the purchases of this category are grouped with those of X category.

Biscuits market: The data contain information on the type of biscuits (e.g., Jaffa Cakes, Mallows, Rich Tea, Shortbread, Wafer). In contrast to the non-alcoholic beverages market, the supply of biscuit is country-specific. We cannot construct homogeneous sub-categories of biscuits. These sub-categories are presented in Table A.4.

Table A.4: Biscuit sub-categories

France	*Assortiment, Barquette, Barre Biscuite, Boudoir,Cookies, Croquant, Feuillete, Genoise, Petit Beurre, Sable, Speculos*
UK	*Assortment, Breakfast, Cereal Bars, Coated, Cookies, Digestives, Dips, Fig Rolls, Fingers, Fruit Bars, Half Iced, Jaffa Cakes, Jam, Mallows, Rich Tea, Shortbread, Wafer*
Spain	*Barquillo, Especialidades, Galleta Banada, Galleta Bizcocho, Galleta Mantequila, Galleta Maria, Galleta Relieve,Galeta Relena, Galleta tostada, Pasta de Te, Surtido Galleta*

Notes: This table describes the sub-categories in the biscuit market. A sub-category is created for each country, named "Biscuit", which represents an aggregate of products that did not enter the previous subcategory.

Fresh desserts market: As for biscuits, the supply of fresh desserts is country-specific. Despite some similarities, we cannot construct homogeneous sub-categories of fresh desserts. These sub-categories are presented in Table A.5.

Table A.5: Fresh desserts sub-categories

France	*Plain yogurts without added sugar, Plain yogurts with added sugar, Flavored yogurts, Yogurts with fruits, Diverse (ODD), Creams, Liégeois, Mousses, Egg creams, Rice/semolina puddings, Plain FCPS without added sugar, Flavored FCPS*
UK	*Plain yogurts without added sugar, Plain yogurts with added sugar, Yogurts with fruits, Yogurts with assortment, Yogurts diverse, Liquid yogurts and juices without added sugar, Liquid yogurts and juices with added sugar, Tiramisus, Cheesecakes, Rice puddings, Trifle, Diverse (ODD), Plain FCPS without added sugar, FCPS with fruits, FCPS diverse*
Spain	*Plain yogurts without added sugar, Plain yogurts with added sugar, Flavored yogurts, Yogurts with cereals, Yogurts with accompaniments, Yogurts with fruits, Creams, Flans, Jellies, Natillas, Diverse (ODD)*

Notes: This table describes the sub-categories in the dairy dessert market.

Added sugar content

In the non-alcoholic beverages market, natural sugars come only from fruit. This means that pure fruit juices and fruit juices from concentrate do not contain added sugar. We assume that all other drinks with a positive sugar content contain added sugar. We consider all biscuit products to contain added sugar in the three countries. Natural sugar comes from milk in the dairy desserts market. Plain yogurt and FBPS contain natural sugars, but no added sugars. The amount of sugar in plain dairy desserts can vary from 3 to 7 g per 100 g. We consider added sugar to be present when the sugar content exceeds 7 g per 100 g of product.

Definition of the differentiated products

Non-alcoholic beverages markets: The definition of the differentiated products is based on information on the firm name (e.g., Coca-Cola), the brand name (e.g., Coca-Cola, Fanta, Sprite, ...), the drinks subcategory, and other product characteristics (diet or regular for SSBs, and the presence of added sugar and flavour for fruit juice).[2,3] Beverages in a given subcategory with low purchase frequency are aggregated with similar products from the same firm or with a hypothetical product defined as "other firm/other brand" in the same subcategory. Following this product differentiation, we obtain 319, 402 and 285 distinct beverage varieties (hereafter referred to as "alternatives"), which we consider in our analysis of the non-alcoholic beverage market in France, the UK and Spain, respectively. These alternatives fall into five nutritional

[2]Private labels are aggregated into one firm and one brand.

[3]A Flavoured water is considered as diet if it contains 1 gram or less of sugar per 100 ml.

categories: diet SSB, regular SSB and fruit juices, which are divided into three sugar content levels: low, medium and high. Table A.6 presents a summary of the market structure and the definition of alternatives in the non-alcoholic beverages market. We also report the number of purchases and the average price per litre of non-alcoholic beverages and non-alcoholic beverages with added sugar in each market. The number of firms and national brands is similar in France and Spain (60 in France, 78 in the UK and 50 in Spain, Table A.6). The UK market is characterised by a higher number of national brands (151 vs. 119 in France and 109 in Spain), resulting in a greater variety of alternatives in the non-alcoholic beverage market.

Biscuits market: We identify 57 firms competing in the French biscuits market, 70 in the UK and 71 in Spain. The market is characterized by a substantial heterogeneity in the size of firms. In contrast, there is much more national brands in the UK than in Spain (104 vs. 84 and 87 in France and Spain, respectively, Table A.6). A key characteristic of the market is that huge multinational companies, such as Mondelez and Nestlé, co-exist with a large number of small firms. To reduce the number of product alternatives, we aggregate small firms into a group called "Other firms" and gather all private labels sold by retailers into one group. Following our process, we also consider sub-brand information. For example, to distinguish between LU Granola and LU Prince, which are both from the LU brand, we consider sub-brands, in this case "Granola" or "Prince". We then use country-specific subcategories of biscuits to define our alternatives. Finally, we use information on the flavour of the biscuits (e.g., chocolate or vanilla) to describe these products more precisely. Crossing these characteristics yields 407 alternatives in France, 500 in the UK and 309 in Spain, with at least 50 purchases of each product.

Desserts market: The definition of the differentiated products is based on information on the firm name, the brand name, the drinks sub-category, and other product characteristics such as plant-based ingredient instead of dairy milk, fatness class, and presence of sweeteners.[4,5] Desserts in a given sub-category with low purchase frequency are aggregated with similar products from the same firm or with a hypothetical product defined as "other firm/other brand" in the same sub-category. This yields 266 alternatives in France, 171 in the UK, and 281 in Spain. The number of firms is similar in France and Spain (14), but substantially higher

[4] Private labels are aggregated in one firm and one brand.

[5] The plant-based characteristics are available for each country, but the fatness classes are only present in Spain and France, and the presence of sweeteners only in Spain. The fatness classes are defined by the type of skimming for yogurts (which may not be fully correlated with the actual fat content) and the fat category that must be legally displayed on FCPS.

in the UK (25). The number of retailers among the considered firms is similar in France (8), the UK (10), and Spain (9).

Prices

The price of each alternative is calculated as the weighted ratio of total expenditure in euros over the total quantities in litres or kilogram of all items belonging to the alternative in a four-week period.[6] The weights used are Kantar period-specific household sample weights.[7]

Table A.6: Market structure

Non-alcoholic beverages	France	UK	Spain
Number of firms	60	78	50
Number of national brands	119	151	109
Number of sub-categories	8	11	10
Number of alternatives	319	402	285
Number of observations	666,482	1,319,069	270,211
Mean price (per litre)	1.18 €	0.78 €	0.84 €
Mean price of non-alcoholic beverages with added sugar (per litre)	1.02 €	0.67 €	0.82 €
Biscuits	**France**	**UK**	**Spain**
Number of firms	57	70	71
Number of national brands	84	104	87
Number of sub-categories	12	18	12
Number of alternatives	407	500	309
Number of observations	482,154	860,461	141,177
Mean price (per kg)	6.10 €	4.24 €	3.34 €
Desserts	**France**	**UK**	**Spain**
Number of firms	7	14	6
Number of national brands	32	44	36
Number of sub-categories	13	15	11
Number of alternatives	266	171	281
Number of observations	1,213,460	1,056,660	346,860
Mean price (per kg)	2.47€	3.01€	2.18€

Notes: This table presents a summary of the market structure for the three countries with the number of firms, national brands, sub-categories, alternatives, observations and the average price. The number of observations refers to the number of Kantar references purchased per household, date and store. Mean price is computed as the ratio of the weighted sum of expenses to the weighted sum of quantities.

[6] The following conversion rate is used: 1 pound = 1.15 euros for the UK market

[7] These weights are calculated by Kantar. They ensure that the panel is representative and correct for reporting biases related to periods away from home.

The average prices in Table A.6 are calculated as the ratio of the total expenditure in euros to the total quantity in litres of all drinks or in kilograms of all biscuits or dairy desserts purchased in each market. On average, non-alcoholic beverages are more expensive in France than in the UK and Spain (1.18 € per litre, vs. 0.67 and 0.84 € in the UK and Spain, respectively). Non-alcoholic beverages with added sugar are on average less expensive than the other categories of non-alcoholic beverages in the all three countries. Biscuits are much more expensive than non-alcoholic beverages. They are more expensive in France than in the other two countries (6.10 € per kg of biscuit vs. 4.24 and 3.34 € in the UK and Spain, respectively). Desserts are more expensive than non-alcoholic beverages but cheaper than biscuits. They are cheapest in Spain (2.12€/kg) followed by France (2.46€/kg) and the UK (3.01€/kg).

A.4 Additional tables

Table A.7: Initial sugar purchases (g/day/capita)

	Non-alcoholic beverages			Biscuits			Desserts		
	France	**UK**	**Spain**	**France**	**UK**	**Spain**	**France**	**UK**	**Spain**
All	9.84	6.36	6.16	4.32	4.30	2.65	7.82	3.61	5.06
Household composition									
Without children	9.52	6.28	6.19	4.02	4.54	2.46	8.23	4.46	5.06
With children <6	8.79	4.70	5.19	3.83	2.78	2.18	6.75	2.76	4.35
With children 7-16	11.52	8.19	6.70	5.23	4.62	3.40	7.32	3.31	5.36
With children <6 & 7-16	9.51	6.09	6.28	4.88	4.00	2.99	7.22	3.24	5.62
Obesity status									
No overweight or obese	9.22	6.08	5.02	4.26	3.87	2.50	7.30	3.36	4.83
At least one	10.12	6.47	6.52	4.29	4.18	2.69	7.66	3.49	4.86
All overweight or obese	10.29	6.44	6.63	4.43	4.64	2.74	8.66	3.85	5.55
Socio-economic class									
Rich	8.64	5.90	5.69	3.60	3.73	2.59	7.89	3.52	4.87
Middle	9.85	6.33	6.08	4.35	4.31	2.73	7.98	3.70	5.10
Poor	10.91	6.88	6.83	4.85	4.85	2.50	6.95	3.47	5.14

Notes: This table displays the (non-weighted) average sugar purchases observed in the panel, computed across households. It is expressed in grams per day per capita.

B Empirical modelling: demand and supply models

In line with the empirical industrial organisation literature, the market is modelled by combining a flexible discrete-choice model of demand for differentiated products with a supply model that assumes oligopolistic competition. The estimation method involves two steps. First, we estimate a demand model independently in order to understand household preferences for each of the three markets in each country. Secondly, we use the estimated consumer substitution patterns to model the supply side (i.e., the nature of competition between firms) in order to determine the pricing strategies and marginal costs of each product.

B.1 The demand model

We use a flexible discrete-choice model to estimate demand and obtain own- and cross-price elasticities for each alternative. We opt for this type of demand model because accurately evaluating the impact of policies on specific markets is imperative. Specifically, we use a random coefficient logit model (RCLM) (Berry et al., 1995; McFadden and Train, 2000). This model specifies preferences over product characteristics in a flexible manner, allowing for both observed and unobserved heterogeneity in consumer preferences.

B.1.1 The random coefficient logit model

Following Revelt and Train (1998), let t denote the index of time ($t = 1,\ldots,T$), i the index of the household in the sample ($i = 1,\ldots,N$) and j the index of the product inside the choice set of differentiated products ($j = 1,\ldots,J_t$) at time t.

Utility. The indirect utility function V_{ijt} for household i buying product j in period t is given by

$$V_{ijt} = \alpha_i p_{jt} + \beta_i X_{jt} + \epsilon_{ijt} \tag{1}$$

where p_{jt} is the price of product j in period t, α_i is the marginal disutility of the price for household i, X_{jt} is a vector of observed product characteristics, β_i is the vector of associated parameters that capture the individual taste for product characteristics, and ϵ_{ijt} is an individual error term.

We assume that parameter α_i varies across households, with some unobserved heterogeneity. Indeed, households can have a different price disutility. It can be rewritten as

$$\alpha_i = \alpha + \pi^{\alpha} D_i + \sigma \nu_i \tag{2}$$

where α is the mean marginal disutility of the price for all households, π the vector of parameters associated with demographic characteristics D_i (family composition, obesity status and socio-economic class of the household), and ν_i measures the unobserved heterogeneity of the households. We denote $P_\nu(.)$ the distribution of parameter ν. For all markets and all countries, we specify the price disutility as follows: $\alpha_i = \alpha + \alpha_{\text{child(i)}} + \alpha_{\text{obesity(i)}} + \alpha_{\text{class(i)}} + \sigma \nu_i$. The vector product characteristics vary per market and country. A summary of variable choices is presented in column 1 of Table B.1. Additionally, the parameter β_i also depends on household characteristics. It can be rewritten as $\beta_i = \beta + \pi^{\beta} H_i$ where β represents the vector of the average individual's taste for product characteristics and π^{β} is the vector of coefficients associated with household demaographics D_i. Table B.1 in column 2 summarises the interactions considered for each market and country.

We can divide the indirect utility between a mean utility $\delta_{jt} = \alpha p_{jt} + \beta X_{jt} + \xi_{jt}$ where ξ_{jt} captures all unobserved product characteristics and a deviation from this mean utility $\mu_{ijt} = (\sigma \nu_i + \pi^{\alpha} D_i) p_{jt} + \pi^{\beta} H_i X_{jt}$. Hence the indirect utility is given by

$$V_{ijt} = \delta_{jt} + \mu_{ijt} + \epsilon_{ijt} \tag{3}$$

A household is defined by the vector $(\nu_i, D_i, \varepsilon_{i0t}, ..., \varepsilon_{iJt})$.

Outside option. The household can decide not to buy one of the considered products. It is represented by the non-purchase behavior at period t.The utility of this option is normalised to zero. The indirect utility of choosing the outside option is written as $V_{i0t} = \epsilon_{i0t}$.

Market share. We assume that ϵ_{ijt} is independently and identically distributed as an extreme value type I distribution. The conditional probability that household i chooses product j in period t is:

$$s_{ijt}(\nu) = \frac{exp(\delta_{jt} + \mu_{ijt})}{1 + \sum_{k=1}^{J_t} exp(\delta_{kt} + \mu_{ikt})} \tag{4}$$

The market share of product j in period t is (Nevo, 2001):

$$s_{jt} = \int_{A_{jt}} \left(\frac{\exp(\delta_{jt} + \mu_{ijt})}{1 + \sum_{k=1}^{J_t} \exp(\delta_{kt} + \mu_{ikt})} \right) dP_{\nu}(\nu) \tag{5}$$

where A_{jt} is the set of households who have the highest utility for product j in period t and P_{ν} is the cumulative distribution function of ν which is typically assumed to be standard normal.

Elasticity. The random coefficient logit model generates a flexible pattern of substitutions between products. We can then write the own-price and cross-price elasticities of the market share s_{jt} as:

$$\theta_{jkt} = \frac{\partial s_{jt}}{\partial p_{kt}} \frac{p_{kt}}{s_{jt}} = \begin{cases} \frac{p_{jt}}{s_{jt}} \int \alpha_i s_{ijt}(1 - s_{ijt}) \phi(\nu_i) \mathrm{d}\nu_i & \text{if } j = k \\ -\frac{p_{kt}}{s_{jt}} \int \alpha_i s_{ijt} s_{ikt} \phi(\nu_i) \mathrm{d}\nu_i & \text{otherwise} \end{cases} \tag{6}$$

where $\phi()$ is the density function of $P_{\nu}(.)$.

Table B.1: Summary demand specification

Market/Country	Product characteristics X_j	Demographic interaction with X_j
Non-alcoholic beverages markets		
France	Pure juice, diet, sugar content for SSBs, sugar content for fruit juices, brand fixed effects	Diet is interacted with children < 6 and children 7-16 , sugar content (SSBs and fruit juices) is interacted with children < 6 and children 7-16
UK	Diet, sugar content for SSBs, sugar content for fruit juices, subcategory and brand fixed effects	Diet is interacted with children < 6 and children 7-16, sugar content (SSBs and fruit juices) is interacted with children < 6 and children 7-16
Spain	Pure juice, fruit drink, fruit juice with milk diet, sugar content for SSBs, sugar content for fruit juices, subcategory and brand fixed effects	Diet is interacted with children < 6 and children 7-16 , sugar content SSBs and fruit juices) is interacted with children < 6 and children 7-16
Biscuits markets		
France	Sugar content, lipid content, an interaction term between both, brand fixed effects	Sugar is interacted with children < 6 and children 7-16 , sugar x lipid is interacted with children < 6 and children 7-16
UK	Sugar content, lipid content, an interaction term between both, brand fixed effects	Sugar is interacted with children < 6 and children 7-16 , sugar x lipid is interacted with children < 6 and children 7-16
Spain	Sugar content, lipid content, an interaction term between both, brand fixed effects	Sugar is interacted with children < 6 and children 7-16 , sugar x lipid is interacted with children < 6 and children 7-16
Desserts markets		
France	Sugar content, saturated fat, planted-based, subcategory and brand fixed effects	Sugar is interacted with children < 6 and children 7-16
UK	Sugar content, fat, planted-based, subcategory and brand fixed effects	Sugar is interacted with children < 6 and children 7-16
Spain	Sugar content, saturated fat, sweeteners, subcategory and brand fixed effects	Sugar is interacted with children < 6 and children 7-16

Notes: This table summarizes the specifications of the nine demand estimations.

B.1.2 Identification

This method relies on the assumption that all product characteristics X_{jt} are independent of the error term ϵ_{ijt}, which can be decomposed into a product-specific error term and an individual error term, $\epsilon_{ijt} = \xi_{jt} + e_{ijt}$. However, there is empirical evidence that unobserved factors included in ξ_{jt} can be correlated with observed characteristics X_{jt}, producing endogeneity problems (Berry, 1994). Such unobserved characteristics can be promotions or advertising, for example. For instance, promoted products are often moved to the front of the shelf, advertised, and sold at a lower price at the same time. Since we do not have any information on advertising expenditure spent by firms, the estimated impact of observed prices on demand will then capture both a true price effect and the effect of unobserved marketing efforts. Prices may also be endogenous if some unobserved characteristics are positively valued by consumers, who are thus ready to pay a premium for them. This may be taken into account by firms in setting their prices.

To solve the problem that omitted product characteristics might be correlated with prices, we use a control function approach as in Petrin and Train (2010). We then regress prices on instrumental variables (W_{jt}) and observed characteristics X_j of the demand equation:

$$p_{jt} = W_{jt}\gamma + X_j\mu + \eta_{jt} \tag{7}$$

where η_{jt} is an error term that captures the remaining unobserved variations in prices. The estimated error term $\widehat{\eta}_{jt}$ of the price equation includes some omitted variables such as advertising variations and promotions or omitted product characteristics that could explain price variations across products and time periods. Introducing this term in the mean utility of consumers δ_{jt} allows us to capture unobserved product characteristics varying across time. Prices are now uncorrelated with the new product-specific error term varying across periods ($\zeta_{jt} = \xi_{jt} - \lambda\widehat{\eta}_{jt}$). We then write

$$\delta_{jt} = \alpha p_{jt} + \beta X_{jt} + \lambda\hat{\eta}_{jt} + \zeta_{jt} \tag{8}$$

where λ is the estimated parameter associated with the estimated error term of the first stage.

To instrument prices, we use cost shifters, which represent a proxy for production costs, and BLP instruments, which represent the competitive environment of products, as described in (Berry et al., 1995). The cost shifters come from the following sources: INSEE price production indices for France, ONS price production indices for the United Kingdom, and INE price production indices for Spain.[8,9,10]

As they only represent a very small share of the demand for those inputs, they are not

[8]France: https://www.insee.fr/fr/plan-du-site/famille-bdm/102776019
[9]UK: https://www.ons.gov.uk/economy/inflationandpriceindices
[10]Spain: https://www.ine.es/jaxiT3/Tabla.htm?t=8381

likely to be correlated with unobserved determinants of demand in each market. This justifies the absence of correlation between input prices and unobserved determinants of demand. BLP instruments are the sum of the product characteristics of competing products offered on the market in the same segment or offered by competitive firms. In our analysis, we use either the number or the sum of the sugar content of competing products. The list of instruments used in our first-stage regression and the estimation are provided in Tables B.2, B.3 and B.4 for each market. The F-test for the nine estimations is greater than 10, indicating that the instrumental variables used are not weak.

Table B.2: Results on price equation - Non-alcoholic beverages market

	France	UK	Spain
	Coefficient (se)	Coefficient (se)	Coefficient (se)
Instrumental variables			
BLP instruments			
Number of competing products			
offered by other firms within			
- the nutritional category	-0.02*** (0.00)		
- the product category		-0.01*** (0.00)	
- the product and nutritional category			-0.02*** (0.01)
Total sugar content of competing products			
- products offered by other firms			
within the nutritional category	0.00*** (0.00)		
- within the nutritional category		-0.00*** (0.00)	
- within the product and nutritional category			0.00*** (0.00)
Cost shifter (input prices)			
Aluminium	-0.00*** (0.00)		-0.00*** (0.00)
Glass	0.00*** (0.00)	-0.00*** (0.00)	-0.00*** (0.00)
Exogenous variables			
Pure fruit juice	-0.01 (0.04)		0.65*** (0.05)
Fruit-flavoured drink			-0.05 (0.06)
Fruit juice with milk			0.10 (0.07)
Diet	0.38*** (0.06)	0.11*** (0.04)	0.10* (0.06)
Sugar (Soft drinks)	0.05*** (0.01)	0.07*** (0.01)	0.02*** (0.01)
Sugar (Fruit juices)	0.03*** (0.01)	0.28*** (0.01)	0.01 (0.01)
Brand fixed effects	yes	yes	yes
Category fixed effects	no	yes	no
IV joint significance test	F(4,3950) = 21.41	F(3,5035) = 35.97	F(4,3438) = 19.11
	Prob > F = 0.0000	Prob > F = 0.0000	Prob > F = 0.0000
Observations	4,077	5,182	3,539
R^2	0.950	0.944	0.875

Notes: This table reports the estimates from the price regression (Equation 7) for the non-alcoholic beverage market. Price is regressed on a set of instruments and all exogenous variables. Estimators' standard errors (se) are in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B.3: Results on price equation - Biscuits market

	France	**UK**	**Spain**
	Coefficient (se)	Coefficient (se)	Coefficient (se)
Instrumental variables			
BLP instruments			
Number of competing products of other firms			
- within the category	-0.00*** (0.00)		
- within the category and the flavor			-0.02*** (0.00)
Total sugar content of competing products offered by other firms within the category		-0.00*** (0.00)	-0.06*** (0.01)
Total lipid content of competing products offered by other firms within the flavor		-0.01*** (0.00)	0.00*** (0.00)
Cost shifter (input prices)			
Chocolat	0.00*** (0.00)		
Exogenous variables			
Lipid	0.17*** (0.0)	0.03 (0.01)	0.10* (0.06)
Sugar	0.09*** (0.02)	0.04*** (0.01)	0.02*** (0.01)
SugarLipid	-32.00*** (5.22)	0.07 (0.01)	0.02*** (0.01)
Brand fixed effects	yes	yes	yes
IV joint significance test	F(2,5018) = 15.84 Prob > F = 0.0000	F(2,5989) = 18.72 Prob > F = 0.0000	F(3,3743) = 59.90 Prob > F = 0.0000
Observations	5,107	6,097	3,869
R^2	0.909	0.921	0.898

Notes: This table reports the estimates from the price regression (Equation 7) for the biscuit market. Price is regressed on a set of instruments and all exogenous variables. Estimators' standard errors (se) are in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B.4: Results on price equation - Dairy desserts market

	France	UK	Spain
	Coefficient (se)	Coefficient (se)	Coefficient (se)
Instrumental variables			
BLP instruments			
Number of competing products offered			
- within the same fatness class	-0.02*** (0.00)		
- by other firms with the same category		-0.01*** (0.00)	
- by the same firm within the same category			0.03*** (0.01)
Sugar quantity of competing products offered			
- by the same firm in the same fatness class	0.00*** (0.00)		
- by the same firm with the same plant-based		-0.00*** (0.00)	
- with the same plant-based characteristics			0.00*** (0.00)
Exogenous variables			
Fats	0.13*** (0.01)		
Saturated fats		0.53*** (0.02)	0.27*** (0.01)
Sugar	0.04*** (0.01)	-0.04*** (0.01)	0.03*** (0.01)
Plant-based ingredients	0.51*** (0.11)		
Sweeteners			0.40*** (0.07)
Subcategory fixed effects	yes	no	yes
Brand fixed effects	yes	yes	yes
IV joint significance test	F(2,3162) = 15.77	F(2,2,016) = 17.32	F(2,3,075) = 41.31
	Prob > F = 0.0000	Prob > F = 0.0000	Prob > F = 0.0000
Observations	3,162	2,016	3,075
R^2	0.93	0.93	0.94

Notes: This table reports the estimates from the price regression (Equation 7) for the dairy dessert market. Price is regressed on a set of instruments and all exogenous variables. Estimators' standard errors (se) are in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

B.1.3 Estimation procedure

We estimated the demand model using individual data. We used the simulated maximum likelihood method as in Revelt and Train (1998). In our model, as purchases are independent considering household and period, the likelihood function for household i can be written as:

$$L_i = \int \prod_{t=1}^{T} \prod_{j=0}^{J_t} [\frac{exp(\delta_{jt} + \mu_{ijt})}{1 + \sum_{k=1}^{J_t} exp(\delta_{kt} + \mu_{ikt})}]^{Y_{ijt}} dP_{\nu}(\nu) \tag{9}$$

where Y_{ijt} is a dummy variable equal to 1 if household i chooses product j in period t and 0 otherwise.

We estimate the vector of demand parameters by maximizing the simulated log-likelihood function given by:

$$SLL = \sum_{i=1}^{N} W_i \times ln[\hat{s}_{ijt}] \tag{10}$$

where N is the total number of purchases registered by Kantar for a given market, and $W_i = N_i \times W_i^{ht}$ is the weight associated with purchase i. N_i is the number of units bought at purchase i, used to account for multiple purchases of the same product (i.e., buying three bottles of the same product at once). W_i^{ht} is the Kantar period-specific household sample weight for period t, associated with the household h that made the i^{th} purchase. $\hat{s}_{ijt}$ stands for the individual simulated market share of product j in market t:

$$\hat{s}_{ijt} = \frac{1}{R}\sum_{r=1}^{R} w_r \prod_{j=0}^{J_t} [\frac{exp(\alpha_i^r p_{jt} + \beta_i X_{jt} + \lambda \hat{\eta}_{jt})}{\sum_{k=1}^{J_t} 1 + exp(\alpha_i^r p_{kt} + \beta_i X_{kt} + \lambda \hat{\eta}_{kt})}]^{Y_{ijt}} \tag{11}$$

where R is the number of draws, w_r is the r^{th} entry in the vector of weights and $\alpha_i^r = \alpha + \pi DM_i + \sigma \nu_i^r$ with $\nu^r \sim \mathcal{N}(0,1)$.[11]

B.2 The supply side

Firms are likely to adjust to exogenous shocks, and ignoring their strategic behaviour may lead to biased estimates of the effect of public policies (Griffith et al., 2010; Bonnet and Réquillart, 2013; Allais et al., 2015). The simulation of the effects of policy shocks on the market equilibrium therefore requires a structural model of the supply side. Below, we assume that only price strategies are implemented by firms in reaction to tax. Other strategic firms' reactions, such as modifying the set of products or products reformulation, are beyond the scope of our assessment.

We consider F firms that compete in prices on the considered market and sell products to

[11] To address the curse of dimensionality, we use a sparse grid method as it is developed in Heiss and Winschel (2008). The choice for the number of simulations is explained on http://www.sparse-grids.de/. Integration on sparse grids has low computational costs compared to other methods. The number of draws is especially reduced because each draw is associated with a weight. Let R be the number of simulations which depends on the type of integration rule, the number of dimensions and the chosen accuracy. Let x_r and w_r be the r^{th} entries respectively in the vector of draws and the vector of weights. We want ν^r to follow a standard normal distribution so we apply a transformation (inverse of the standard normal cumulative distribution function) to x_r ($x_r \in [0,1]\ \forall r$) so that $\nu^r = \Phi^{-1}(x_r)$ and $\nu^r \sim \mathcal{N}(0,1)$.

consumers and set prices. At each period, the firm maximizes its profit, conditional on the demand parameters and other firms' prices, holding the set of products offered and every other observed and unobserved characteristics constant:

$$\Pi_{ft} = \sum_{j \in G_{ft}} [M_t(p_{jt} - c_{jt}) s_{jt}(p_t)] \tag{12}$$

where G_{ft} is the set of products sold by firm f in period t, M_t is the size of the market in period t, p_{jt} is the price of product j in period t, c_{jt} is the constant marginal cost to produce and sell product j in period t, $s_{jt}(p_t)$ is the market share of product j in period t given the vector of product price p_t.

The equation of prices of products $j \in G_{ft}$ is determined with the first order conditions:

$$s_{jt}(p_t) + \sum_{k \in G_{ft}} [M_t(p_{kt} - c_{kt}) \frac{\partial s_{kt}}{\partial p_{jt}}] = 0 \ \forall j \in G_{ft} \tag{13}$$

We recover estimates of firms' margins $\gamma_{jt} = p_{jt} - c_{jt}$ for each product using the first-order conditions and estimates of the demand model. Using equation (13), the vector of margins $\gamma_t = (p-c)_t$ can be written in matrix notation.

$$\gamma_t = (p-c)_t = -\Big(\sum_{f=1}^{F} I_{ft} S_{pt} I_{ft}\Big)^{-1} \Big(s_t(p_t)\Big) \tag{14}$$

where I_{ft} is the ownership diagonal matrix $(J_t \times J_t)$ of firm f in period t with elements $I_{ft}(j,j)$ equal to 1 if product j is produced by firm f in period t and zero otherwise, S_{pt} is the matrix $(J_t \times J_t)$ of the first derivatives of all market shares with respect to all prices in period t, i.e., $S_{pt} = (\frac{\partial s_{kt}}{\partial p_{jt}})_{(j=1,\dots,J_t;k=1,\dots,J_t)}$ and $s_t(p_t)$ is the vector of product market shares in period t. We then derive estimates of marginal costs, given observed prices.

B.3 Demand and supply results

Table B.5: Estimates of the random coefficient logit model - Non-alcoholic beverages market

	France	**UK**	**Spain**
Price (p_{jt})			
Mean (α)	-2.65 (0.00)	-6.84 (0.00)	-5.35 (0.00)
× children below 6 years old	0.05 (0.00)	0.13 (0.00)	0.15 (0.00)
× children 7-16 years old	0.03 (0.00)	-0.03 (0.00)	-0.22 (0.00)
× middle socio-economic class	-0.36 (0.00)	-0.24 (0.00)	-0.13 (0.00)
× poor socio-economic class	-0.70 (0.00)	-0.35 (0.00)	-0.36 (0.00)
× at least one obese	-0.06 (0.00)	-0.12 (0.00)	-0.08 (0.00)
× all obese	-0.24 (0.00)	-0.15 (0.00)	0.00 (0.00)
Standard deviation (σ)	0.91 (0.00)	1.64 (0.00)	0.61 (0.00)
Pure juice	0.66 (0.00)		3.35 (0.00)
Fruit drink			0.64 (0.00)
Fruit juice with milk			1.48 (0.00)
Diet	-1.59 (0.00)	1.02 (0.00)	-0.34 (0.00)
× children below 6 years old	0.09 (0.00)	0.13 (0.00)	0.30 (0.00)
× children 7-16 years old	0.06 (0.00)	0.07 (0.00)	0.21 (0.00)
Sugar (SSBs)	-0.05 (0.00)	0.16 (0.00)	0.11 (0.00)
× children below 6 years old	0.05 (0.00)	0.03 (0.00)	0.02 (0.00)
× children 7-16 years old	0.04 (0.00)	0.02 (0.00)	0.02 (0.00)
Sugar (fruit juices)	-0.06 (0.00)	0.03 (0.00)	0.14 (0.00)
× children below 6 years old	0.04 (0.00)	0.05 (0.00)	0.08 (0.00)
× children 7-16 years old	0.04 (0.00)	0.04 (0.00)	0.07 (0.00)
Fixed effects			
Sub-category	no	yes	no
Brand (NBs & PLs)	yes	yes	yes
Error ($\hat{\eta}_{jt}$)	0.51 (0.00)	4.09 (0.00)	4.49 (0.00)
Observations	708,940	1,364,000	270,000
Log-likelihood	-1.53588e+10	-2.32081e+10	-9.05930e+09

Notes: This table reports the estimates from the demand estimation (Equation 11) for the non-alcoholic beverage market. Standard errors of coefficient estimates are in parentheses.

Table B.6: Estimates of the random coefficient logit model - Biscuits market

	France	**UK**	**Spain**
Price (p_{jt})			
Mean (α)	-0.42 (0.00)	-1.33 (0.00)	-0.92 (0.00)
× children below 6 years old	-0.02 (0.00)	0.02 (0.00)	0.03 (0.00)
× children 7-16 years old	-0.01 (0.00)	0.04 (0.00)	0.06 (0.00)
× middle Socio-economic class	-0.02 (0.00)	-0.01 (0.00)	-0.01 (0.00)
× poor socio-economic class	-0.05 (0.00)	-0.05 (0.00)	-0.07 (0.00)
× at least one obese	0.03 (0.00)	0.12 (0.00)	0.05 (0.00)
× all obese	-0.01 (0.00)	-0.00 (0.00)	0.02 (0.00)
Standard deviation (σ)	0.17 (0.00)	0.21 (0.00)	0.20 (0.00)
Sugar	0.02 (0.00)	0.09 (0.00)	-0.02 (0.00)
× children below 6 years old	0.02 (0.00)	0.01 (0.00)	0.02 (0.00)
× children 7-16 years old	0.02 (0.00)	0.02 (0.00)	0.03 (0.00)
Lipid	0.06 (0.00)	0.22 (0.00)	0.09 (0.00)
SugarLipid	-14.97 (0.00)	-40.38 (0.00)	-10.51 (0.00)
× children below 6 years old	1.44 (0.00)	-4.55(0.00)	-5.46 (0.00)
× children 7-16 years old	5.47 (0.00)	-1.75 (0.00)	-0.02 (0.00)
Fixed effects			
Brand (NBs & PLs)	yes	yes	yes
Error ($\hat{\eta}_{jt}$)	0.14 (0.00)	1.00 (0.00)	0.56 (0.00)
Observations	544,980	928,920	170,080
Log-likelihood	-7.63538e+09	-7.10512e+09	-2.05663e+09

Notes: This table reports the estimates from the demand estimation (Equation 11) for the biscuit market. Standard errors of coefficient estimates are in parentheses.

Table B.7: Estimates of the random coefficient logit model - Desserts market

	France	**UK**	**Spain**
Price (p_{jt})			
Mean (α)	-1.33 (0.00)	-1.22 (0.00)	-2.86 (0.00)
× children below 6 years old	-0.07 (0.00)	-0.09 (0.00)	-0.21 (0.00)
× children 7-16 years old	-0.03 (0.00)	-0.08 (0.00)	-0.30 (0.00)
× middle socio-economic class	0.01 (0.00)	-0.07 (0.00)	-0.12 (0.00)
× poor socio-economic class	0.00 (0.00)	-0.09 (0.00)	-0.20 (0.00)
× at least one obese	0.02 (0.00)	0.01 (0.00)	-0.03 (0.00)
× all obese	0.02 (0.00)	0.02 (0.00)	0.04 (0.00)
Standard deviation (σ)	0.14 (0.00)	0.16(0.00)	0.55 (0.00)
Sugar	0.09 (0.00)	0.04 (0.00)	0.14 (0.00)
× children below 6 years old	0.01 (0.00)	0.03 (0.00)	0.05 (0.00)
× children 7-16 years old	-0.00 (0.00)	0.04 (0.00)	0.07 (0.00)
Fats	0.21 (0.00)		
Saturated Fats		0.50 (0.00)	0.85 (0.00)
Plant-based ingredient	-2.20 (0.00)		
Sweeteners			1.80 (0.00)
Fixed effets			
Subcategory	yes	yes	yes
Brands	yes	yes	yes
Error ($\hat{\eta}_{jt}$)	1.17 (0.00)	1.10 (0.00)	1.61 (0.00)
Observations	1,213,460	1,056,660	346,860
Log-likelihood	-7.14e+10	-1.22e+10	-1.90e+10

Notes: This table reports the estimates from the demand estimation (Equation 11) for the dairy dessert market. Standard errors of coefficient estimates are in parentheses.

Table B.8: Elasticities and margins by categories - Non-alcoholic beverages market

	France		UK		Spain	
Firms	**Own-price elasticities**	**Margins (% price)**	**Own-price elasticities**	**Margins (% price)**	**Own-price elasticities**	**Margins (% price)**
Colas	-2.8	48.0	-5.7	24.3	-4.7	30.6
Iced tea	-3.4	41.9			-4.9	45.3
Fruit-flavoured drinks	-3.4	40.3	-6.3	30.5	-4.4	35.6
Flavoured waters	-2.8	47.9	-3.4	50.8	-2.9	69.7
Tonic waters	-5.1	42.6				
Lemonades			-4.1	53.2	-3.4	54.7
Energy drinks			-8.3	15.9	-7.1	23.1
Other SSBs	-3.2	51.3	-5.7	37.6	-6.2	65.8
Nectars	-3.8	40.5	-7.1	23.3	-4.9	38.7
Fruit juices	-3.7	42.0				
Pure fruit juices	-4.5	32.2	-7.8	20.8	-6.3	30.1
Smoothies	-12.5	10.4				
Fruit juices with milk					-4.9	32.0
Flavoured milk			-9.8	12.7		

Notes: This table reports the own-price elasticities and margins (as a percentage of the price) by product categories for the non-alcoholic beverage market.

Table B.9: Elasticities and margins by sugar content - Biscuits market

	France		UK		Spain	
Sugar content (g/100g)	**Own-price elasticities**	**Margins (% price)**	**Own-price elasticities**	**Margins (% price)**	**Own-price elasticities**	**Margins (% price)**
[0 ; 10 [	-3.8	26.9	.	.	-4.7	26.5
[10 ; 20 [	-2.3	63.9	-4.8	37.4	-3.1	52.3
[20 ; 26 [	-2.6	53.6	-5.2	45.4	-2.8	63.9
[26 ; 31 [	-2.6	56.6	-5.8	31.9	-3.5	46.4
[31 ; 37 [	-2.6	60.1	-7.0	26.2	-5.2	26.9
[37 ; 43 [	-2.7	56.8	-7.7	17.9	-4.4	35.7
>= 43	-3.1	43.7	-7.7	22.9	-3.6	45.1

Notes: This table reports the own-price elasticities and margins (as a percentage of the price) by sugar content categories for the biscuit market.

Table B.10: Elasticities and margins by categories - Dairy desserts market

	France		UK		Spain	
Categories	Own-price elasticities	Margins (% price)	Own-price elasticities	Margins (% price)	Own-price elasticities	Margins (% price)
Yogurts	**-3.8**	**55.7**	**-3.7**	**38.9**	**-6.3**	**55.9**
plain	-2.7	66.6	-3.5	43.8	-5.8	62.5
other	-3.2	51.8	-3.7	38.5	-6.4	54.9
ODD	**-4.9**	**34.8**	**-5.0**	**29.9**	**-7.3**	**46.0**
FCPS	**-3.7**	**42.5**	**-4.2**	**33.6**		
plain	-3.4	47.7	-3.5	43.2		
other	-4.2	34.8	-4.3	32.4		

Notes: This table reports the own-price elasticities and margins (as a percentage of the price) by product categories for the dairy dessert market.

Table B.11: Own-price elasticities by markets, countries, and household characteristics

	Non-alcoholic beverages			Biscuits			Dairy desserts		
	France	UK	Spain	France	UK	Spain	France	UK	Spain
Household composition									
Without children	-4.71	-8.93	-7.39	-3.26	-9.28	-5.35	-3.08	-4.27	-3.05
With children <6	-4.64	-8.84	-7.21	-3.49	-9.19	-5.20	-3.00	-4.34	-3.13
With children 7-16	-4.67	-9.01	-7.69	-3.40	-9.12	-5.05	-2.98	-4.37	-3.19
With children <6 & 7-16	-4.59	-8.92	-7.51	-3.64	-9.04	-4.91	-2.98	-4.43	-3.25
Obesity status									
No overweight or obese	-4.48	-8.84	-7.42	-3.50	-9.18	-5.24	-2.97	-4.48	-3.26
At least one	-4.58	-8.95	-7.52	-3.28	-9.11	-4.99	-2.96	-4.39	-3.25
All overweight or obese	-4.89	-8.98	-7.42	-3.55	-9.19	-5.14	-3.00	-4.43	-3.24
Socio-economic class									
Rich	-4.06	-8.73	-7.24	-3.24	-9.04	-4.97	-3.17	-4.05	-2.82
Middle	-4.66	-8.96	-7.40	-3.42	-9.12	-5.04	-3.08	-4.18	-2.96
Poor	-5.24	-9.08	-7.71	-3.68	-9.31	-5.36	-3.01	-4.35	-3.16

Notes: This table reports the own-price elasticities by household characteristics for the three markets and the three countries. Own-price elasticities are calculated at the alternative level. For a given household characteristic, it is the mean elasticity computed across all the alternatives' own-price elasticities.

C Counterfactual calibration

C.1 2018 UK soda tax

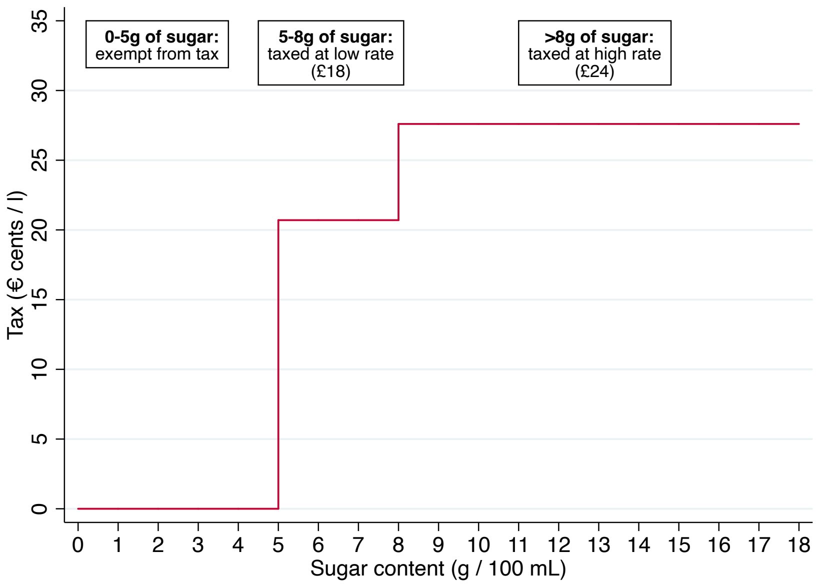
The UK government introduced the Soft Drinks Industry Levy (SDIL) in 2018. The levy is targeted at all soft drinks except pure fruit juices (which contain no added sugar) and drinks with a high milk content.

There are two levels of tax based on the sugar content:

- products with less than 5g of sugar per 100ml are exempt from the tax
- products with more than 5g and less than 8g of sugar per 100ml are taxed 0.18 GBP per liter
- products with more than 8g of sugar per 100ml are taxed 0.24 GBP per liter

The tax is not subject to the VAT tax.

Figure C.1: Design of the SDIL

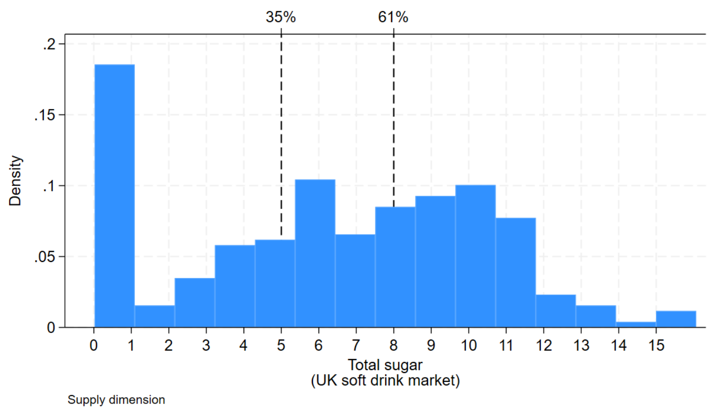


Notes: This figure describes the design of the SDIL implemented in the UK in 2018. The y-axis plots the tax rate (in euro cents per L) and the x-axis represents the sugar content of products (in grams per 100 mL).

C.2 Characteristics of the tax in the UK market

The average observed price of the targeted beverages in the UK soft drinks market is 6.5 cents per litre. Of these products (i.e., those containing added sugar but no milk), 35% have a sugar content below 5 g per 100 ml and are therefore exempt from the tax. Products with a sugar content between the 35^{th} and 61^{st} percentiles are taxed at the rate defined by the first threshold, while products with a sugar content above the 61^{st} percentile are taxed at the rate set by the second threshold.

Figure C.2: Distribution of targeted product



Notes: This graph shows the distribution of total sugar across the supply dimension. The distribution is calculated only for targeted products. The 35th and the 61st percentiles correspond to the location of the two sugar thresholds (at 5 and 8 grams of sugar per 100 mL of products) in the SDIL.

C.3 Equivalent policy design for other markets

To simulate an equivalent policy in the other eight markets, we adopt an design similar to the one implemented in the UK. The simulated tax will be a two-tiered tax based on sugar content. Thresholds will be set according to the sugar content of products in the relevant market. The first threshold will be set at the 35^{th} percentile in the distribution, and the second at the 61^{st} percentile in the distribution. As with the SDIL, the counterfactual policy will not be subject to VAT.

The amount of tax of product j containing added sugar will be obtained by the following formula:

$$\tau(\text{sugar}_j) = \begin{cases} 0 & \text{if sugar}_j < p35, \\ 0.18 \times 1.15 \times \frac{\text{mean price in the market}}{0.65} & \text{if } p35 \leq \text{sugar}_j < p61 \\ 0.24 \times 1.15 \times \frac{\text{mean price in the market}}{0.65} & \text{if } p61 \leq \text{sugar}_j \end{cases}$$

where

- $\tau()$ is the tax level (in € cents/L or kg) defined for each bracket of sugar content
- $p35$ and $p61$ = 35th and 61st percentiles in the distribution of total sugar across products containing added sugar (rounded down to the nearest integers)
- 0.18 and 0.24 = tax levels for the 1st and 2nd thresholds (in the SDIL, GBP/L)
- 1.15 = conversion rate GBP to euro
- 0.65 = mean price in the targeted soft drinks in the UK in 2017 (€/L)

Table C.1 summarizes the tax scenario in each market and country.

Table C.1: Tax scenarios in the nine markets

	Mean price (€ / L)	**Ratio of prices**	**Sugar thresholds [p35 ; p61]** (g / 100 g or ml)	**Tax amount** (€ / L)
Non-alcoholic beverages				
UK	0.65	1	[5 ; 8]	[0.21 ; 0.28]
France	1.02	1.57	[8 ; 10]	[0.33 ; 0.43]
Spain	0.82	1.26	[8 ; 10]	[0.26 ; 0.35]
Biscuits				
UK	4.33	6.66	[27 ; 33]	[1.38 ; 1.84]
France	6.10	9.38	[29 ; 33]	[1.94 ; 2.59]
Spain	3.31	5.09	[20 ; 28]	[1.05 ; 1.41]
Dairy desserts				
UK	3.01	4.63	[11 ; 13]	[0.96 ; 1.28]
France	2.47	3.80	[12 ; 14]	[0.79 ; 1.05]
Spain	2.18	3.35	[11 ; 13]	[0.69 ; 0.92]

Notes: Column 2 provides the average price (in € per liter or kilogram) of targeted products in the market. Column 3 shows the ratio between the average price in column 2 and the average price of soft drinks targeted by the SDIL in the UK market. Column 4 lists the 35th and 61st percentiles of sugar content (in grams per 100 g or ml) for targeted products. Finally, column 5 presents the tax amounts for the two thresholds (in € per liter).

C.4 New price equilibrium

We simulate the impact on prices and consumption of a change in tax design. We denote $\tau = (\tau_1, \ldots, \tau_j, \ldots, \tau_{J_t})$ the vector of the amounts of the excise tax paid for each alternative j at period t in tax design d, and $\hat{c}_t = p_t - \gamma_t = (\hat{c}_{1t}, \ldots, \hat{c}_{j_t}, \ldots, \hat{c}_{J_t})$ estimated marginal costs vector, obtained from firms profit maximization conditional on demand parameters estimates (see Section B.2). We find the new equilibrium prices vector in period t, denoted $p_t^\star = (p_{1t}^\star, \ldots, p_{j_t}^\star)$, using the following optimizing programme:

$$\min_{\{p_{jt}^\star\}_{j=1,\ldots,J_t}} ||\underbrace{p_t^\star - \gamma_t^*(p_t^\star)}_{\hat{c}_t(p_t^\star)} - \tilde{c}_t|| \tag{15}$$

where $\tilde{c}_t = \hat{c}_t + \tau$ stands for the new marginal costs vector when the tax amounts vector is τ, and the function $\gamma_t^*(p_t^\star)$ is defined in equation (14).[12]

C.5 Change in welfare

We compute the change in different components of welfare resulting from the implementation of the tax.

Consumer surplus.
Let ΔCS be the annual variation in consumer surplus:

$$\Delta CS = CS(p^*) - CS(p) = \sum_{t=1}^{T} \sum_{d=1}^{D} \frac{M_t^d}{|\alpha_d|} \int \left(ln \frac{\sum_{j=1}^{J_t} \exp \delta_{djt}(p_t^*)}{\sum_{j=1}^{J_t} \exp \delta_{djt}(p_t)} \right) \mathrm{d}P_\nu(\nu) \tag{16}$$

where p_t^* is the vector of equilibrium prices after the tax, and p_t is the vector of observed equilibrium prices, and d is the household type defined by the combination of demographics used in the utility (see Table B.1), and M_t^d is the total market size in period t for households of type d.

Profit.

[12]To be in the same pre-tax conditions as in other markets, we have to remove the 2012 soda tax (0.0716€$/L$), from the French non-alcoholic beverage market. First, we estimate the equilibrium prices following the removal of this tax. We then use these estimated prices as the "ex-ante" prices to evaluate the impact of the tax τ.

The annual variation in firms' profits at the market level is computed as follows:

$$\Delta\Pi = \Pi^* - \Pi = \sum_{t=1}^{T}\sum_{j=1}^{J}\Big(M_t(s^*_{jt}(p^*_t)\gamma^*_{jt}(p^*_t) - s_{jt}(p_t)\gamma_{jt}(p_t))\Big) \tag{17}$$

where M_t is the total market size in period t, $s_{jt}(p_t)$ is the market share of product j in period t, $\gamma_{jt}(p_t)$ is the margin of product j in period t, considering the price vector p_t. s^*_{jt} is the market share of product j in period t, $\gamma^*_{jt}(p_t)$ is the margin of product j in period t, considering the vector of equilibrium prices after tax, p^*_t.

Welfare.

The annual variation in welfare resulting from the tax is then:

$$\Delta WF = \Delta\Pi + \Delta CS + \Delta TR \tag{18}$$

where $\Delta TR = \sum_{t=1}^{T} M_t \sum_{j=1}^{J} s^*_{jt}(p^*_t)\tau$ is the annual tax revenue.

Welfare including health benefits. To consider the health benefits of a sugar tax, we internalise the social costs of sugar consumption into total welfare to account for the reduction in sugar consumption brought about by the tax. We calculate the social cost of total sugar consumption in the market as follows:

$$SC = ssc\sum_{t=1}^{T} M_t \sum_{j=1}^{J} s_{jt}(p_t)sugar_j \tag{19}$$

with ssc is the social cost of one kilogram of sugar, M_t the market size in period t, s_{jt} the market share vector and $sugar_{jt}$ the kg of sugar per kg of product. For the social cost of sugar, we use the value of $ssc = 12.833$ € per kg of sugar consumed estimated by Seidel et al. (2023), using data from Institute for Health Metrics and Evaluation (2022), Lara Castor et al. (2024), and von Philipsborn et al. (2023).

The annual variation in total welfare resulting from the tax, including the health benefits, is then:

$$\Delta WF = \Delta\Pi + \Delta CS + \Delta TR + \Delta SC \tag{20}$$

where $\Delta SC = SC^* - SC$ and $SC^* = ssc\sum_{t=1}^{T} M_t \sum_{j=1}^{J} s^*_{jt}(p^*_t)sugar_j$.

2 - Balancing Health Benefits and Economic Costs : A Structural Evaluation of Sugar Taxes on French Desserts

Balancing Health Benefits and Economic Costs: A Structural Evaluation of Sugar Taxes on French Desserts

Olivier Allais[*], Céline Bonnet[†], Marine Spiteri[‡]and Maxime Tranchard[§][¶]

Abstract

Governments are increasingly using food taxes to combat diet-related diseases. While taxes on sugar-sweetened beverages have proven effective, similar measures for other food categories remain underused. This study evaluates the potential effects of a tiered sugar-based excise tax on the French desserts market, covering compotes, yogurts, "fromage blanc"/"petits suisses" and other dairy desserts, that contribute substantially to sugar intake and show wide variation in sugar content. We estimate a structural demand and supply model that incorporates firms' strategic pricing responses and the possibility of reformulation under technical and regulatory constraints. Assuming firms reformulate to avoid the tax, we also account for consumer responses to changes in prices and taste. A €0.67 tax on desserts with more than 12 g of sugar per 100 g would reduce purchases by about 10% and sugar intake by 22%. The tax generates inter- and intra-category substitution effects, redirecting demand towards reformulated or initially lower-sugar options. The impact differs across households: more than a quarter of people cut their sugar intake by more than three teaspoons per week. Firms amplify the tax's effect by passing on more than its value to consumers. Compared to a no-reformulation scenario, taxation combined with reformulation leads to smaller sugar reductions but lowers economic costs for consumers and firms. Reformulation thus plays a decisive role in acceptability, balancing health benefits with social and economic concerns. These findings highlight the need for taxes that incentivize reformulation to achieve health gains while ensuring policy support.

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Contents

1 Introduction

Obesity, particularly among children and adolescents, has been identified as a major global public health challenge. Since 1990, adult obesity worldwide has more than doubled, while adolescent obesity has quadrupled. Obesity is a complex, multifactorial disease characterised by excessive body fat that poses a health risk (WHO, 2022). In most cases, obesity results from an imbalance between calorie intake and expenditure, whereby the body stores excess calories. Excess calorie intake comes mainly from poor diets high in ultra-processed foods containing added saturated fats and sugars (WHO, 2015). The economic cost of obesity is huge, estimated at over 10 trillion for China, 2.5 trillion for the United States, $850 billion for India, and over $100 billion for Germany, Canada, Australia, Brazil, the United Kingdom and Japan. In France, Caby (2016) estimated that the social cost of obesity was around €20 billion in 2012, which is comparable to the costs associated with tobacco and alcohol. This figure is expected to reach $133 billion (2.29% of GDP) by 2060 (Okunogbe et al., 2022). However, these costs are not fully reflected in market prices, meaning that consumers do not face the true health-related cost of their food choices. This stems from several market failures. First, consumers do not fully internalize the long-term health consequences of their food and drink consumption. This is partly because they have imperfect information about the links between diet and health: they may misunderstand complex dietary recommendations and may not make effective use of the nutritional information provided on product packaging. Second, a sizable body of evidence in behavioral economics indicates that consumers can exhibit present bias and limited self-control, overweighting short-term taste and convenience relative to future health, so that their choices may deviate from their own long-run welfare. Finally, obesity generates negative externalities. Because obesity-related health costs are largely covered by public health insurance, excessive consumption of sugar, fat, and salt creates social costs that are not borne by the individual consumer at the point of purchase.

One of the policy options proposed to reduce this social cost is the use of economic instruments, including fiscal policy, to both discourage the consumption of less healthy foods and promote a healthier food environment. To illustrate, the World Health Organisation (WHO) has recommended taxes on sugar-sweetened beverages (SSBs) as an effective intervention that can achieve both goals, particularly by encouraging SSB reformulation (World Health Organization et al., 2017). Such taxes were enacted in 38% of countries worldwide in 2019 (World Health Organization et al., 2022). A systematic review shows that SSB taxes have actually been effective in reducing purchases of the targeted SSBs by an average of -15% through price increases

(Andreyeva et al., 2022). There is also evidence of beverage reformulation and reduction in sugar content when the tax is designed as an excise tax with thresholds for sugar (Andreyeva et al., 2022). However, due to the narrow scope of these taxes, their impact on overall dietary intake is correspondingly small (World Health Organization et al., 2022). Accordingly, health authorities are considering extending such taxes to foods that contribute the most to sugar and fat intakes, particularly among children (World Health Organization et al., 2016; Department for Environment, Food and Rural Affairs, 2020; The Lancet Gastroenterology Hepatology, 2020), and several countries have already implemented them. In 2017, seven WHO member states adopted such taxes, rising to 29 by 2022 (World Health Organization et al., 2022). In Mexico, non-essential foods with an energy density greater than 275 kcal/100 g are taxed (World Cancer Research Fund International, 2022). The Hungarian "Public Health Product Tax" targets products high in sugar, salt, or caffeine (Bíró, 2015; World Cancer Research Fund International, 2022). Recently, Colombia introduced an excise tax on ultra-processed foods based on unhealthy nutrients in 2023 (Cadena et al., 2025).

In this paper, our objective is to show that extending the tax to foods beyond sodas can effectively reduce sugar purchases. We focus our analysis on a sugar tax on the French dessert market, i.e. compotes, yogurts, fromages blancs/petits suisses (FBPS) and other dairy desserts (ODD). [1] Desserts are important contributors to simple carbohydrate intake. In particular, yogurts and FBPS were the second largest contributors (9.4%) to the sugar intake of French children aged 1 to 10 years in 2014-2015, and the fifth-largest (6.7% of total sugar intake) for French adults aged 18 to 79 years (Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail (France), 2017). We evaluate the impact of a sugar-based excise tax with a single threshold. Compared with other fiscal instruments (e.g. VAT, sales taxes, or taxes based only on volume), nutrient-based tiered excise taxes are increasingly recognized as more effective in improving health outcomes, since they directly target the nutrient responsible for health harms (Allcott et al., 2019; Grummon et al., 2019) and can encourage reformulation. From a theoretical perspective, such a design provides firms with clear incentives to reformulate products: Réquillart et al. (2016) show that when thresholds are not excessively stringent, firms prefer to reduce sugar content rather than pay the tax, generating positive health and welfare outcomes (see also Duvaleix-Tréguer et al. 2012). Empirical evidence supports this mechanism. Several studies show that firms strategically

[1] We have decided to tax sugar. Taxing fat in desserts would have been another option. However, a significant proportion of the fat comes from milk, the basic ingredient in yogurt and FBPS, which is also a source of essential minerals (e.g. calcium and magnesium). In contrast, with the exception of sugar from fruit in compotes, most of the sugar in desserts is added sugar.

reduced sugar content to fall just below the lower levy threshold (Scarborough et al., 2020; Pell et al., 2021; Allais et al., 2023). This firms' strategic reaction of bunching at the threshold to avoid the policy was also found for warning label policy in Chile (Barahona et al., 2023). Overall, this evidence supports the choice of an excise tax on sugar with a single threshold, as even this straightforward design appears sufficient to encourage reformulation.

To assess the impact of the tax in the French dessert market, we develop and estimate a model of supply and demand for dessert that accounts for consumer food substitution patterns and firms' pricing strategies. We also consider a likely product reformulation response in which firms reformulate their products to avoid the tax, when it is technically and sensorially feasible. On the demand side, consumers care about the price and taste of products. We model consumer preferences using a random coefficient logit model, controlling for endogeneity of prices. It captures heterogeneity in observed and unobserved consumer preferences and allows for flexible substitution patterns between differentiated products in the market. Consumer preferences are estimated using household-level scanner data from a representative panel of French households on dessert purchases describing product and household characteristics. On the supply side, firms compete on prices to maximize profit. We model the supply side as an oligopoly offering differentiated products and competing à la Nash in a Bertrand game, in the spirit of Berry et al. (1995) and Nevo (2001).

We use our estimated model to quantify the impact of a €0.67 sugar tax on products exceeding 12 g of sugar per 100 g on market equilibrium.[2] Consistent with previous evidence (Scarborough et al., 2020; Pell et al., 2021; Allais et al., 2023), we assume that firms reformulate by lowering added sugar so that the final sugar content of the product is just below the threshold when feasible, while leaving recipes unchanged otherwise. We also conduct a second counterfactual exercise, assuming no product reformulation and therefore no supply-side quality response. This additional scenario enables us to better understand the implications of our reformulation assumptions.

Our findings highlight that the tax could encourage consumers to switch to categories or products with lower sugar content, thereby steering them away from non-reformulated and high-sugar options. The effect on sugar intake varies widely across the population, but more than a quarter of French households reduce their sugar intake by more than three teaspoons per week. Furthermore, we demonstrate that the taxation scenario combined with our likely reformulation assumptions implies a smaller reduction in sugar intake but reduces the economic costs incurred by

[2] The rationale for the specific threshold level and tax amount will be discussed in the Section 3.3 devoted to the simulation method.

consumers and firms, compared to a taxation scenario without reformulation. This study highlights the decisive role of reformulation in the acceptability of the tax: although it mitigates the health impact of the tax, it increases its acceptability by limiting losses for consumers and producers. These results underscore the importance for public policymakers to design taxes that encourage companies to reformulate in order to achieve substantial health benefits while promoting social and economic acceptability.

This paper contributes to the existing literature on the reaction of firms facing a regulatory measure. While previous studies have examined the price adjustments firms are likely to make due to taxation (Bonnet and Réquillart, 2013; Nesheim et al., 2018; Allais et al., 2015; Dubois et al., 2018), to our knowledge only one empirical study has integrated the potential changes in product characteristics resulting from food policy interventions (Barahona et al., 2023). In contrast to this study, which assumes that sugar is replaced by artificial ingredients to maintain taste as firms reformulate their products, our analysis includes the demand response to changes in product taste due to added sugar reduction, which is assumed to be compensated by an increase in milk for yogurt and FBPS, or fruit for compote. Our assumption seems to be a more credible reformulation scenario for our market given the low proportion of dessert products with artificial sweeteners marketed in France (10% in our dataset). By considering this demand-side response, we analyze how consumers may adjust their choices and behavior in reaction to tax-induced changes in both prices and product taste. We thus contribute to a more accurate and policy-relevant assessment of nutrient-based taxes.

The remainder of the paper is organized as follows. Section 2 introduces the data and provides a descriptive analysis of the French dessert market. Section 3 presents the conceptual and empirical framework by describing our demand and supply model, the simulation methodology including the reformulation scenario, and the results on price elasticities, margins and marginal costs in the dessert market. Section 4 shows the equilibrium effects of our counterfactual scenarios, including changes in sugar intake, the impact on consumer welfare and profits, and heterogeneous effects across the population. The final section concludes with some limitations of the counterfactual exercise.

2 Data and dessert market

We use data from a French representative consumer panel data of 20,144 households collected by Kantar Worldpanel. This is a home-scan data set providing detailed information on all purchases of food products. We consider all purchases of desserts over the period January-May 2009, corresponding to more than 1,600,000 observations. In particular, purchased quantities, prices, brands, and characteristics of goods are registered. We chose to consider the dessert market, which we define as four broad dessert categories: yogurts, FBPS,[3] ODD [4] and fruit compotes or stewed fruits. We classify yogurts and FBPS into brand, fat content, sugar content and flavor categories.[5] We distinguish 13 primary national brands (NBs), and merge all private label (PL) brands into one brand. We get 75 different yogurts and 41 different FBPS. We have nine different compotes defined by brand and sugar content level.[6] ODDs are only brand differentiated. Overall, the product set is composed of 131 differentiated products. Consumers can substitute the considered products with an alternative product, the so-called 'outside option' (OG), which includes other desserts (fruits, pastries and cheese).[7] The outside option represents 60% of the entire market on average.[8] Our sample also includes information on household characteristics, such as the presence of children under the age of eighteen, socio-economic class (divided into three categories: poor, medium, and rich), and obesity status (divided into three categories: none of the adults in the household are overweight or obese; at least one of the adults in the household is overweight or obese; and all of the adults in the household are overweight or obese). Table A.1 in the Appendix describes our sample and the distribution of these characteristics.

Compote, yogurts, FBPS, and ODD account for about 4%, 16%, 6%, and 13% of all dessert purchases, respectively. Their respective average prices per kg are €2.58, €2.24, €2.89, and €3.31. For each of the four product categories, PL brands are the cheapest and have the highest market shares (see Table A.2). This is a market feature now common to many food product categories and may be due to the fact that consumers do not perceive large quality differences

[3]Fromage blanc is a creamy, soft, fresh, white cheese made with whole, semi-skimmed or skimmed milk. Petit suisse is creamy fresh cheese, with a cylindrical shape, the fat and dry extract contents of which are regulated, often targeted for children.

[4]ODD is cream desserts; 'crême brulée' desserts; coffee and chocolate mousses; style custard flans, French rice puddings; floating Island desserts, a classic French dessert that consists of meringue floating on a sea of vanilla custard

[5]We define three fat content categories: full-fat (more than 3% fat for yogurts, more than 5% fat for FBPS), semi-skimmed (between 1% and 3% fat for yogurts, between 2% and 5% fat for FBPS), and skimmed (fat close to 0%); and four sugar content and flavor categories (plain, sweetened, flavored, and with fruits) for yogurts and three sugar content and flavor categories (plain, flavored, with fruits) for FBPS.

[6]We define three sugar content categories: pure blended fruit without added sugar; low added sugar; and with added sugar.

[7]We do not consider ice cream as this product is rarely purchased in France during the period of time chosen, accounting for less than 1% of the average dessert budget share over the period.

[8]The outside option also includes minor brands producing products from the four categories analyzed. All of these minor brands account for only 2% of the whole market. Because we do not have precise information on these brands, we integrate them into the outside option.

between PL and NB products. Another feature of this market is the heterogeneity in NB product prices within each category, except for NB compotes that are produced by two firms only.

Yogurt prices are the highest for brands that sell products designed to reduce cholesterol (Brand 3), contain probiotics (Brand 4 and Brand 5 to a lesser extent), and soy milk (Brand 13). The other dairy dessert prices range from €2.72 to €6.12 per kg. The large difference in prices is mainly due to the high heterogeneity of the products within the category.

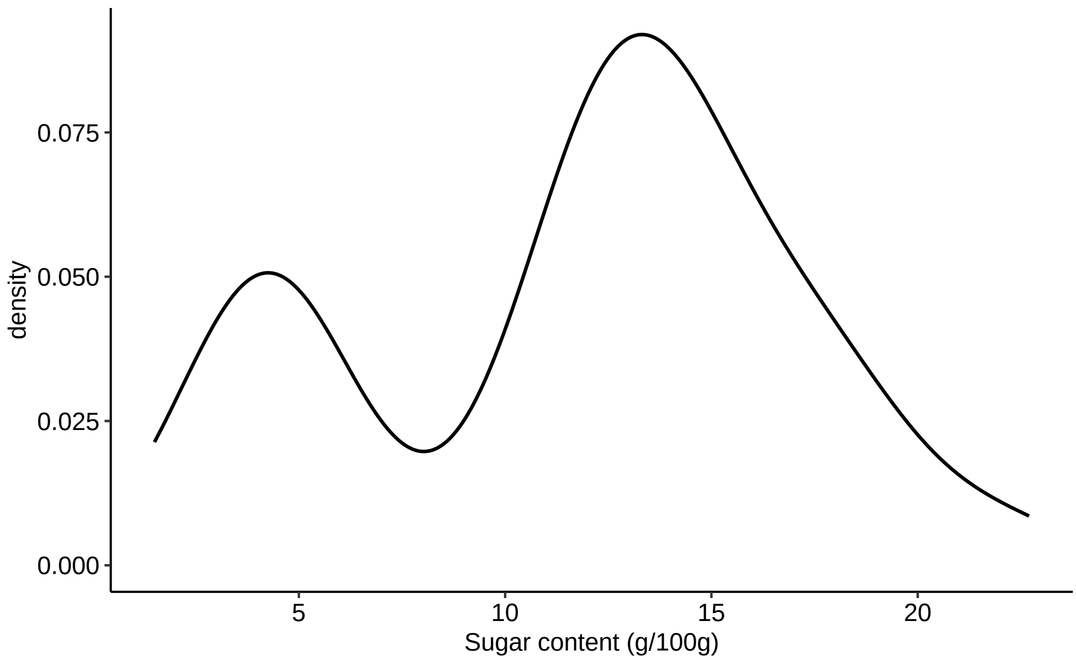

Figure 1: Distribution of product sugar content in the dessert market

Products' nutritional characteristics are not collected by Kantar. We use data from the French Food Observatory Oqali[9] and other data sources[10] to obtain the ingredient lists and the nutritional composition (values of the sugar, fat, protein and calorie content) of the desserts. Figure 1 shows the distribution of the sugar content of products within the French market. Although there are some products that contain few sugars (4-6g per 100g), which corresponds to plain yoghurt and FBPS, the distribution of products is more dense between 12-18g of sugar per 100g of product. In order to account for product reformulation, information is required on the quantities of added caloric sweetener per 100 g of product. These quantities are computed for the 131 products using

[9] Oqali aims to monitor changes in processed foods supply available on the French market, by measuring nutritional quality evolution, over time (nutritional composition and labelling information).

[10] The other data sources were Open Food Facts, a free, online and crowd-sourced database, or the brand or manufacturer's websites.

the methodology described in the Appendix B.1.[11] We also need to measure the 'sugar' taste of each product. We therefore provide a product sweetness index (see Table A.3) which considers both the quantity of caloric sweeteners and the presence of non-caloric sweeteners. We proxy the sweetness index of products without artificial sweeteners by their sugar content. For products that contain some (or only) artificial sweeteners, we proxy their sweetness index by the sweetness of a similar product that does not contain any artificial sweetener.

Table 1: **Per capita dessert purchase (g/week) and corresponding sugar and fat intake (g/week) by household type**

Household		Children		Social class			Obese adults		
	All	With	Without	Rich	Medium	Poor	None	One	All
Dessert	658.90	632.70	675.60	672.20	674.60	588.50	657.30	617.00	738.40
Sugar	71.40	75.70	68.70	67.00	73.00	68.30	72.10	67.80	76.80
Fat	19.70	18.80	20.20	20.50	20.10	17.70	19.70	18.50	21.90

Notes: The per capita consumption and intake of a household are calculated using the following rule: we count one point for an individual 15 years of age or older, and 0.5 point for an individual less than 15 years of age.

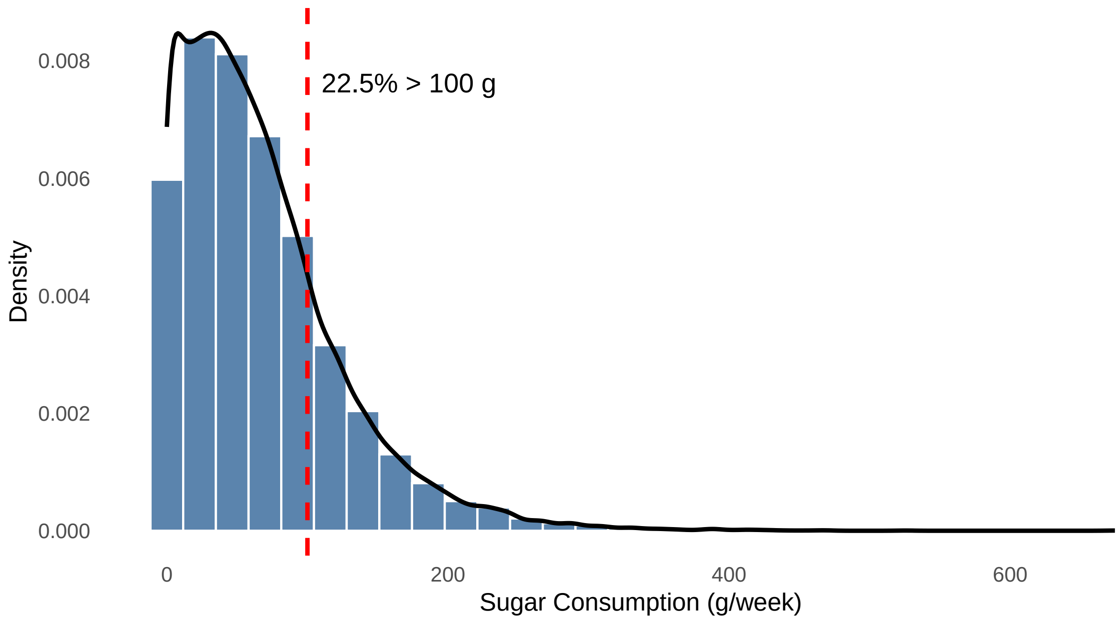

Figure 2: Distribution of sugar intake in the Dessert market

[11]Caloric sweeteners are both naturally present sweeteners, such as lactose in milk or fructose in fruits, and added caloric sweeteners, such as sugar or glucose

Overall, according to Table 1, French households buy 659 grams of desserts (dairy desserts and compotes) per capita per week, which corresponds to five yogurts.[12] The sugar intake from this market is 71 grams per week and per capita, which is equivalent to an average of almost twelve teaspoons of sugar. Figure 2 represents the distribution of sugar intake in the French dessert market. 22.5% of French households consume more than 100g of sugar from this sector per person per week. Dessert consumption varies according to household characteristics (see Table 1). Households without children consume more desserts, but since they consume fewer sweetened dessert products, households with children have a higher sugar intake from this market. We also observe a higher consumption if the household is richer or consists of overweight and obese adults, which translates to a higher sugar intake for the latter.

3 Conceptual and empirical framework

In this section, we set out the demand and supply model and describe the simulation method used to evaluate the impact of our taxation scenario, including the reformulation scenario and its associated costs. The model provides estimates of household preferences, price elasticities, marginal costs and margins.

3.1 The demand model: a random coefficient logit model

We use a random coefficient logit model as this model allows flexible consumer substitution patterns (Berry et al., 1995; McFadden and Train, 2000). The indirect utility function V_{ijt} for household i buying product j, for $j = 1, ..., J_t$, in period t is given by:

$$V_{ijt} = \beta_{b(j)} + \gamma_{c(j)} - \alpha_i p_{jt} + \delta_{Si} S_j + \delta_{Li} L_j + \delta_{SL} S_j L_j + \theta_N N_j + \theta_F F_j + \varepsilon_{ijt}$$

where $\beta_{b(j)}$ is a brand fixed effect that capture time-invariant unobserved brand characteristics, $\gamma_{c(j)}$ is a dessert category fixed effect that controls for time-invariant unobserved household's preferences for the category c, p_{jt} is the price of product j in period t, α_i is the marginal disutility of price for household i, S_j is the sugar taste of product j, and δ_{Si} captures the individual taste for sugar of the household i, L_j is the fat content of product j, and δ_{Li} captures the individual preference for fat taste of the household i, δ_{SL} captures the average consumer preference for the interaction between fat and sugar taste, N_j is a dummy related to the natural flavor of product j and θ_N captures the average consumer taste for this characteristic, F_j is a dummy if product j

[12] We assume that a yogurt weighs 125 g, which is common in France.

contains fruits in dairy desserts and θ_F captures the average consumer taste for this characteristic and ε_{ijt} is an unobserved individual error term.

We allow sugar and fat tastes to vary across household characteristics.

$$\delta_{Si} = \delta_S + \delta_S^c C_i + \delta_S^o O_i$$

$$\delta_{Li} = \delta_L + \delta_L^c C_i + \delta_L^o O_i$$

Households are differentiated according to the presence of children below 18 years-old named C_i (household with or without children) and the number of overweight or obese individuals within the household named O_i (no overweight or obese, at least one overweight or obese adult or all adults are overweight or obese). The coefficients δ_S^c and δ_L^c allow the marginal effects of sugar and fat taste on the utility function V_{ijt} to shift with the presence of children, the coefficients δ_S^o and δ_L^o to shift with the number of overweight or obese adults within the household, and the coefficients δ_S and δ_L represent the average consumer taste for sugar and fat of French households, respectively.

In our model, households can have a different price disutility; the α_i varies across households. First, we assume that the distribution of α_i follows a lognormal distribution and is a function of household characteristics with α, α^c, α^o, α^I and σ as parameters:

$\alpha_i = \exp(\alpha + \alpha^c C_i + \alpha^o O_i + \alpha^I I_i + \sigma \nu_i)$ where $\nu_i \sim \mathcal{N}(0,1)$ captures unobserved consumer attributes

and I_i stands for a socio-economic class (poor, middle, and rich).

The household can decide not to choose one of the considered products. Thus, we introduce an outside option that permits substitution between the considered products and a substitute, define in section 2. The utility of the outside option is normalized to zero. The indirect utility of choosing the outside good is $V_{i0t} = \varepsilon_{i0t}$.

Assuming that ε_{ijt} is independently and identically distributed as an extreme value type I distribution, we are able to write the conditional probability that household i buys the product j at period t:

$$s_{ijt}(\theta) = \frac{\exp(\beta_{b(j)} + \gamma_{c(j)} - \alpha_i p_{jt} + \delta_{Si} S_j + \delta_{Li} L_j + \delta_{SL} S_j L_j + \theta_N N_j + \theta_F F_j)}{1 + \sum_{k=1}^{J_t} \exp(\beta_{b(k)} + \gamma_{c(k)} - \alpha_i p_{kt} + \delta_{Si} S_k + \delta_{Li} L_k + \delta_{SL} S_k L_k + \theta_N N_k + \theta_F F_k)} \quad (1)$$

where θ is the vector of demand parameters to be estimated.

We can then write the market share of product j at period t in the following way (Nevo, 2001):

$$s_{jt}(\theta) = \int s_{ijt}(\theta)\, dP_\nu(\nu_i) dP_D(D_i) \quad (2)$$

where P_ν is the cumulative normal distribution function of ν, $D_i = (O_i, I_i, C_i)$ is the vector of demographics, and P_D is the observed cumulative distribution function of D.

The random coefficient logit model generates a flexible pattern of substitutions between products that is driven by the different household price disutilities α_i, such that, the own- and cross-price elasticities of the market share s_{jt} take the following forms:

$$\frac{\partial s_{jt}}{\partial p_{kt}} \frac{p_{kt}}{s_{jt}} = \begin{cases} -\frac{p_{jt}}{s_{jt}} \int \alpha_i s_{ijt}(1-s_{ijt})\, dP_\nu(\nu_i) dP_D(D_i) & \text{if } j=k \\ \frac{p_{kt}}{s_{jt}} \int \alpha_i s_{ijt} s_{ikt}\, dP_\nu(\nu_i) dP_D(D_i) & \text{otherwise.} \end{cases} \tag{3}$$

3.2 Supply model

We assume an oligopolistic competition between manufacturers. We consider F manufacturers that compete in prices on the dessert market. By doing so, we abstract from the role of retailers in setting prices of NBs. We assume that the prices of PLs are chosen by a 'specific' manufacturer representing the retailers price decisions. Formally, a manufacturer maximizes its profit:

$$\Pi_t^f = \sum_{j \in G_{ft}} [M_t(p_{jt} - c_{jt}) s_{jt}(p|\theta)] \tag{4}$$

where G_{ft} is the set of products that are sold by manufacturer f at period t, M_t is the size of the market at time t, p_{jt} is the final price of product j at time t, c_{jt} is the constant marginal cost to produce and sell product j at time t, $s_{jt}(p|\theta)$ is the market share of product j at time t, given the vector of product price p and demand parameters θ. The first order conditions that determine the prices of products are given by:

$$s_{kt}(p|\theta) + \sum_{j \in G_{ft}} (p_{jt} - c_{jt}) \frac{\partial s_{jt}(p|\theta)}{\partial p_{kt}} = 0, \quad \forall k \in G_{ft} \tag{5}$$

Using the above conditions, prices, and estimates of the demand model, we are able to recover margins of manufacturers $\gamma_{jt} = p_{jt} - c_{jt}$, we note $\gamma_t(p|\theta)$ the vector of margins. Marginal costs c_{jt} for each product j at time t are the difference between the observed prices p_{jt} and the estimated margins γ_{jt}.

3.3 Simulation method

In this section, we present the simulation method used to assess the impact of an excise tax of €0.67 per kg of products if their sugar content exceeds the threshold of 12g of sugar per 100g of products. The threshold of 12 g/100 g was chosen based on the distribution of sugar content in dessert products, as illustrated in Figure 1. The figure shows that around 52% of products exceed this limit. The tax amount was set so that the price of products with more than 12 g of sugar would increase by around 20%. This section describes how we incorporate firms' reformulation into the model, the implications for marginal production costs, and how we recover new equilibrium prices and market shares from the estimated demand and supply model.

Desserts are well suited to this analysis because of the wide variation in sugar content across products within each dessert subcategory, which suggests a broad scope for reformulation (see Table A.3 in the Appendix). However, some products may be subject to technical or sensory limitations. Furthermore, these products consist of several ingredients in addition to sweeteners. Reducing the sugar content of a product by removing added caloric sweeteners may result in an increase in the amount of other ingredients, and consequently other nutrients, such as milk fat or fructose from fruit. The net impact on nutrient intakes can be either positive or negative, depending on the product reformulation and consumer response to changes in product characteristics, including taste and price.

Product reformulation scenario An exogenous product reformulation based on a set of hypothesis is considered. First, we assume that only items belonging to compotes, yogurts, and FBPS with added sugar are reformulated. The recipes of items in the ODD category are assumed to remain constant, due to their complex recipes and because of manufacturers' uncertainty about consumers' reaction to the reformulation of gourmet foods (Réquillart et al., 2016). Second, when firms face taxes, we assume that firms decide to avoid the tax altogether, where possible: they set the level of the sugar content of their products just below the tax threshold to fully escape the tax, if reaching this level is technically feasible and sensory acceptable for consumers. This manufacturers' strategic reaction of bunching just below the threshold to avoid the tax or mitigate its effects was found not only for the UK Soft Drink Industry Levy (SDIL) (Scarborough et al., 2020; Pell et al., 2021; Allais et al., 2023), but also for warning label in Chile (Barahona et al., 2023; Alé-Chilet and Moshary, 2022). We also assume that firms compensate added sugar reduction by an equivalent increase in the quantity of the ingredient plain yogurt for yogurts, ingredient plain FBPS for FBPS or ingredient fruit puree for compotes, such as $\Delta Q_{Yogurt,j} = -\Delta Q_{Sugar,j}$ for yogurts, $\Delta Q_{FBPS,j} = -\Delta Q_{Sugar,j}$ for FBPS, and $\Delta Q_{fruit puree,j} = -\Delta Q_{Sugar,j}$ for compotes.[13] The other ingredients such as fruits in fruity yogurts or FBPS, aroma in flavored yogurts or FBPS,

[13]We interviewed food scientists who confirmed that this is the most credible scenario of how reformulation would be achieved in the dessert market. Given the low proportion of artificially sweetened dessert products marketed in France (10% in our dataset), a strategic reaction by firms aiming to preserve the sugary taste by adding artificial sweeteners is unlikely.

and additives (e.g. preservatives) in compotes, yogurts, and FBPS with added sugar are assumed to be constant. If setting product sugar content just below the tax threshold is not technically feasible or sensory acceptable, we assume that the firm will not change the sugar content of the products.

To assess this feasibility, we calculate the minimum amount of added sugar compatible with each recipe. This involves first approximating the original product recipes. They are determined using the ingredient lists and nutrition facts provided by the French Food Observatory Oqali (see appendix sub-section B.1 for details). The minimum amount of added sugar is then calculated for all compotes, yogurts, and FBPS with added sugar by minimizing the amount of sweetening ingredients per 100 g of product subject to technical constraints of formulation, such as product sweetness, texture, fermentation, and gelation process, and regulatory constraints (see Tables B.1, B.2, B.3 and B.4 in the Appendix) if any, knowing the original recipes. The computation of this amount, including the exact specification of each constraint, is detailed in the Appendix B.2. The resulting changes in sugar and fat contents are reported by brand and product category in Table B.5 in the Appendix. Under this methodology, 37 of the 131 products have been subject to reformulation, which represents 28% of the total number of products. We can observe that no compote product has been reformulated, as reducing the sugar content to 12 g is technically unfeasible. Furthermore, although all yogurt products above the 12 g threshold were reformulated, only FBPS products without fruit were, including some from brands 1, 5, 7 and PL.

Note that the reformulation scenario is to some extent conservative, as it uses what is observed on the market as the range of possible changes to the product recipe. For a given type of a product, the amount of caloric sweetener added in a reformulated product will not be lower than the observed value of a product available on the market. As a consequence, we do not explore further reduction.[14]

Product cost implications As the recipes change with product reformulation, so do the production costs. We assume that the variation in marginal cost due to reformulation Δcc_j for product j follows this linear function :

$$\Delta cc_j = \rho_S \Delta Q_{S,j} + \rho_Y \Delta Q_{Y,j} + \rho_{FBPS} \Delta Q_{FBPS,j} + \rho_F \Delta Q_{F,j} \tag{6}$$

[14]We do not take into account the fact that companies may reformulate their products by replacing a caloric sweetener with a non-caloric one to maintain the sweetness. Evaluating this reformulation scenario would require estimating consumer preferences for non-caloric sweeteners in the demand model. However, only 14 out of 131 products contain non-caloric sweeteners, making it difficult to estimate preferences for non-caloric sweeteners and suggesting that this reformulation scenario may not yet be credible for the French dessert market.

where $\Delta Q_{A,j}$ is the variation in the quantity of ingredient A due to reformulation of product j, ρ_A represent the average price of the ingredient A per kilo, where $A \in \{$S, Y, FBPS, F$\}$ corresponds respectively to sugar, yogurt, FBPS, and fruit purée. We set sugar price at €555 per ton, $\rho_S = 0.555$ (see the report of the European Commission 2013). The prices of plain yogurt and plain FBPS are derived from that of milk, taking into account the quantity of milk necessary to make yogurt and FBPS. We consider that one kilogram of yogurt is produced with one litre of milk and that one kilogram of FBPS is produced with 2.5 litres of milk (Capt et al., 2011). The price of milk is set at €274 per ton, $\rho_Y = 0.274$ and $\rho_{FBPS} = 0.685$ (see the report of the French national inter-professional center for the dairy industry 2014). The price of fruit puree is considered the same as that of fruits. The average price of fruits for industry is calculated from trade figures in volume and value included in a report of Adepale (2006), the French Association of Elaborated Food Products Companies. We set the price of fruits at €407 per ton on average, $\rho_F = 0.407$. The resulting cost variations reported in Table B.5 in the Appendix are weak, less than 1 cent of euro per kg.

Estimating new market share and price equilibrium The objective is to find the new vector of equilibrium prices p_t^*, given the vector of estimated marginal costs $\hat{c}_t$ obtained from the equation (5), input prices and changes in recipes (if any), the amount of the tax, as well as the other estimated structural demand parameters.

These assessments are carried out if all the firms reformulate in reaction to tax and if none reformulate. In the former scenario, the marginal cost of production is modified not only by the excise tax but also by the cost of reformulation. The profit-maximization program for firm f is now given by:

$$\max_{\{p_{kt}\}_{k \in G_f}} \sum_{j \in G_f} (p_{jt} - \tilde{c}_{jt}) M_t \tilde{s}_{jt}(p|\hat{\theta}) \tag{7}$$

where $\tilde{c}_{jt} = \hat{c}_{jt} + \tau_j + \Delta cc_j$ is the new marginal cost including the per-unit level of the tax τ_j which depends on the sugar content of product j and Δcc_j, the variation in cost due to reformulation, and the market share $\tilde{s}_{jt}(p|\hat{\theta}) = s_{jt}(p, \Delta S, \Delta L|\hat{\theta})$ that incorporates demand shifts following reformulation-driven adjustments in the sugar and fat content of products.[15]

The new price equilibrium vector p_t^* is deduced from the following optimization program:

$$\min_{\{p_{jt}^*\}_{j=1,..,J_t}} \left\| p_t^* - \tilde{\gamma}_t \left(p^* | \hat{\theta} \right) - \tilde{c}_t \right\| \tag{8}$$

[15] The tax τ_j is 0 for non-taxed product j and if there is no reformulation, then $\Delta cc_j = 0$.

where $\|.\|$ is the Euclidean norm in $\mathbb{R}^J$, $\tilde{\gamma}_t(p^*|\theta)$ is the vector of manufacturer margins deduced from (7).

Assessing profit and consumer welfare variations From the new price equilibrium vector p_t^* deduced from the program (8), we can compute the new household quantities using the individual probabilities of the equation (1), which now depend on new prices p_{jt}^*.

We use the new prices and market shares to compute the variation in profits using equation (4) and the variation in consumer welfare using the following expression of the consumer surplus:

$$CS_{it} = \frac{1}{|\alpha_i|} \int \left(\ln \sum_{j \in J_t} exp(\beta_{b(j)} + \gamma_{c(j)} - \alpha_i p_{jt} + \delta_{Si} S_j + \delta_{Li} L_j + \delta_{SL} S_j L_j + \theta_N N_j + \theta_F F_j) \right) \mathrm{d}P_\nu(\nu). \tag{9}$$

3.4 Results on demand and supply

We estimate the demand model using household purchase data, a control function approach for identification issue (see details in the Appendix C.1) and a simulated maximum likelihood method as in Revelt and Train (1998). Table C.2 in the Appendix C.2 shows the estimated coefficients of the demand model. We see that the marginal utility of price is heterogeneous. This is mainly due to unobserved household characteristics, as the effects of income, obesity status and the presence of children on price are weak. Households prefer compote more than the three other dairy dessert categories, on average. They also prefer yogurt with fruit. Figure 3 shows that households experience positive estimated utility from sugar when products contain a sufficiently high amount of it. This is particularly the case for households without children and for FBPS and ODD products. Moreover, household obesity status appears to have a minimal impact on sugar preferences.

Using the structural demand estimates, we compute price elasticities for each differentiated product. At the brand level (Table C.3 in the Appendix), we find that yogurts are less elastic, except for three brands that are characterized by the lowest sugar contents.[16] Consumers react more to a change in prices for these expensive yogurts. For FBPS and ODD, we also find an heterogeneity in own-price elasticities for NB products. Furthermore, in each category, PL products are less price sensitive than those of NBs, a result which is commonly found.

From the supply model, we deduce the margins and marginal costs (see Table C.4 in the Appendix). Margins vary from 27% to 73%, and they are higher on average in the yogurt

[16] The first brand is specialized in soy products, the second in 'probiotics' products and the third in cholesterol lowering products.

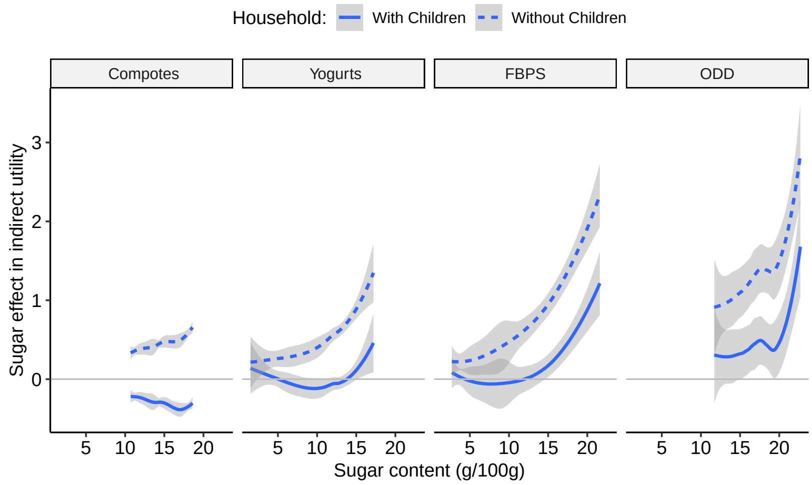

Figure 3: Sugar preferences for households with and without children and by product category

Notes: Smoothed curves illustrate the estimated relationship between sugar content and its effect on indirect utility for product categories and household types. The indirect utility part is given by $\delta_{Si}S_j + \delta_{Li}L_j + \delta_{SL}S_jL_j$, where δ_{Si} and δ_{Li}, δ_{SL} are the estimated parameters of sugar, fat, and the interaction between them, respectively, and L_j and S_j are vectors of fat and sugar content, respectively. FBPS stands for Fromages Blancs/Petits Suisses, and ODD for Other Dairy Desserts.

category. This is in line with the empirical literature which typically finds margins in this range (Bonnet et al., 2016). For each product category, PLs have both the lowest marginal cost and the highest percent margin. This latter result is consistent with the theoretical literature showing that percent margins on PLs are likely to be larger than those on NBs (Mills, 1995). In each category, except ODD, marginal costs of brands are, in most cases, similar. Larger marginal costs correspond to brands producing specific products (Brands 3, 4, 13 for yogurt and 6 and 12 for FBPS). In the ODD category, the comparison of marginal costs is more difficult as products are very heterogeneous.

4 Tax results

We present the results of our counterfactual analysis in which products containing more than 12 grams of sugar per 100 grams are subject to a tax of €0.67 per kilogram of dessert. We mainly report the results for the scenario in which firms reformulate products. Results when firms do not reformulate are provided in Appendix E.

Firstly, our results suggest that firms have passed on more of the tax than was actually levied, meaning that the price increase is higher than the tax rate itself (see Table D.2 with reformulation and E.2 without reformulation in the Appendix). This finding is consistent with previous analyses of the impact of taxes on the French soft drinks market (Bonnet and Réquillart, 2013). Firms' strategic responses in pricing then amplify the health effect of the tax and reduce profit losses as margins increase.

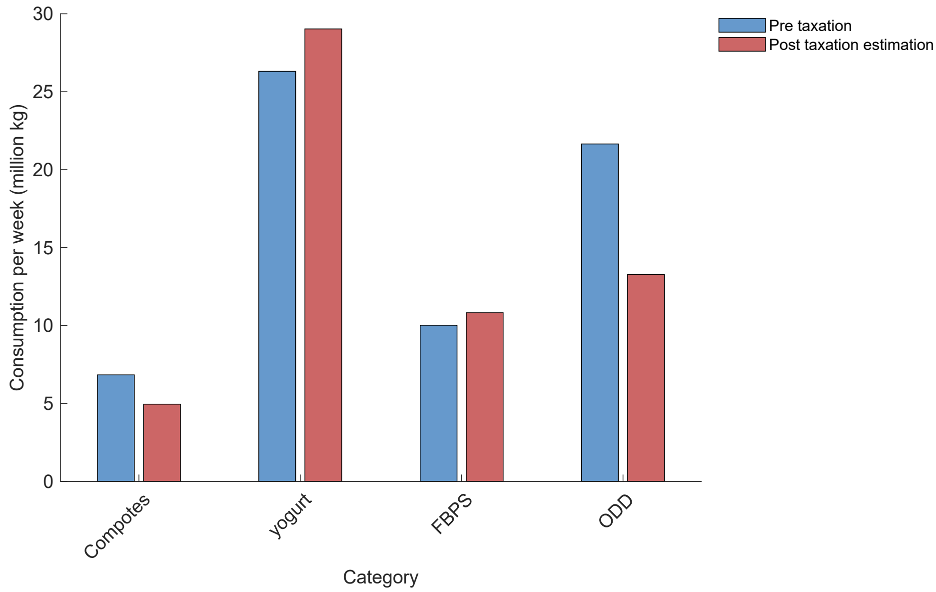

Figure 4: Comparison of pre- and post-tax purchases by category, with reformulation.
FBPS and ODD stand for fromage blanc and petit suisse, and other dairy dessert, respectively.

Figure 4 shows the total quantities consumed by French households in the pre-tax situation (blue bars) and the counterfactual situation in which the tax is introduced (red bars), assuming reformulation, for each product category. We find that compote and ODD consumption decrease by 27.5% and 38.7%, respectively. Conversely, consumption of yogurt and FBPS increases by 10.3% and 8% respectively. These results reveal an inter-category substitution effect between compote and ODD, and yogurt and FBPS. This is primarily due to the distribution of sugar content across these four product categories. Indeed, compote and ODD products contain more sugar than yogurt and FBPS products (see Table A.3 in the Appendix). The reformulation exacerbates this difference as yogurt and FBPS products are reformulated (see Figure E.1 in the Appendix when there is no reformulation). Therefore, the tax affects more products in the compote and ODD categories, which then increases their prices. Table D.1 in the Appendix shows that the average price variation is €0.57 and €0.77 for compote and ODD, respectively, and €-0.01 and €0.05 for yogurt and FBPS, respectively.[17] In contrast, when assuming no reformulation, average

[17]The negative price variation of yogurt products can be explained by the reformulation scenario. All yogurt products are exempt from tax. The small price variation of FBPS products is also explained by the reformulation

price variation for yogurt is €0.41 (see Table E.1 in the Appendix), which explains the decrease in purchases (see Figure E.1 in the Appendix). We can also observe intra-category substitution effects in the FBPS and ODD categories, which can be explained by the fact that some products in these categories were taxed while others were not. For example, see the large price increase of brand 6 in the FBPS category compared to the small price increases of all the other brands in that category and the small price increase of brand 2 in the ODD category compared to the other brands in that category (Table D.1). These outcomes confirm that the tax generates inter- and intra-category substitution effects, redirecting demand toward products that are either reformulated or initially lower in sugar.

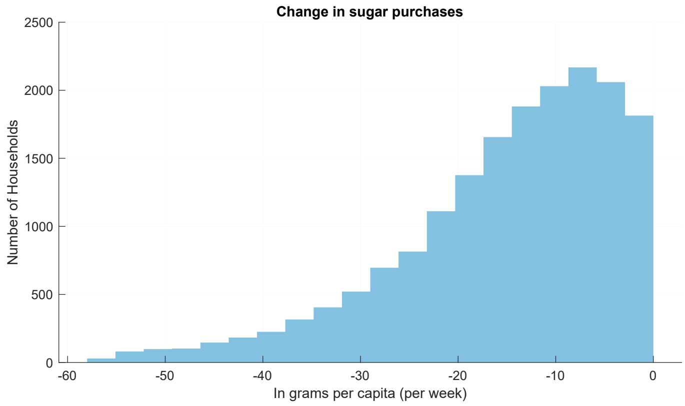

Figure 5: Changes in household sugar intake (g/week) between the post- and pre-tax scenarios, with reformulation

. The top 1% and bottom 1% of absolute sugar intake change values have been excluded to reduce the influence of outliers.

Changes in dessert consumption affect the household sugar intake from this market. Figure 5 shows the distribution of absolute changes in household-level sugar intake and demonstrate that taxation policy significantly reduces the quantities of sugar purchased from the Dessert market.[18] For 25.8% of households, sugar intake are reduced by at least 20 g per capita per week in the reformulation scenario, equivalent to more than three teaspoons of sugar. We can also observe some heterogeneous impacts according to household characteristics (Table 2). Households without children, rich households, and households in which all adults are obese or overweight experienced the sharpest decline in dessert purchases. Indeed, their purchases decreased by 74 g, 71 g and 78 g per capita per week, respectively, corresponding to a 11% decrease in their initial level of dessert purchases in the reformulation scenario. The amount of sugar and fat consumed by these

scenario, even though some products remain taxed, as reformulating them to contain less than 12g of sugar was not technically feasible.

[18]Similar results are found in the tax scenario without reformulation, see E.2 in the Appendix.

Table 2: Change in dessert, sugar and fat purchases (g/week per capita) by household type under the tax-with-reformulation scenario

	Dessert		Sugar		Fat	
	g/week	(%)	g/week	(%)	g/week	(%)
All Households	-68.55	(-10.40%)	-15.59	(-21.84%)	-3.01	(-15.27%)
Children						
With	-58.36	(-9.22%)	-15.61	(-20.62%)	-2.51	(-13.35%)
Without	-74.02	(-10.96%)	-15.35	(-22.36%)	-3.28	(-16.18%)
Social Class						
Rich	-71.42	(-10.62%)	-14.75	(-22.00%)	-3.22	(-15.71%)
Medium	-70.16	(-10.40%)	-15.94	(-21.83%)	-3.06	(-15.27%)
Poor	-59.85	(-10.17%)	-14.80	(-21.67%)	-2.62	(-14.79%)
Obese adult						
None	-68.09	(-10.36%)	-15.69	(-21.75%)	-3.00	(-15.24%)
One	-63.86	(-10.35%)	-14.78	(-21.80%)	-2.81	(-15.19%)
All	-77.96	(-10.56%)	-16.92	(-22.03%)	-3.38	(-15.45%)

Notes: Absolute changes are shown first, with percentage changes in parentheses below. Per capita changes are computed using the same weighting method as in Table 1.

households is significantly reduced as a result, with sugar intake falling by around 22% and fat consumption by around 16%.

Finally, we compute the overall societal impact of such a tax. Table 3 presents the variation in profit, consumer surplus, tax revenue, dessert purchase volume, sugar intake and health costs resulting from our tax. The third column shows the results when reformulation is assumed, while the fourth column shows the results without reformulation.

Our findings suggest that the reduction in sugar intake is weaker when firms reformulate. This can be explained by comparing the variation in the global market share of our four product categories for both scenarios with and without reformulation. Table D.1 exhibits a -10.4% variation whereas Table E.1 reveals a stronger impact reaching -17.8%. Reformulation reduces the estimated impact of the tax on sugar intake in the dessert market, rendering the policy 22% less effective. This would result in a smaller reduction in health costs due to sugar consumption. However, under our reformulation assumption, the policy would turn out to be more socially acceptable, as it could result in reduced losses for consumers and firms alike. Even though consumer surplus is significantly affected by the policy, we observe that its reduction is 35% weaker when firms reformulate. On the other hand, firms lose profit as a result of the tax policy, but this loss is 37%

Table 3: **Comparative impact: with vs. without reformulation (per week)**

Indicator	Measurement Unit	With Reformulation	Without Reformulation
Δ Profit	million €	-7.84	-12.46
Δ Consumer Surplus	million €	-13.18	-20.19
Δ Tax Revenue	million €	10.27	17.34
Δ Desserts	million kg	-6.74	-11.54
Δ Sugar	million kg	-1.75	-2.24
Δ Health Cost	million €	-22.42	-28.70
Nutritional and health impact including outside option			
Δ Sugar (OG effect)	million kg	-1.29	-1.46
Δ Health Cost (OG)	million €	-16.61	-18.73

Notes: All values are weekly impacts, expressed in millions of euros, except desserts and sugar which refer to total quantity reduction per week (in millions of kg). Positive values indicate gains (tax revenue), and negative values indicate losses or reductions. Variation in health costs is calculated based on the change in sugar intake and the estimated social cost of sugar consumption (€12.83 per kg), derived from Seidel et al. (2023) using data from Institute for Health Metrics and Evaluation (2022), Lara Castor et al. (2024), and von Philipsborn et al. (2023).

smaller if they avoid the tax by adjusting the sugar content to just below the threshold when it is technically feasible. Rather than losing 12.46 million €per week from the introduction of the tax without changing the recipes of their products, firms would only lose 7.84 million €. Finally, as expected, tax revenue is lower when firms reformulate and escape tax on certain products.

It should be noted that, as the global market share of desserts decreases, the market share of the outside option (defined in our model as pastries, fruits and cheeses) increases. Considering the nutritional impact of the outside option, our taxation policy continues to reduce sugar intake and health costs, albeit to a lesser extent. The weaker effect of the reformulation scenario also remains.

5 Conclusion and limitations

This paper provides an analysis of the impact of a taxation policy on the dessert market. We develop and estimate a structural demand and supply model, and construct a likely reformulation scenario that corresponds to what is observed in implemented soda taxes and predicted by the economic theory. We find that our tax scenario could reduce by almost 22% the sugar intake from this market. Our results reveal that, in our case, the reformulation of products is slowing down the reduction of sugar intake as the global quantities of dessert purchases become less affected. However, even if a reformulation strategy could reduce the efficiency of the tax, it allows reducing the economic costs of the tax for both firms and consumers.

Overall, our results suggest that extending the tax to foods beyond sodas can effectively reduce sugar purchases. However, we acknowledge that our findings should be validated in other food markets. One feature of our market is that the cost of reformulation is very low at less than one cent per kg for all products, compared to a simulated tax of 67 cents per kg. In a market where reformulation would incur higher costs, this scenario could not be considered credible, except for products close to the threshold.

We also acknowledge that our results under the reformulation scenario should be viewed with caution. One limit of our analysis is that product reformulation is not endogenous in our setting and that we cannot claim that the scenario in which all firms reformulate their products is an equilibrium (in terms of characteristics). Modeling how firms endogenously adjust/reformulate their product portfolio would involve adding a second stage to the supply model in which firms simultaneously choose product offerings, including product characteristics, with the understanding that their actions and the actions of their rivals will affect demand and markups. We leave these developments to future research. We argue that it will lead to limited changes in this specific market and policy. Indeed, as reformulation costs in the dessert market are low compared to the tax costs, our hypothesis that firms bunch at the threshold may constitute an efficient strategy.

There are other debates about taxes that are not covered in this paper. In particular, there is no discussion of the possible regressivity of taxes and, more generally, of tax optimality, as in Allcott et al. (2019). To carry out this analysis, a more comprehensive optimal taxation setting should be developed. We leave these developments for further work.

References

Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail (France) (2017): *Étude individuelle nationale des consommations alimentaires 3 (INCA 3): avis de l'Anses: rapport d'expertise collective*, Anses.

Alé-Chilet, J. and S. Moshary (2022): "Beyond consumer switching: Supply responses to food packaging and advertising regulations," *Marketing Science*, 41, 243–270.

Allais, O., G. Enderli, F. Sassi, and L.-G. Soler (2023): "Effective policies to promote sugar reduction in soft drinks: lessons from a comparison of six European countries," *European Journal of Public Health*, ckad157.

Allais, O., F. Etilé, and S. Lecocq (2015): "Mandatory labels, taxes and market forces: An empirical evaluation of fat policies." *Journal of Health Economics*, 43, 27–444.

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

Andreyeva, T., K. Marple, S. Marinello, T. E. Moore, and L. M. Powell (2022): "Outcomes following taxation of sugar-sweetened beverages: a systematic review and meta-analysis," *JAMA Network Open*, 5, e2215276–e2215276.

Association des entreprises de produits alimentaires élaborés (ADEPALE) (2006): "Cahier fruits," Tech. rep., not publicly available.

Barahona, N., C. Otero, and S. Otero (2023): "Equilibrium effects of food labeling policies," *Econometrica*, 91, 839–868.

Berry, S., J. Levinsohn, and A. Pakes (1995): "Automobile Prices in Market Equilibrium," *Econometrica*, 63, 841–890.

Bonnet, C., T. Corre, and V. Réquillart (2016): "Price transmission in food chains: The case of the dairy industry. Food Price Dynamics and Price Adjustment in the EU edited by Steve McCorriston," .

Bonnet, C. and V. Réquillart (2013): "Tax incidence with strategic firms on the soft drink market," *Journal of Public Economics*, 106, 77–88.

Bíró, A. (2015): "Did the junk food tax make the Hungarians eat healthier?" *Food Policy*, 54, 107–115.

Caby, D. (2016): "Obesite : quelles consequences pour l'economie et comment les limiter ?" Tech. rep., Tresor-Eco, n? 179.

Cadena, E. M., I. Gallo, and V. E. Soto (2025): "Reformulation of ultra-processed products in Colombia after the introduction of public health regulations," *BMC medicine*, 23, 446.

Capt, D., G. Gervreau, A. Leseigneur, and A. Diallo (2011): "Elaboration d'un référentiel technico-économique dans le domaine des circuits courts de commercialisation. Partie

2 : Exploitations bovines laitières en circuits courts : diversité, localisation et approche des performances," Tech. rep.

Centre national interprofessionnel de l'économie laitière (2014): "L'économie laitière en chiffre," Tech. rep., available online at https://www.calameo.com/read/002230051aea002d0612e, accessed January, 2022.

Commission to the European Parliament and the Council (2013): "Evolution of the sugar imports in the European Union from LDC and ACP countries," Tech. rep., available online at https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52013DC0323&from=FR, accessed January, 2022.

Department for Environment, Food and Rural Affairs (2020): "National Food Strategy: part two," Available online at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1025825/national-food-strategy-the-plan.pdf, accessed May, 2023.

Dubois, P., R. Griffith, and M. O. Connell (2018): "The Effects of Banning Advertising in Junk Food Markets," *The Review of Economic Studies*, 85, 396–436.

Duvaleix-Tréguer, S., A. Hammoudi, L. Rouached, and L.-G. Soler (2012): "Firms' responses to nutritional policies," *European Review of Agricultural Economics*, 39, 843–877.

Grummon, A. H., B. B. Lockwood, D. Taubinsky, and H. Allcott (2019): "Designing better sugary drink taxes," *Science*, 365, 989–990.

Institute for Health Metrics and Evaluation (2022): "GBD Compare — IHME Viz Hub," Available online: https://vizhub.healthdata.org/gbd-compare/.

Lara Castor, L., R. Micha, F. Cudhea, V. Miller, P. Shi, J. Zhang, J. Sharib, J. Erndt-Marino, S. Cash, S. Barquera, D. Mozaffarian, and A. Memon (2024): "Intake of sugar sweetened beverages among children and adolescents in 185 countries between 1990 and 2018: population based study," *BMJ (Clinical research ed.)*, 386, e079234.

McFadden, D. and K. Train (2000): "Mixed MNL Models for discrete Response," *Journal of applied Econometrics*, 15(5), 447–470.

Mills, D. E. (1995): "Why retailers sell private labels," *Journal of Economics & Management Strategy*, 4, 509–528.

Nesheim, L., R. Griffith, and M. O'Connell (2018): "Income Effects and the Welfare Consequences of Tax in Differentiated Product Oligopoly," *Quantitative Economics*, 9.

Nevo, A. (2001): "Measuring Market Power in the Ready-To-Eat Cereal Industry," *Econometrica*, 69, 307–342.

Okunogbe, A., R. Nugent, G. Spencer, J. Powis, J. Ralston, and J. Wilding (2022): "Economic impacts of overweight and obesity: current and future estimates for 161 countries," *BMJ Glob Health*, 9(9).

Pell, D., O. Mytton, T. L. Penney, A. Briggs, S. Cummins, C. Penn-Jones, M. Rayner, H. Rutter, P. Scarborough, S. J. Sharp, et al. (2021): "Changes in soft drinks purchased by British households associated with the UK soft drinks industry levy: controlled interrupted time series analysis," *bmj*, 372.

Petrin, A. and K. Train (2010): "A Control Function Approach to Endogeneity in Consumer Choice Models." *Journal of Marketing Research (JMR)*, 47, 3 – 13.

Réquillart, V., L.-G. Soler, and Y. Zang (2016): "Quality standards versus nutritional taxes: Health and welfare impacts with strategic firms," *Journal of Health Economics*, 50, 268 – 285.

Revelt, D. and K. Train (1998): "Mixed Logit With Repeated Choices: households' Choices Of Appliance Efficiency Level." *Review of Economics & Statistics*, 80, 647 – 657.

Scarborough, P., V. Adhikari, R. A. Harrington, A. Elhussein, A. Briggs, M. Rayner, J. Adams, S. Cummins, T. Penney, and M. White (2020): "Impact of the announcement and implementation of the UK Soft Drinks Industry Levy on sugar content, price, product size and number of available soft drinks in the UK, 2015-19: A controlled interrupted time series analysis," *PLoS medicine*, 17, e1003025.

Seidel, F., B. Oebel, L. Stein, A. Michalke, and T. Gaugler (2023): "The True Price of External Health Effects from Food Consumption," *Nutrients*, 15, 3386.

The Lancet Gastroenterology Hepatology (2020): "Voluntary agreements with industry: no sweet success," .

von Philipsborn, P., O. Huizinga, A. Leibinger, D. Rubin, J. Burns, K. Emmert-Fees, S. Pedron, M. Laxy, and E. Rehfuess (2023): "Interim Evaluation of Germany's Sugar Reduction Strategy for Soft Drinks: Commitments versus Actual Trends in Sugar Content and Sugar Sales from Soft Drinks," *Annals of Nutrition and Metabolism*, 79.

WHO (2015): *Guideline: sugars intake for adults and children.*

——— (2022): *European Regional Obesity Report*, Regional Office for Europe.

World Cancer Research Fund International (2022): "NOURISHING and MOVING Policy Databases," Tech. rep., available online at https://www.wcrf.org/int/policy/nourishing-database, accessed January, 2022.

World Health Organization et al. (2016): "Fiscal policies for diet and the prevention of noncommunicable diseases." .

——— (2017): "Taxes on sugary drinks: Why do it?" Tech. rep., World Health Organization.

——— (2022): "Fiscal policies to promote healthy diets: policy brief," .

Appendix

A Additional tables for descriptive statistics

Table A.1: Distribution of households in the panel by demographic characteristic

Household type	**Number of households**	**Percentage (%)**
Income class		
Poor	2584	14
Middle	13768	72
Rich	2670	14
Children in household		
With children	6398	34
Without children	12624	66
Adult obesity status		
No overweight or obese adult	4876	26
One overweight or obese adult	6458	34
All obese or overweight adults	7688	40

Notes: Percentages sum to 100 within each demographic characteristic.

Table A.2: **Average prices (€/kg) and market shares (%) by brand and product category**

	Product category							
	Compote		Yogurt		Fromage blanc, petits suisse		Other dairy dessert	
	Price	MS	Price	MS	Price	MS	Price	MS
Firm 1								
Brand 1			2.58	1.78	3.32	1.19	3.08	2.04
Brand 2			2.08	0.56	3.22	0.31	4.01	0.34
Brand 3			4.96	0.13				
Brand 4			3.58	0.59				
Brand 5			2.70	1.92	4.05	0.60		
Firm 2								
Brand 6			2.42	1.19	5.52	0.11	3.87	2.30
Firm 3								
Brand 7			1.95	0.62	2.74	0.54	3.91	0.12
Brand 8			2.23	0.99				
Brand 9			2.30	0.38				
Firm 4								
Brand 10	3.33	0.62	2.75	0.42	2.68	0.09	4.88	0.72
Firm 5								
Brand 11	3.34	0.59					4.67	0.20
Firm 6								
Brand 12			2.94	0.21	3.60	0.08	6.12	0.49
Brand 13			3.71	0.19			3.82	0.20
PL firms	2.28	3.00	1.80	7.21	2.41	3.25	2.72	6.92
All	2.58	4.20	2.24	16.20	2.89	6.16	3.31	13.33

Notes: The reported price of a brand in a category is the average of the prices of that brand in that category across retailers, weighted by product market shares. MS stands for Market Share, PL stands for Private Label.

Table A.3: **Content in fat, sugar (g / 100g of product) and sweetness index by brand and product category**

	Compote			Yogurt			Fromage blanc, petit suisse			Other dairy dessert		
	Sugar	Sweetness	Fat	Sugar	Sweetness	Fat	Sugar	Sweetness	Fat	Sugar	Sweetness	Fat
Firm 1												
Brand 1				9.96	9.96	4.12	9.20	9.20	5.56	20.05	20.05	5.74
Brand 2				6.42	10.18	0.10	4.97	8.09	0.10	11.20	17.70	0.90
Brand 3				5.27	8.82	0.64						
Brand 4				7.33	11.06	0.84						
Brand 5				9.72	11.09	2.62	8.46	8.46	3.15			
Firm 2												
Brand 6				9.11	10.60	2.17	19.37	19.37	8.11	16.46	16.68	7.03
Firm 3												
Brand 7				11.08	11.08	4.77	5.91	5.91	2.42	16.90	16.90	2.20
Brand 8				11.16	13.88	1.90						
Brand 9				12.20	12.20	1.40						
Firm 4												
Brand 10	14.52	14.52	0.46	13.83	13.83	3.66	2.80	2.80	3.00	15.92	15.92	8.57
Firm 5												
Brand 11	14.82	14.82	0.50							14.11	14.11	3.21
Firm 6												
Brand 12				5.46	7.75	1.03	3.29	3.29	2.88	17.66	17.66	7.42
Brand 13				6.09	6.09	2.40				12.10	12.10	2.10
PLs	14.77	14.77	0.26	9.76	10.79	2.52	7.56	7.62	4.20	16.76	16.76	4.65
Average	14.74	14.74	0.32	9.69	10.91	2.56	7.77	7.96	4.03	16.95	17.15	5.36
Min	10.70	10.70	0.20	1.50	1.50	0.00	2.70	2.70	0.00	11.20	11.70	0.80
First quartile	11.65	11.65	0.28	4.80	6.00	0.90	3.60	3.60	2.20	14.75	15.20	2.95
Median	14.40	14.40	0.30	10.15	12.10	2.15	4.55	4.55	3.30	16.40	16.85	5.65
Third quartile	17.53	17.53	0.53	13.10	13.50	3.30	12.60	12.90	6.50	18.60	18.60	8.40
Max	18.60	18.60	0.90	17.20	17.20	10.10	21.60	21.60	9.50	22.70	22.70	12.50

Notes: For each brand and product category, we report the weighted average sugar and fat content calculated across all products of each brand. PL stands for Private Label.

B Reformulation scenario

B.1 Recipe calculation

Step 1: Determination of recipes prior to food reformulation

Since nutritional information necessary to determine the recipes is not reported in the Kantar database, we used Oqali database which records the ingredient lists and nutrition facts label as displayed on the packaging, at the branded product level. We used compotes and fruit purees, and milk products Oqali dataset, built in 2009. We documented product characteristics for 476 marketed yogurts, 183 FBPS and 408 compotes and fruit purees. These data were completed by carrying out an Internet research for products not collected by Oqali. This concerned 67 additional products.

To simplify, we considered that each recipe consists of three main ingredients:

- the sweetening ingredients. Different sweeteners can be used to cook the product. Sugar is the most common but glucose syrup, inverted sugar and other types of sweetening ingredients can also be used;
- a matrix ingredient, which substitutes the sweetening ingredients in case of reformulation. The matrix ingredient is plain yogurt for yogurts, plain fromages blancs or petits suisses for FBPS and fruit puree for compotes;
- a fixed ingredient for which quantity remains constant when reformulating. This corresponds to the aroma used in flavored yogurts or fruits in fruity yogurts, for example.

The amounts of each main ingredient were deduced from both the ingredients list and the nutrition facts. In the ingredients statement, ingredients are listed in descending order of weight. Moreover, in some cases, the ingredients list indicates precisely the quantity of one or several ingredients. Thus, in the best case, all the necessary information to determine the recipe of a product was found in the ingredients list. In other cases, the ingredients list provided some indications that were not precise enough to determine the recipe. In such cases, we used the fact that the nutrient content of a product is the quantity-weighted average of the nutrient content of its ingredients. We were able, in most cases, to determine the quantity of each main ingredients, by solving the system of equations. Otherwise, some realistic hypotheses based on the usual recipe of the product or its ingredients had to be made. When the information displayed on the packaging was not sufficient to determine the recipe without making strong assumptions, the recipe was not estimated and its characteristics have not been taken into account when aggregating data at the group of products' level (see step 2). This was the case for only a few products.

Step 2: Aggregation into the 131 groups of products of our demand model

Individual marketed products recorded in Oqali dataset were assigned to one of the 131 groups of products, as defined in the demand model. Thus, they were aggregated based on their type (yogurts, fromages blancs/petits suisses, compotes, other dairy desserts), brand, aroma (plain, sweetened, flavored, fruits), and nutritional composition (fat and sugar contents). Mean nutritional composition and mean recipe (amounts of sweetening and matrix ingredients) were computed for the 131 groups of products.

B.2 Computation of the minimum amount of added sugar

The minimum amount of added sweeteners to use has then been estimated for each of the following 18 recipes:

- sweet yogurt with skimmed, semi-skimmed, or whole milk;
- flavored yogurt with skimmed, semi-skimmed, or whole milk, and flavored Greek yogurt;
- fruit yogurt with skimmed, semi-skimmed, or whole milk and fruit Greek yogurt;
- fruit petits suisses with semi-skimmed, or whole milk;
- flavored fromages blancs with skimmed milk;
- fruit fromages blancs with semi-skimmed, or whole milk;
- compotes, diet compotes.

To simplify, we considered that sugar is the only sweetener used when minimizing the amount of added sweeteners. In order to determine the minimum content of sugar technically feasible and sensory acceptable in a given product, we applied an optimization model. Specifically, we minimized the proportion of sugar y_s subject to the technical constraints of formulation, such as product sweetness, texture or other constraints related to manufacturing. Constraints were identified during previous interviews with manufacturers. They are defined in Table B.1. The limit values of constraint were derived from Oqali dataset, by neglecting the extreme observations corresponding to very specific recipes. Table B.2 reports those extrema and the values set to calibrate the optimization models for the 18 recipes. Ingredient characteristics used in the constraints are shown in table B.3. The optimization models were solved using Simplex LP Solving method of Excel Solver, except for fruit dairy products for which we ran the non-linear GRG algorithm, starting from different sets of initial values in order to make sure the solution is not a local optimum. The calculated minimum amount of sugar are reported in Table B.4.

Then we assigned the minimum amount of sugar to be added to each of the 131 groups of products defined for the demand model, by matching the recipes.

Table B.5 shows the mean change in sugar and fat content and the resulting cost implications after reducing the amount of added sweeteners, by brand and product category.

B.3 Changes in average nutrient contents and marginal costs

Table B.1: **Technical constraints of formulation**

Constraint	**Description**	**Mathematical transcription**
Texture	In order to obtain a satisfying texture, the dry extract of the product has to be in a certain scale of values	$B^- \leq \frac{(B_m * y_m + B_s * y_s)}{(y_m + y_s)} \leq B^+$ where B_i is the dry extract of ingredient i
Sweetness	In order to obtain a satisfying taste, the sweetness of the product has to be in a certain scale of values	$S^- \leq \frac{(S_m * y_m + S_s * y_s)}{(y_m + y_s)} \leq S^+$ where S_i is the sweetening power of ingredient i
Quantity	The sum of the proportions of each ingredient must be equal to 100%	$y_m + y_s + y_f = 100\%$ Due to other ingredients encountered such as water or starch, this constraint has been released for sweet and flavored dairy product with skimmed milk, as follows: $y_m + y_s + y_f \leq 100\%$
Fermentation	Sweetening ingredients, in too high proportion, can inhibit the growth of bacteria, and thus the fermentation process	$\frac{B_s * y_s}{(y_m + y_s)} \leq F^+$ where B_s is the dry extract of the sweetening ingredient
Gelation	Properties of yogurt gels are influenced by the protein content of the matrix ingredient	$\frac{y_m * Prot_m}{(y_m + y_s)} \geq G^+$ where $Prot_m$ is the protein content of matrix ingredient
Regulation	According to French regulations, fermented milks (such as yogurts) may be supplemented with ingredients (sugar, flavorings, fruit preparations, additives) to give it a specific flavor, provided that this addition does not exceed 30% of the weight of the finished product	$y_s + y_f \leq 30\%$

Notes: y_s, y_m and y_f stand for the proportions of sweetening ingredient, matrix ingredient and fixed ingredient, respectively; fermentation and gelation constraints could have been released in the case of fruity dairy products because part of the sugar can

Table B.2: **Constraints specifications**

Recipe	Matrix ingredients	Fixed ingredients	B^-	B^+	S^-	S^+	F^+	G^+
Sweet yogurt with skimmed milk	Plain yogurt with skimmed milk	-	18.6%	18.9%	10.6	12	11.7%	3.50%
Sweet yogurt with semi-skimmed milk	Plain yogurt with semi-skimmed milk	-	19.5%	22.4%	9.7	11.9	11.7%	3.85%
Sweet yogurt with whole milk	Plain yogurt with whole milk	-	21.1%	22.1%	9.4	14.2	11.7%	3.80%
Flavored yogurt with skimmed milk	Plain yogurt with skimmed milk	Aroma 0.5%	18.6%	18.9%	10.7	12	11.8%	3.50%
Flavored yogurt with semi-skimmed milk	Plain yogurt with semi-skimmed milk	Aroma 0.5%	18.0%	21.3%	8.3	11.8	11.8%	3.80%
Flavored yogurt with whole milk	Plain yogurt with whole milk	Aroma 0.5%	20.4%	22.6%	9.3	11.2	11.8%	3.63%
Flavored Greek yogurt	Plain yogurt with whole milk and cream	Aroma 0.5%	21.4%	24.8%	9.0	13.3	11.8%	3.38%
Fruit yogurt with skimmed milk	Plain yogurt with skimmed milk	Fruits $\leq 13\%$	18%	19.4%	9.5	10	16.1%	4.10%
Fruit yogurt with semi-skimmed milk	Plain yogurt with semi-skimmed milk	Fruits $\leq 7.4\%$	19.4%	24.3%	9.2	14.4	16.1%	3.60%
Fruit yogurt with whole milk	Plain yogurt with whole milk	Fruits $\leq 19\%$	20.3%	27.4%	8.7	16.3	16.1%	3.50%
Fruit Greek yogurt	Plain yogurt with whole milk and cream	Fruits $\leq 9\%$	22%	29.3%	8.5	16.9	16.1%	3.30%
Fruit "petit suisses" semi-skimmed milk	Plain "petit suisses" semi-skimmed milk	Fruits $\leq 7\%$	25.7%	26%	11.4	16.3	-	-
Fruit "petit suisses" whole milk	Plain "petit suisses" whole milk	Fruits $\leq 13\%$	25.58%	30.1%	13	15.7	-	-
Flavored fromages blancs with skimmed milk	Plain fromages blancs with skimmed milk	Aroma 0.5%	21.3%	22.8%	10.9	11.8	-	-
Fruit fromages blancs with semi-skimmed milk	Plain fromages blancs with semi-skimmed milk	Fruits $\leq 8\%$	22.95%	30.4%	8.3	18.1	-	-
Fruit fromages blancs with whole milk	Plain fromages blancs with whole milk	Fruits $\leq 10\%$	28.2%	33.4%	11.6	19.3	-	-
Compotes	Fruit puree	Additives such as ascorbic acid 0.1%	19.4%	30.1%	16.5	26.8	-	-
Diet compotes	Fruit puree	Additives such as ascorbic	17.4%	23.1%	14.5	21.5	-	-

Table B.3: **Dry extract, sweetening power and protein content of ingredients**

Ingredient	**Type of ingredient**	**Dry extract** B_i	**Sweetening power** S_i	**Protein content** $Prot_i$
Plain yogurt with skimmed milk	Matrix ingredient (m)	11.70%	1.42	4.50%
Plain yogurt with semi-skimmed milk	Matrix ingredient (m)	12.30%	1.39	4.25%
Plain yogurt with whole milk	Matrix ingredient (m)	14.30%	1.36	4.20%
Plain yogurt with whole milk and cream	Matrix ingredient (m)	15.75%	1.21	3.92%
Plain "petit suisses" semi-skimmed milk	Matrix ingredient (m)	16.3%	0.576	-
Plain "petit suisses" whole milk	Matrix ingredient (m)	19.5%	0.544	-
Plain fromages blancs with skimmed milk	Matrix ingredient (m)	13.2%	0.680	-
Plain fromages blancs with semi-skimmed milk	Matrix ingredient (m)	16.3%	0.576	-
Plain fromages blancs with whole milk	Matrix ingredient (m)	19.5%	0.544	-
Fruit puree	Matrix ingredient (m)	15.3%	12.70	-
Sugar	Sweetening ingredient (s)	100%	100	-

Table B.4: **Optimized minimum amount of added sugar**

Recipe	**Minimum amount of added sugar** $Y_s min$
Sweet yogurt with skimmed milk	9.5%
Sweet yogurt with semi-skimmed milk	8.4%
Sweet yogurt with whole milk	8.2%
Flavored yogurt with skimmed milk	9.5%
Flavored yogurt with semi-skimmed milk	7.0%
Flavored yogurt with whole milk	8.0%
Flavored Greek yogurt	7.8%
Fruit yogurt with skimmed milk	7.1%
Fruit yogurt with semi-skimmed milk	7.5%
Fruit yogurt with whole milk	6.0%
Fruit Greek yogurt	6.8%
Fruit "petit suisses" with semi-skimmed milk	10.4%
Fruit "petit suisses" with whole milk	10.9%
Flavored fromages blancs with skimmed milk	10.2%
Fruit fromages blancs with semi-skimmed milk	7.3%
Fruit fromages blancs with whole milk	10.0%
Compotes	4.8%
Diet Compotes	2.5%

Table B.5: **Changes in average nutrient contents and marginal costs across brands and product categories due to reformulation**

	Compote			Yogurt			FBPS		
	Sugar Δ in grams	Fat Δ in grams	MC Δ in eurocents	Sugar Δ in grams	Fat Δ in grams	MC Δ in eurocents	Sugar Δ in grams	Fat Δ in grams	MC Δ in eurocents
Firm 1									
Brand 1				-0.85	0.06	-0.24	-1.49	0.11	0.20
Brand 2				0.00	0.00	0.00	0.00	0.00	0.00
Brand 3				0.00	0.00	0.00			
Brand 4				0.00	0.00	0.00			
Brand 5				-0.53	0.02	-0.15	-0.45	0.02	0.06
Firm 2									
Brand 6				-0.81	0.02	-0.23	0.00	0.00	0.00
Firm 3									
Brand 7				-0.55	0.02	-0.16	-0.40	0.02	0.05
Brand 8				-1.29	0.05	-0.37			
Brand 9				-0.20	0.00	-0.06			
Firm 4									
Brand 10	0.00	0.00	0.00	-1.83	0.09	-0.52	0.00	0.00	0.00
Firm 5									
Brand 11	0.00	0.00	0.00						
Firm 6									
Brand 12				0.00	0.00	0.00	0.00	0.00	0.00
Brand 13				0.00	0.00	0.00			
PLs	0.00	0.00	0.00	-0.80	0.05	-0.23	-0.13	0.01	0.02
All	0.00	0.00	0.00	-0.73	0.04	-0.21	-0.43	0.03	0.06

Notes: Reported values are market-share-weighted averages (using pre-policy shares). Nutrient entries are changes in g/100g. MC Δ is the change in marginal cost due to reformulation in eurocents per kg. As explained earlier no compote product has been reformulated, as reducing the sugar content to 12 g is technically unfeasible. Hence, as intended, all variations are null in the first three columns.

C Estimation and results of the demand and supply model

C.1 Identification of demand estimates

This method relies on the assumption that all product characteristics are independent of the error term ε_{ijt}. However, assuming $\varepsilon_{ijt} = \xi_{jt} + e_{ijt}$ where ξ_{jt} is a product-specific error term varying across periods and e_{ijt} is an individual-specific error term, the independence assumption cannot hold if unobserved factors included in ξ_{jt} (and hence in ε_{ijt}) such as promotions, displays and advertising are correlated with observed characteristics X_{jt}. For instance, we do not know the amount of advertising expenditure that firms incur each month for their brand. This effect is thus included in the error term because advertising might play a role in the choice of products by households. As advertising is an appreciable share of production costs, it is obviously correlated with prices. To solve the problem that omitted product characteristics might be correlated with prices, we use a control function approach, as in Petrin and Train (2010). We then regress prices on instrumental variables (W_{jt}) and the exogenous variables X_j of the demand equation :

$$p_{jt} = W_{jt}\gamma + X_{jt}\mu + \eta_{jt}$$

where η_{jt} is an error term that captures the remaining unobserved variations in prices. The estimated error term $\widehat{\eta}_{jt}$ of the price equation includes some omitted variables such as advertising variations and promotions that could explain price variations across products and time periods. Prices are now uncorrelated with the new product-specific error term varying across periods ($\zeta_{jt} = \xi_{jt} - \lambda\widehat{\eta}_{jt}$). We then write the equation 2

$$s_{jt}(\theta) = \int \frac{\exp(\beta_{b(j)} + \gamma_{c(j)} - \alpha_i p_{jt} + \delta_{Si}S_j + \delta_{Li}L_j + \delta_{SL}S_jL_j + \theta_N N_j + \theta_F F_j + \lambda\widehat{\eta}_{jt})}{1 + \sum_{k=1}^{J_t}\exp(\beta_{b(k)} + \gamma_{c(k)} - \alpha_i p_{kt} + \delta_{Si}S_k + \delta_{Li}L_k + \delta_{SL}S_kL_k + \theta_N N_k + \theta_F F_k + \lambda\widehat{\eta}_{kt})} dP_\nu(\nu_i)dP_D(D_i) \tag{10}$$

where λ is the estimated parameter associated with the estimated error term of the first stage.

In practice, we use BLP's instruments as the total number of competing products offered by the other manufacturers in each category, the percentage of fruit products and plain products, and the average sugar taste offered by the other manufacturers in each category. Table C.1 shows the results of the estimation of the price regression. All instrumental variables are significant and the F-test amounts to 12.37, meaning that the instrumental variables are not weak.

Table C.1: **Results on Price Equation**

Variable	**Mean (Std)**
Instrumental Variables	
Distance of competing products: nature	0.18 (0.01)*
Distance of competing products: sugar content	0.00 (0.00)***
Number of competing products	-0.16 (0.04)***
Input cost: cream	0.00 (0.00)***
Exogenous Variables of the utility Function	
Compote	-
Yogurt	0.68 (0.67)
FBPS	-0.88 (0.72)
ODD	-3.03 (0.84)***
Fruit	-0.10 (0.13)
Nature	-0.30 (0.19)
Taste: sweetness	0.04 (0.02)
Taste: fat	0.15 (0.03)***
Interaction sweetness $\times$ fat	0.00 (0.00)*
R^2	0.95
IV F-test	12.37 (0.00)
Number of observations	653

* $p < 0.05$, *** $p < 0.001$; Coefficients $\beta_{b(j)}$ not shown.
FBPS and ODD stand for fromage blanc and petit suisse, and other dairy dessert, respectively.

C.2 Results of the random coefficient logit model and price elasticities

Table C.2: **Results of the random coefficient logit model**

	Estimate (std)
Price	
α	0.130*** (0.000)
Without children	0.029*** (0.000)
Middle income	0.013*** (0.000)
Poor income	0.031*** (0.000)
One obese	0.009*** (0.000)
All obese	0.017*** (0.000)
σ	0.547*** (0.000)
Compote	-
Yogurt	-1.434*** (0.000)
FBPS	-1.005*** (0.000)
ODD	-0.184*** (0.000)
Fruit in Yogurt	0.491*** (0.000)
Nature	0.010*** (0.000)
Sugar taste	-0.023*** (0.000)
Without children	0.051*** (0.000)
One obese	-0.002*** (0.000)
All obese	-0.006*** (0.000)
Fat taste	0.022*** (0.000)
Without children	-0.012*** (0.000)
One obese	0.004*** (0.000)
All obese	0.002*** (0.000)
Sugar taste* Fat taste	0.857*** (0.000)
Error term	0.509*** (0.000)
LL	-3,677,800
Number of observations	1,528,220
Coefficients $\beta_{b(j)}$ not shown	

Notes: FBPS and ODD stand for fromage blanc and petit suisse, and other dairy dessert, respectively. *** means that coefficients are significant at 1% level.

Table C.3: **Average own-price elasticities by brand and product category**

	Compote	Yogurt	Fromage blanc, petit suisse	Other dairy dessert
Firm 1				
Brand 1		-2.29	-2.76	-2.65
Brand 2		-2.08	-2.70	-3.10
Brand 3		-3.45		
Brand 4		-2.91		
Brand 5		-2.43	-3.10	
Firm 2				
Brand 6		-2.26	-3.69	-2.97
Firm 3				
Brand 7		-1.94	-2.46	-3.07
Brand 8		-2.18		
Brand 9		-2.23		
Firm 4				
Brand 10	-2.78	-2.39	-2.44	-3.45
Firm 5				
Brand 11	-2.80			-3.33
Firm 6				
Brand 12		-2.57	-2.90	-3.86
Brand 13		-2.94		-3.02
PLs	-2.19	-1.85	-2.26	-2.37
All	-2.37	-2.13	-2.52	-2.68

Note: The reported own-price elasticity of a brand and a category is the weighted average (using market shares as weight) of the own-price elasticity of products of this brand in this category. PL stands for Private Label.

Table C.4: **Average margins (%) and marginal costs (€/kg) by brand and product category**

	Product category Compote	Yogurt	Fromage blanc, petit suisse	Other dairy dessert	All
			Margin		
Firm 1					
Brand_1		53.38	41.77	43.41	46.57
Brand_2		54.98	43.07	36.92	46.84
Brand_3		33.82			33.82
Brand_4		39.53			39.53
Brand_5		47.47	36.88		44.96
Firm 2					
Brand_6		48.10	28.86	36.87	40.37
Firm 3					
Brand_7		56.54	42.41	33.69	48.42
Brand_8		47.23			47.23
Brand_9		46.19			46.19
Firm 4					
Brand_10	37.08	46.72	42.10	29.86	36.69
Firm 5					
Brand_11	36.18			31.09	34.90
Firm 6					
Brand_12		40.20	35.17	27.05	31.40
Brand_13		35.17		33.74	34.45
PLs	59.60	72.79	58.74	58.66	63.82
All	**53.00**	**59.35**	**50.06**	**48.29**	**53.55**
			Marginal cost		
Firm 1					
Brand_1		1.36	1.96	1.77	1.67
Brand_2		0.95	1.88	2.53	1.63
Brand_3		3.33			3.33
Brand_4		2.17			2.17
Brand_5		1.45	2.56		1.71
Firm 2					
Brand_6		1.32	3.94	2.54	2.18
Firm 3					
Brand_7		0.95	1.60	2.60	1.38
Brand_8		1.18			1.18
Brand_9		1.24			1.24
Firm 4					
Brand_10	2.10	1.62	1.55	3.42	2.48
Firm 5					
Brand_11	2.14			3.28	2.43
Firm 6					
Brand_12		1.78	2.34	4.53	3.57
Brand_13		2.43		2.53	2.48
PLs	0.93	0.56	1.03	1.30	0.94
All	**1.27**	**1.04**	**1.53**	**1.91**	**1.43**

Notes: The reported marginal cost (margin) of a brand and a category is the weighted average (using market shares as weight) of the marginal costs (margins) of the products for each brand in each category. PL stands for Privale Label.

D Additional tables on the effect of the tax policy with reformulation

Table D.1: **Changes in average price (€/kg) and market share (%) across brands and product categories with reformulation**

	Compote		Yogurt		FBPS		ODD		All	
	Price	MS	Price	MS	Price	MS	Price	MS	Price	MS
Firm 1										
Brand 1			0.02	6.66	0.02	4.06	0.83	-42.49	0.35	-13.96
Brand 2			0.02	10.26	0.02	11.68	0.02	13.27	0.02	11.47
Brand 3			0.02	13.03					0.02	13.03
Brand 4			0.02	12.39					0.02	12.39
Brand 5			0.02	9.47	0.02	10.98			0.02	9.83
Firm 2										
Brand 6			0.00	10.06	0.54	-17.50	0.79	-37.41	0.52	-21.07
Firm 3										
Brand 7			0.02	8.18	0.02	9.49	0.80	-37.03	0.09	4.38
Brand 8			0.02	7.05					0.02	7.05
Brand 9			0.02	10.42					0.02	10.42
Firm 4										
Brand 10	0.57	-25.30	0.00	5.26	0.01	11.59	0.60	-21.35	0.43	-15.04
Firm 5										
Brand 11	0.56	-23.88					0.52	-19.45	0.55	-22.75
Firm 6										
Brand 12			0.01	12.12	0.01	12.69	0.76	-28.98	0.49	-13.80
Brand 13			0.01	12.95			0.79	-37.09	0.40	-12.31
PLs	0.57	-28.69	-0.03	12.14	0.06	9.06	0.80	-43.73	0.35	-13.34
All	0.57	-27.52	-0.01	10.35	0.05	8.01	0.77	-38.71	0.32	-10.39

Notes: The reported change in price of a brand and a category is the weighted average (using market shares as weights) of the change in price of all products from this brand in this category. FBPS and ODD stand for fromage blanc and petit suisse, and other dairy dessert, respectively. MS stands for market share, PL stands for Private Label.

Table D.2: **Firm-level results of the simulation with reformulation**

Firm	Δ price	Pass-through	Δ Market Share (%)	Δ Margin (%)
Firm 1	0.09	1.24	-2.37	3.78
Firm 2	0.33	1.16	-21.07	5.99
Firm 3	0.07	1.19	6.25	2.25
Firm 4	0.36	1.17	-15.04	5.10
Firm 5	0.48	1.18	-22.75	6.95
Firm 6	0.36	1.14	-13.30	4.44
Private label	0.23	1.18	-13.34	3.24
All Firms	**0.22**	**1.17**	**-10.39**	**3.75**

Notes: Margins are weighted by initial market shares. Pass-trough is computed for the taxed products only. Change in price in euro per kg.

E Additional tables and figures on the effect of the tax policy without reformulation

We provide supplementary material on the estimation of the impact of the policy without taking into account the reformulation process undertaken by firms.

Table E.1: **Changes in average price (€/kg) and market share (%) across brands and product categories without reformulation**

	Compote		Yogurt		FBPS		ODD		All	
	Price	MS	Price	MS	Price	MS	Price	MS	Price	MS
Firm 1										
Brand 1			0.39	-8.82	0.38	-5.14	0.82	-38.01	0.56	-19.83
Brand 2			0.01	18.30	0.01	20.12	0.00	22.10	0.01	19.84
Brand 3			0.00	21.46					0.00	21.46
Brand 4			0.01	21.06					0.01	21.06
Brand 5			0.43	-11.34	0.40	-6.25			0.43	-10.13
Firm 2										
Brand 6			0.32	-5.02	0.53	-12.21	0.78	-33.24	0.62	-23.22
Firm 3										
Brand 7			0.57	-28.02	0.14	9.68	0.78	-32.29	0.41	-12.62
Brand 8			0.57	-24.36					0.57	-24.36
Brand 9			0.81	-42.08					0.81	-42.08
Firm 4										
Brand 10	0.57	-20.12	0.80	-40.28	0.01	18.90	0.59	-16.02	0.60	-21.22
Firm 5										
Brand 11	0.55	-18.70					0.51	-14.12	0.54	-17.54
Firm 6										
Brand 12			0.01	19.36	0.01	20.08	0.76	-24.54	0.48	-8.32
Brand 13			0.01	20.35			0.79	-32.87	0.40	-6.51
PLs	0.55	-22.60	0.44	-15.42	0.18	8.33	0.78	-39.09	0.53	-20.73
All	0.55	-21.69	0.41	-12.10	0.23	4.93	0.75	-34.04	0.51	-17.81

Notes: The reported change in price of a brand and a category is the weighted average (using market shares as weights) of the change in price of all products from this brand in this category. FBPS and ODD stand for fromage blanc and petit suisse, and other dairy dessert, respectively. MS stands for market share, PL stands for Private Label.

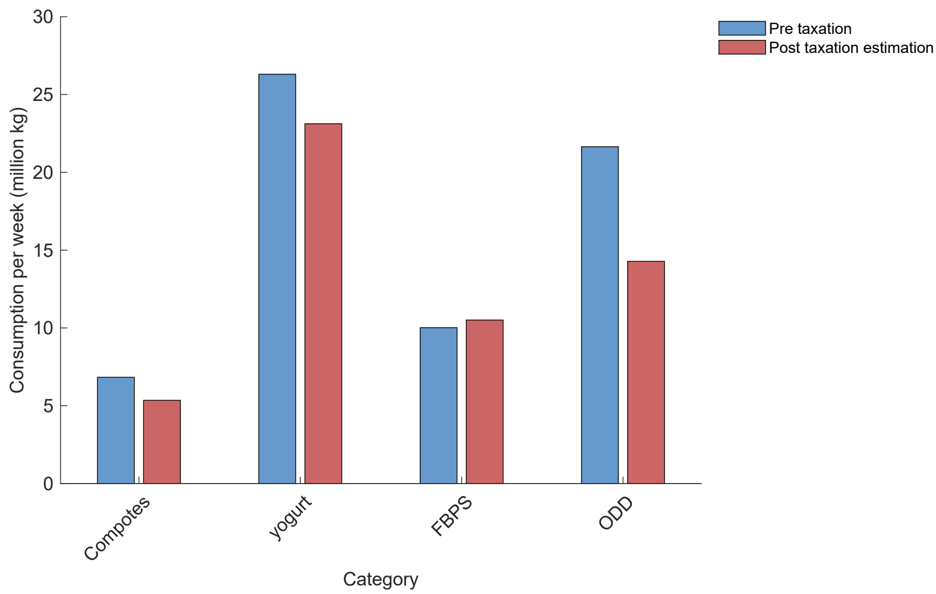

Figure E.1: Comparison of pre-taxation and simulated post-taxation purchases by category without reformulation

FBPS and ODD stand for fromage blanc and petit suisse, and other dairy dessert, respectively.

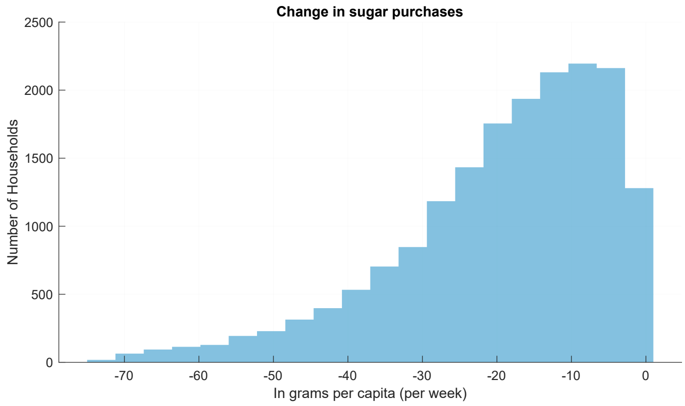

Figure E.2: Distribution of relative changes in household sugar purchases without reformulation.

The top 1% and bottom 1% of absolute sugar purchases change values have been excluded to reduce the influence of outliers.

Table E.2: **Firm-level results of the simulation without reformulation**

Firm	Δ price	Pass-through	Δ Market Share (%)	Δ Margin (%)
Firm 1	0.29	1.21	-9.06	5.93
Firm 2	0.45	1.17	-23.22	7.23
Firm 3	0.41	1.20	-21.25	8.77
Firm 4	0.57	1.17	-21.22	7.00
Firm 5	0.48	1.18	-17.54	6.76
Firm 6	0.36	1.14	-7.71	4.29
Private label	0.45	1.17	-20.73	4.93
All Firms	**0.41**	**1.18**	**-17.81**	**5.69**

Notes: Margins are weighted by initial market shares. Pass-trough is computed for the taxed products only. Change in price in euro par kg.

3 - Strategic behavior in quality and price : Empirical evaluation of sin taxes in the French dairy market

Strategic behavior in quality and price: Empirical evaluation of sin taxes in the French dairy market

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Abstract

JEL codes: H32, L13, Q18, I18

Key words: Taxation, strategic pricing, product reformulation

A growing number of countries have introduced taxes on products with high sugar content. Existing empirical evidence has primarily focused on price pass-through and demand responses, showing that the transmission of the tax to retail prices is heterogeneous across products and market environments. However, fiscal policies that target product composition also create incentives for firms to modify product characteristics. Ignoring these quality responses may therefore lead to an incomplete assessment of the effects of such policies.

In this paper we develop and estimate a structural demand and supply model that integrates firms' price and quality responses to sugar taxation in a differentiated-product market. The model allows manufacturers to compete in prices while endogenously adjusting product sugar content, subject to fixed reformulation costs. Using household purchase data from the Kantar WorldPanel combined with detailed nutritional information from the Oqali database, we study the potential implementation of a linear tax on sugar in the French dessert market.

Our framework recovers product-level lower bounds on reformulation costs from observed equilibrium behavior and embeds them in a counterfactual analysis of a sugar tax. We show that accounting for endogenous reformulation is crucial. When product characteristics are held fixed, the tax mainly operates through demand reallocation and price adjustments. Once reformulation is taken into account, a large share of the reduction in sugar consumption comes from changes in product composition rather than from substitution across existing products, and the contraction of the market is substantially attenuated.

The equilibrium response is highly heterogeneous across product categories and firms, reflecting differences in margins, baseline sugar content, and reformulation costs. These results highlight that the effectiveness of taxes depend not only on prices change but also on firms' incentives and ability to adjust quality.

More generally, the paper provides a tractable structural framework to study quality adjustment in response to fiscal policies in industries where changing product characteristics is infrequent and costly.

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Contents

1 Introduction

Over the past decade, the prevalence of obesity and diet-related chronic diseases has increased in many countries, leading policymakers to evaluate fiscal measures aimed at reducing the consumption of products with high sugar content. Among these instruments, taxes that target specific nutrients have received growing attention. While these policies are often implemented for SSB," in several cases they extend beyond beverages and apply to a broader set of food products.

The standard economic rationale for these taxes is straightforward: by increasing the price of products that generate negative health externalities, taxation is expected to reduce their consumption. A large empirical literature has evaluated this mechanism by studying tax pass-through and demand responses. Existing evidence shows that the transmission of the tax to retail prices is heterogeneous across products, retail environments, and market structures (Silver et al., 2017; Capacci et al., 2019). These findings imply that the final effect of the tax on consumers depend crucially on firms' pricing strategies, consumers substitution patterns and on competitive interactions.

An additional strategic channel that has received increasing attention is product reformulation. When the tax base is the nutrient content of a product, firms may have incentives to modify their recipes in order to reduce tax cost. Such quality adjustment has been emphasized in theoretical analyses (Réquillart et al., 2016) and documented in several policy contexts (Scarborough et al., 2020; Bercholz et al., 2022), but empirical evaluations that jointly account for consumer demand, price competition, and endogenous product characteristics remain limited. Most existing studies either treat product attributes as fixed or analyze reformulation in reduced form, without embedding it in an equilibrium framework(Allcott et al., 2019b; Dubois et al., 2018; Griffith et al., 2017a).Understanding their effects therefore requires analyzing markets in which products differ not only in prices but also in nutritional composition.

This paper develops and estimates a structural demand and supply model that integrates firms' price and quality responses to a sugar tax in a differentiated-product market. We consider a two-stage game in which manufacturers compete in prices, while changes in sugar content are infrequent and require paying a fixed reformulation cost. This formulation captures the idea that modifying a recipe involves technological, organizational, and demand-adjustment costs. Using this decisions process, we recover product-level lower bounds on reformulation costs from observed equilibrium and embed them in a counterfactual analysis of nutrient-based taxation.

We estimate the model using a unique dataset that combines household purchase data from the Kantar WorldPanel with detailed nutritional information from the Oqali database for the French dessert market. This setting provides substantial variation in both prices and product composition across a wide range of categories, including yogurts, compotes, fromages blancs and petits suisses (FBPS) and more complex desserts. It therefore offers a suitable environment to study how firms adjust both prices and product characteristics in response to fiscal incentives.

Our analysis delivers several results. First, we document substantial heterogeneity across product categories in equilibrium markups and in the magnitude of reformulation costs relative to revenues. These differences translate into sharply uneven incentives to adjust sugar content. Second, we show that accounting for endogenous reformulation is crucial for evaluating the effects of a sugar tax. When product characteristics are held fixed, the tax mainly operates through demand reallocation and price adjustments. When reformulation is taken into account, a large share of the reduction in sugar consumption comes from changes in product composition, and the contraction of the market is substantially attenuated. Third, we uncover strong heterogeneity in reformulation behavior across firms and products, reflecting differences in baseline sugar content, demand elasticities, and the magnitude of fixed costs.

Contribution to the literature. This paper contributes to several strands of the literature on taxation, product design, and structural industrial organization. First, it relates to the growing empirical literature that evaluates fiscal policies targeting nutrients in imperfectly competitive food markets. Structural analyses of sin taxes have emphasized the importance of market power, pass-through, and heterogeneous demand in shaping policy incidence and welfare (Allcott et al., 2019a; Griffith et al., 2017b; Bonnet and Réquillart, 2013). Our results show that, beyond price adjustments and demand substitution, endogenous product reformulation constitutes a central equilibrium margin. Accounting for this channel substantially alters both the predicted reduction in sugar consumption and the impact of the tax on market size. In this respect, the paper highlights a key mechanism that is absent from models in which product characteristics are held fixed.

Second, the paper contributes to the literature on endogenous product characteristics and cost recovery in differentiated-product markets. A number of studies have shown that firms jointly determine prices and product attributes in equilibrium (Draganska et al., 2009; Fan, 2013; Crawford et al., 2019). Our approach is also closely related to the methodology developed by Koujianou Goldberg and Hellerstein (2013), who recover unobserved fixed cost price adjustment components from equilibrium pricing behavior.

We adapt this framework to a setting in which changes in product composition are infrequent and require paying a fixed reformulation cost. This formulation is particularly well suited to food markets, where modifying a recipe involves technological, organizational, and demand-adjustment costs. Empirically, it allows us to recover product-level lower bound on reformulation costs from observed equilibrium behavior and to embed discrete reformulation decisions in a counterfactual analysis of fiscal policy.

Third, the paper is closely related to recent work that studies firms' incentives to adjust nutritional content in response to regulation. In a recent contribution, Barahona et al. (2023) develop a structural model in which firms optimally choose product sugar content under a label implementation. While their analysis focuses on marginal cost adjustments and abstracts from fixed reformulation costs, we take the opposite normalization by modeling reformulation as a fixed cost and remaining agnostic about the marginal cost channel. Our framework therefore recovers the equilibrium magnitude and heterogeneity of reformulation costs and shows how these costs shape the extensive margin of quality adjustment. In addition, we consider a continuous tax on sugar and quantify the extent to which endogenous reformulation mitigates the contraction of the market that arises when product characteristics are held fixed.

More broadly, the paper contributes to the empirical literature on food taxation, by focusing on a market beyond sugary beverages. It also provides new evidence on the role of product design in the transmission of nutrient-based taxation in multi-product food categories.

Taken together, these contributions show that evaluating taxes on product characteristics requires modeling firms' endogenous quality choices in equilibrium. Ignoring reformulation not only misstates the magnitude of the reduction in the targeted nutrient, but also leads to a different characterization of how the policy affects market competition, prices, and the distribution of outcomes across firms and product categories.

The remainder of the paper is organized as follows. Section 2 describes the French dessert market. Section 3 presents the structural model of supply competition. Section 4 discusses the estimation strategy of the counterfactual,reports the empirical results and the counterfactual analysis of a sugar tax. Section 5 concludes.

2 The French dessert market

We combine Kantar WorldPanel data, which tracks household-level purchases of dessert products, with the Oqali database providing nutritional composition of these products, including sugar and ingredient lists.

2.1 Determination of Recipes Prior to Food Reformulation

As the Kantar database does not include the detailed nutritional information necessary for recipe reconstruction, we relied on the OQALI[1] (Observatoire de la Qualité de l'Alimentation) database. This resource provides ingredient lists and nutrition facts as displayed on product packaging, at the brand and product level. For this analysis, we used data from the 2017 OQALI datasets covering compotes, fruit purees, and milk-based products.

In total, we use data for 5469 marketed products. These products have been regrouped in 130 recipes classifications.

To enable the reconstruction of product formulations, each recipe was decomposed into three principal categories of ingredients. The first category comprised the sweetening agents, including sugar, glucose syrup, inverted sugar, and other similar sweeteners. The second category was the matrix component, which provided the structural basis or served as the reference ingredient in reformulation scenarios; for example, plain yogurt was considered the matrix for yogurt products, plain fromages blancs or petits suisses for FBPS, and fruit purée for compotes. Finally, the fixed components were defined as those whose quantities were assumed to remain constant across formulations, such as added fruit in fruit yogurts or flavoring agents in flavored varieties.

Ingredient quantities were estimated using a combination of information from the ingredient list and the nutritional label. As per labeling regulations, ingredients are listed in descending order by weight, and in some cases, the exact proportion of specific ingredients is explicitly stated. When this information was available, it enabled a straightforward determination of the recipe.

In other cases, where exact proportions were not disclosed, we leveraged the principle that the overall nutritional content of a product corresponds to the weighted average of its ingredients' nutritional values. This allowed us to infer ingredient proportions by solving systems of equations derived from the known nutrition facts.

If neither exact ingredient quantities nor sufficiently detailed nutritional data were available, we applied reasonable assumptions based on standard product recipes or typical ingredient compositions.

Using the formulation constraints describe in annex we have been able to retrieve the minimal (and maximal) amount of sugar for each products type of recipes.

[1] https://www.oqali.fr/

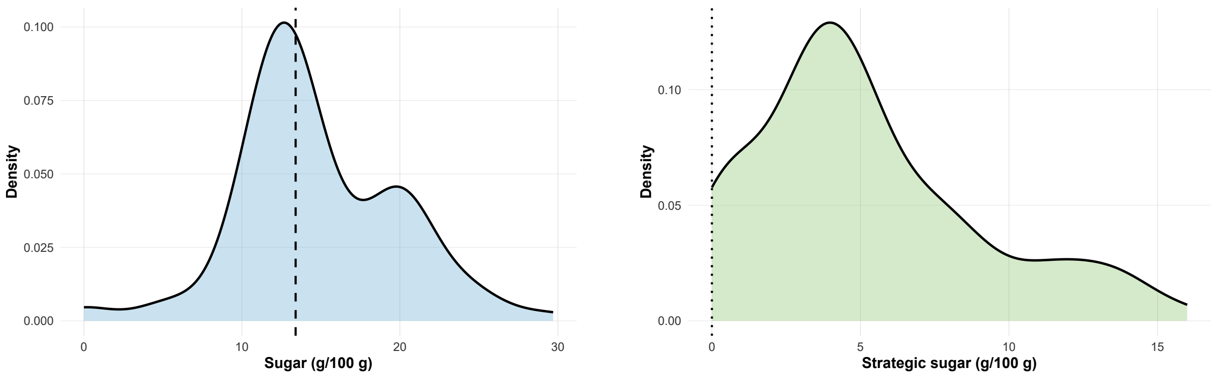
2.2 Consumption on the french dessert market

In order to construct a dataset suitable for structural estimation, we start from the full panel of household purchases in the French dessert market in 2017, which contains more than one million purchase observations and detailed information on product characteristics, including brand, price, and flavor. Because our analysis requires matching products with nutritional information from the OQALI dataset, we restrict attention to products that can be reliably identified in both sources. In practice, we select the 96 products with the largest market shares that could be consistently matched to OQALI entries. Focusing on these leading products ensures that we retain the items most frequently purchased by households while maintaining a precise correspondence with the nutritional database. The final dataset comprises 96 products matched to the OQALI database, which provides information on sugar content and the corresponding recipe classification. The demand model is estimated using panel data on 21,444 households, comprising 567,783 purchase occasions involving these products. They represent 28 of the different recipes classification find within the OQALI data. The presentation of these 28 recipes category can be find in the table 11 in the appendix.

The construction of the dataset at the product level allows us to highlight the considerable heterogeneity in sugar content across desserts. While the 96 products are grouped into 28 recipe classes, their sugar profiles remain far from uniform. Figure 1a illustrates the distribution of sugar content (in g/100g) across products, showing a wide spread distribution centered around 12 g per 100 g of product. This confirms that consumers face highly differentiated options in terms of sugar composition, even within this seemingly close product category. A part from a very few products that have close to zero sugar (artificial sweetener and vegetal milk in the recipe) most of the distribution range from 10 to 25 g of sugar per 100 g.

Beyond sugar content, we also consider the notion of *strategic sugar*[2], capturing the role of sugar as a differentiating attribute to the minimum achievable within recipes. Figure 1b shows that the heterogeneity persists at this level as well: some recipes display narrow distributions of strategic sugar, while others exhibit much broader ranges. Taken together, these figures highlight that the dessert market cannot be meaningfully understood without accounting for this disaggregated variation. The diversity of sugar content both within and across categories suggests that sugar operates as a central but heterogeneous driver of demand, shaping product positioning and consumer choice.

[2]This strategic sugar is the part of sugar that is greater that the minimum required by the recipe.



(a) Distribution of sugar content across the 96 products (g/100g).

(b) Distribution of strategic sugar across recipes (g/100g).

Figure 1: Comparison of sugar distributions.

Table 1 reports the distribution of sugar content across product categories. Average sugar levels vary substantially across segments. Complex desserts and compotes exhibit the highest sugar content, with mean levels around 19 grams per 100g, while yogurts and FBPS display lower averages of roughly 12 grams per 100g. The dispersion within categories is also sizable, particularly for desserts and FBPS, where the range of observed sugar levels is wide. The minimum value of zero grams observed in the dessert and yogurt categories does not reflect fully unsweetened dairy products ,which will not be feasible, but instead corresponds to a small number of items based on plant-based milk substitutes.

Table 1: Observed sugar content by category

Category	Mean sugar	Min sugar	Max sugar
Yogurt	12.05	0.00	16.00
Dessert	19.40	0.00	29.70
Compote	19.25	14.00	24.00
FBPS	12.13	4.70	26.60

Notes: Sugar content is measured in grams per 100g of product.

2.3 The demand model: A random-coefficient logit model

Consumers face alternatives that differ along several dimensions, including particularly price and sweetness. Capturing how these attributes shape substitution patterns is essential in a differentiated market such as desserts. In our specification, heterogeneity across consumers is introduced through a random coefficient on price, while differences in the valuation of sugar are allowed to vary systematically across product categories.

Formally, let V_{ijt} denote the indirect utility of consumer i for product j in period t:

$$V_{ijt} = \zeta_{b(j)} + \gamma_{c(j)} + \tau_t - \alpha_i p_{jt} + \left(\beta + \beta_{c(j)}\right) S_j + \theta_{mg} MG_j + \varepsilon_{ijt}, \tag{1}$$

where $\zeta_{b(j)}$, $\gamma_{c(j)}$, and τ_t denote respectively brand, category, and month fixed effects. The parameter α_i captures consumer-specific price sensitivity, S_j is the sugar content, and MG_j the lipid content.

Consumer heterogeneity is introduced through the price coefficient,

$$\alpha_i = \alpha + \sigma_\alpha \nu_i, \qquad \nu_i \sim \mathcal{N}(0,1),$$

so that individuals differ in their willingness to pay, while the taste for sugar is common across consumers within a given category. Category-specific sugar coefficients, $\beta_{c(j)}$, allow the marginal utility of sugar to differ across recipes, capturing that sweetness is not perceived in the same way in yogurts, compotes, complex desserts, or FBPS.

The mean utility is therefore

$$\delta_{jt} = \zeta_{b(j)} + \gamma_{c(j)} + \tau_t - \alpha p_{jt} + \left(\beta + \beta_{c(j)}\right) S_j + \theta_{mg} MG_j,$$

while the individual deviation from mean utility is

$$\mu_{ijt} = -\sigma_\alpha \nu_i p_{jt}.$$

This specification allows for rich substitution patterns driven by heterogeneous price sensitivity and by systematic differences in the valuation of sugar across product categories. As a result, the model delivers elasticities and counterfactual predictions that reflect both the differentiated nature of the products and the fact that sugar reduction does not have the same demand implications in all segments of the dessert market.

Consumers also have an outside option with utility normalized to zero[3]. Under the assumption that ε_{ijt} follows an i.i.d. Type I Extreme Value distribution, the probability that consumer i chooses product j in period t is

$$P_{ijt}(\theta) = \int \frac{\exp(\delta_{jt} + \mu_{ijt})}{1 + \sum_{k=1}^{J_t} \exp(\delta_{kt} + \mu_{ikt})} \, dP_\nu(\nu). \tag{2}$$

[3]As commonly done in the literature, we take into account the non-purchase decision of households in the sample. Consumers may choose not to buy any of the goods considered in the market. This represents around 10% of purchase occasions.

The corresponding market share is obtained by aggregating these choice probabilities across consumers. Let y_{ijt} be an indicator equal to one if household i purchases product j in period t, and zero otherwise. The model parameters are estimated by maximum likelihood, with log-likelihood function

$$\mathcal{L}(\theta) = \sum_{i} \sum_{t} \sum_{j=0}^{J_t} y_{ijt} \log P_{ijt}(\theta). \tag{3}$$

Own- and cross-price elasticities follow from standard formulas in the random-coefficients logit framework; see, e.g., (Nevo, 2001).

Identification and Endogeneity

This method relies on the assumption that all product characteristics are independent of the error term ε_{ijt}. However, assuming $\varepsilon_{ijt} = \xi_{jt} + e_{ijt}$ where ξ_{jt} is a product-specific error term varying across periods and e_{ijt} is an individual-specific error term, the independence assumption cannot hold if unobserved factors included in ξ_{jt} (and hence in ε_{ijt}) such as promotions, displays and advertising are correlated with observed characteristics X_{jt}. For instance, we do not know the amount of advertising expenditure that firms incur each month for their brand. This effect is thus included in the error term because advertising might play a role in the choice of products by households. As advertising is an appreciable share of production costs, it is obviously correlated with prices. To solve the problem that omitted product characteristics might be correlated with prices, we use a control function approach, as in Petrin and Train (2010). We then regress prices on instrumental variables (W_{jt}) and the exogenous variables X_j of the demand equation :

$$p_{jt} = W_{jt}\gamma + X_{jt}\mu + \eta_{jt}$$

where η_{jt} is an error term that captures the remaining unobserved variations in prices. The estimated error term $\widehat{\eta}_{jt}$ of the price equation includes some omitted variables such as advertising variations and promotions that could explain price variations across products and time periods. Prices are now uncorrelated with the new product-specific error term varying across periods ($\zeta_{jt} = \xi_{jt} - \lambda\widehat{\eta}_{jt}$). Estimates of this regression can be found in annex in table 12.

Demand estimates in table 2 show meaningful heterogeneity in tastes that aligns with the the supply-side positioning evidence arising in Figures 1a and 1b. The mean price coefficient is negative ($\alpha = -1.18$), indicating the expected disutility of higher prices, with substantial dispersion ($\sigma = 0.36$). Under the normal specification $\alpha_i = \alpha + \sigma\nu_i$, the implied share of consumers with positive price slopes is essentially non-existent.

Table 2: Maximum Likelihood Estimates

Parameter	Estimate	95% CI
Price coefficient (α)	-1.1763***	[-1.1765, -1.1760]
	(0.0002)	
Random price s.d. (σ)	0.3634***	[0.3630, 0.3635]
	(0.0001)	
Control function – price (λ_p)	0.9890***	[0.9886, 0.9892]
	(0.0002)	
Sugar coefficient	-0.1314***	[-0.1315, -0.1313]
	(0.0000)	
Lipid coefficient	0.0717***	[0.0716, 0.0717]
	(0.0000)	
Category fixed effects (inside goods)		
Yogurt	-1.5623***	[-1.5608, -1.5585]
	(0.0006)	
Complex dessert	0.7929***	[0.7946, 0.7971]
	(0.0007)	
Compotes	1.5765***	[1.5677, 1.5721]
	(0.0010)	
FBPS	1.8546***	[1.8564, 1.8591]
	(0.0007)	
Sugar × category effects (baseline: FBPS)		
Sugar × Yogurt	0.2455***	[0.2454, 0.2456]
	(0.0001)	
Sugar × Complex dessert	0.1121***	[0.1120, 0.1122]
	(0.0000)	
Sugar × Compotes	0.0756***	[0.0759, 0.0762]
	(0.0001)	
Brand fixed effects	Included	
Period fixed effects	Included	

Notes: Standard errors (in parentheses) are computed using 500 bootstrap. Confidence intervals are percentile bootstrap intervals. Stars denote significance based on bootstrap standard errors using a normal approximation: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$. Brand and period fixed effects are included in the estimation but not reported for brevity.

Turning to sugar preferences, the estimates point to a negative average taste for sugar across all categories, with a baseline effect for FBPS of $\beta_{\text{sugar}} = -0.13$. The interaction terms indicate substantial category heterogeneity around this reference. In particular, the marginal utility of sugar is less negative for yogurts ($-0.13 + 0.25 \simeq 0.11$), slightly negative for complex desserts ($-0.13 + 0.11 \simeq -0.02$), and remains clearly negative for compotes ($-0.13 + 0.08 \simeq -0.06$) and FBPS. Hence, only in the yoghurt segment does additional sugar generate a positive average taste, while in all other categories consumers display, on average, a preference for lower sugar content. This pattern indicates that the vertical differentiation in sugar content documented on the supply side is matched by differentiated demand incentives: products with higher sugar content are primarily valued in the yogurt segment, whereas in the other segments firms face consumers who, on average, reward sugar reduction.

3 Supply side competition

We model the dessert market as an oligopoly where firms strategically select both the quality (defined just below) and the pricing of their products. In particular, we focus on the role of sugar as a quality attribute that firms can adjust in order to influence consumer demand. This choice is subject to important technological and regulatory restrictions. On one hand, certain products must remain sugar-free (for example, "0% sugar" yogurts), while on the other hand recipes require a minimum amount of sugar for feasibility and often face an upper bound for palatability or labeling. Thus, the strategic variable of interest is the *added sugar* beyond this technological minimum. For simplicity, we will use the terms *quality*, *added sugar*, or simply *sugar* interchangeably to denote this decision margin.

The timing of the game follows the standard structure of endogenous product characteristics models. In the first stage, manufacturers select the quality of their products, i.e., the amount of added sugar within the feasible range. In the second stage, conditional on these quality choices, firms compete in prices. This two-stage formulation allows us to capture both dimensions of strategic interaction: how firms differentiate their products quality ex ante, and how they subsequently adjust prices given consumer demand and rival offers.

We introduce the following notation. Let G_f denote the set of products sold by firm f, and M the total market size. For product j, $p_j(q)$ is the final price, c_j the marginal cost of production, and $s_j(p, q)$ its market share given the vector of prices $p(q)$ and qualities q. Let $S(p(q), q|\theta) = S$ denote the vector of market shares across all products. Ownership is captured by the matrix I_f, while I_f^s is the analogous ownership matrix restricted to the subset of products $G_f^s \subseteq G_f$ for which firm f can adjust sugar strategically.

We consider F manufacturers that compete in both added sugar quantities and prices in the dessert market. In doing so, we abstract from the role of retailers in setting prices of national brands (NBs).

We solve this game by backward induction. In the second stage, manufacturers choose their prices given the quality (sugar) levels determined in the first stage.

3.1 Second stage: Price competition given product characteristics

Formally, manufacturer f maximizes its profit function:

$$\Pi^f(p,q) = \sum_{j \in G_f} M\big(p_j(q) - c_j\big) s_j(p,q) \tag{4}$$

The first-order conditions (FOCs) for the price-setting problem of firm f are:

$$\frac{\partial \Pi^f(p,q)}{\partial p_k} = 0 \;\Leftrightarrow\; \underbrace{s_k(p(q),q)}_{\text{(i) Direct effect of raising } p_k \text{ on own revenue}} + \underbrace{\sum_{j \in G_f} \big(p_j(q) - c_j\big) \frac{\partial s_j(p(q),q)}{\partial p_k(q)}}_{\text{(ii) Effect on margins via demand sensitivities}} = 0, \quad \forall k \in G_f \tag{5}$$

This condition reflects two channels shaping firms' price-setting incentives. The first term captures the direct effect of raising the price of product k on its own revenue, while the second term represents the indirect effect through demand sensitivities, namely how changes in p_k shift the demand and profitability of all products in the firm's portfolio. By collecting the FOCs across firms and products, and exploiting the structure of the demand system, we can express the vector of equilibrium margins as:

$$\Gamma(p,q|\theta) = -\left(\sum_{f=1}^{F} I_f S_p(p,q|\theta) I_f \right)^{-1} S(p,q|\theta) \tag{6}$$

where $\Gamma(p,q|\theta)$ is the vector of product-level margins, I_f is the firm ownership matrix, $S(p,q|\theta)$ is the vector of market shares, and $S_p(p,q|\theta)$ is the Jacobian of market shares with respect to prices.

From this system, we recover implied margins $\gamma_j(p,q) = p_j(q) - c_j$ and thereby back out marginal costs c_j in their estimated vector $\hat{c}$.

3.2 First stage: Sugar choice with reformulation costs

The first stage determines the equilibrium sugar content of each product. Sugar q_j represents a technologically constrained and infrequently adjusted characteristic. Changing its level requires modifying the product recipe and production process and therefore entails a fixed reformulation cost.

For each product $j \in G_f^s$, conditional on reformulating in $[\underline{q}_j, \overline{q}_j]$ respectively the minimal amount and the maximum amount of sugar coming from the recipes constraint for that product, firm f chooses its sugar content taking as given the characteristics of all other products and anticipating the second-stage price equilibrium. Let q_{-j} denote the vector of sugar levels of all products except j. The optimal reformulated sugar level is defined as

$$q_j^* \in \arg \max_{q_j \in [\underline{q}_j, \overline{q}_j]} \Pi^f\big(q_j, q_{-j}, p(q_j, q_{-j})\big) \tag{7}$$

where $\Pi^f(\cdot)$ is the profit and equilibrium prices $p(q)$ are obtained from the second-stage pricing game. In the baseline specification, marginal costs c_j are treated as independent of sugar content, so the effect of q_j on profits operates through demand and the induced adjustment of equilibrium prices.

Because firms are observed not to reformulate in the data, profit maximization implies that the gain in variable profits associated with moving from the observed sugar vector q to q_j^* cannot exceed the fixed reformulation cost. This delivers a lower bound for the reformulation cost:

$$A_j \;\geq\; \Pi^f(q_j^*, q_{-j}, p(q_j^*, q_{-j})) - \Pi^f(q, p(q)) \tag{8}$$

In this respect, our interpretation follows the logic of the structural approach developed by Koujianou Goldberg and Hellerstein (2013) in their analysis of local currency price stability. As in their framework, the objects recovered from the model are equilibrium outcomes that reflect a combination of technological and demand-side forces, and the data do not allow us to separately identify the exact origin of the underlying cost components. Because firms optimally choose product attributes, these two channels are jointly embedded in the equilibrium conditions and cannot be disentangled without additional information. Our structural model nevertheless allows us to recover the overall economic magnitude of reformulation costs, which is the relevant object for counterfactual analysis, even though we remain agnostic about their precise decomposition into technological and taste-related components. Even more importantly, it's the relevant economic estimate that will allow us to determine if it's likely that a firm will engage in a reformulation process or no.

3.3 Results on supply

Table 3: Supply estimates by category

Group	Price (€)	Margin (%)	Ref. cost mean (€)	Revenue (%)
Yogurts	2.09	55	248798	14
Complex desserts	3.04	40	267541	11
Compote	2.93	34	2186334	41
FBPS	2.30	44	760028	44

Notes: Reformulation cost is our estimate of a lower bound of A_j . The last column report the mean of $100 \times A_j/\text{rev}_j$ across products within each category.

Table 3 reports the estimated margin by category together with our estimates of the lower bound of the reformulation cost, A_j. Clear differences in markups emerge across segments. Yogurts combine relatively low prices (€2.09 per kg) with the highest percentage margin (55.2%), indicating substantial market power in this large and highly differentiated segment. More sophisticated desserts (Complex desserts) display the highest price level (€3.05) and a slightly higher absolute margin than yogurts (€1.11), but a lower markup rate (40.2%). FBPS occupy an intermediate position, with margins close in level to yogurts (€0.98) and a markup of 44.1%. In contrast, compotes exhibit the lowest margins both in absolute value (€0.97) and as a percentage of price (34.0%), consistent with a more competitive environment and more limited scope for differentiation.

In the yogurt and complex dessert segments, the average cost represents about 14% and respectively 11% of revenues. Given the high margins observed in yogurts, these costs remain moderate, suggesting that firms in this segment have the greatest ability to absorb reformulation expenses. For complex desserts, the similar cost-to-revenue ratio combined with lower margins implies a tighter trade-off between reformulation and profitability.

By contrast, the reformulation cost is much larger in the compote and FBPS segments, where it amounts to more than 40% of revenues on average. In these categories, the cost is of the same order of magnitude as, or even exceeds, the margin, which implies that reformulation cannot be accommodated without substantial adjustments in prices. These segments therefore appear structurally less flexible in response to policies that require changes in product characteristics.

Table 4 reports the direction and magnitude of the optimal change in sugar content implied when products are allowed to adjust their recipes. The pattern of optimal adjustments differs across categories, reflecting the heterogeneity in consumer preferences for sweetness captured by our demand estimates.

Table 4: Direction of the optimal change in sugar content by category

Category	Mean change	Min change	Max change
Yogurt	1.77	-0.02	7.72
Dessert	-16.31	-29.66	0.02
Compote	-15.05	-16.10	-13.50
FBPS	-5.76	-12.99	0.00

Notes: Change in sugar is measured in grams per 100g of product.

In the dessert and compote segments, the optimal adjustment systematically involves large reductions in sugar. For desserts, the mean optimal change is -16.3 grams per 100g, with some products requiring reductions of nearly 30 grams. Compotes display a similarly strong pattern, with an average reduction of about 15 grams and very little dispersion across products. These results indicate that consumer preferences in these segments create strong demand-side incentives to reformulate downward.

The response is more moderate in the FBPS category, where the mean reduction is about 5.8 grams per 100g and the distribution of changes is more dispersed. While most products still experience downward pressure on sugar levels, the presence of products with no optimal change suggests that sugar remains an important attribute for some items within this segment.

Yogurts display a very different pattern. The average optimal change is positive, indicating that for many yogurt products consumers would favor a higher sugar content relative to the observed levels. The distribution of changes is also highly heterogeneous, ranging from essentially no adjustment to increases of more than 7 grams per 100g.

Taken together, these results show that the demand-side incentives to adjust sugar content vary substantially across categories. In segments such as desserts and compotes, consumer preferences create strong pressure toward lower sugar levels, whereas in yogurts the direction of the adjustment is more ambiguous and in some cases points toward higher sugar content.

Overall, these reformulation cost estimates suggest that policy-induced adjustments are likely to be highly uneven across segments. Categories such as yogurts, which combine relatively high margins with moderate reformulation costs, appear structurally better positioned to adjust their product characteristics. By contrast, segments such as compotes and FBPS, where reformulation costs represent a large share of revenues, face much tighter constraints and are therefore more likely to rely on price adjustments or other competitive responses when confronted with policies targeting sugar content.

At the same time, the demand-side incentives described above imply that the direction of the optimal sugar adjustment differs across categories. In segments where consumer preferences already create incentives to reduce sugar content, the introduction of a sugar tax reinforces these incentives and generates a double pressure toward downward reformulation. In contrast, in categories where the demand system points toward higher sugar levels, the incentives created by taxation and by consumer preferences operate in opposite directions.

As a result, the equilibrium response to taxation is expected to be asymmetric across segments. For relatively small tax levels, products that already face downward pressure on sugar content are more likely to reformulate, whereas categories where the demand system favors higher sweetness may display much weaker adjustments because the two forces partially offset each other.

4 Counterfactual reformulation under a sugar tax

We use the estimated reformulation costs $\hat{A}_j$ to evaluate firms' incentives to adjust sugar content in response to a linear tax on sugar. Let τ denote the tax per gram of sugar. The tax enters the model as a marginal cost shifter, so that for any sugar vector q the post-tax marginal cost becomes:

$$\tilde{c}^{\tau}(q) \;=\; \hat{c} + \tau q$$

For each product $k \in G_f^s$, given a candidate sugar q_k^*, equilibrium prices are obtained from the second-stage Bertrand game exactly as in the baseline and are denoted $p^*(q_k^*, q_{-k}, \tau)$

The post-tax marginal cost becomes:

$$\tilde{c}^{\tau}(q_k^*, q_{-k}) \;=\; \hat{c} + \tau(q_k^*, q_{-k})$$

Firm f's profit under the tax is therefore:

$$\Pi^f(q_k^*, q_{-k}, \tau) = \sum_{j \in G_f} M\left(p_j^*(q_k^*, q_{-k}, \tau) - \tilde{c}_j^{\tau}(q_k^*, q_{-k})\right) s_j(p^*(q_k^*, q_{-k}, \tau), q_k^*, q_{-k}) \tag{9}$$

For each product $k \in G_f^s$, the firm compares the profit obtained when the product is reformulated to the profit obtained when its sugar content is kept at the pre-tax level. Let again q_k^* denote the optimal sugar content of product k (while other products remain at their observed levels), and let q^0 denote the vector with no reformulation. Product j is reformulated if and only if:

$$\Pi^f(q_k^*, q_{-k}, \tau) - \hat{A}_j \;\geq\; \Pi^f(q^0, \tau) \tag{10}$$

This condition defines a discrete product-level adoption decision: reformulation occurs when the gain in variable profits generated by the reduction in the tax burden is large enough to compensate for the fixed reformulation cost. Because prices are determined in equilibrium in the second stage, both $\Pi^f(q_k^*, q_{-k}, \tau)$ and $\Pi^f(q^0, \tau)$ incorporate the endogenous adjustment of markups and market shares induced by the tax and by the change in product characteristics.

Operationally, for a given tax level τ, we first compute the post-tax equilibrium holding the observed sugar vector fixed, which delivers $\Pi^f(q^0, \tau)$. We then consider, for each product $k \in G_f^s$, the counterfactual in which the product is reformulated, while all other products remain unchanged. A product is reformulated whenever condition (10) is satisfied. The resulting set of reformulated products determines the counterfactual sugar vector, prices, market shares, and profits under the tax.

The reformulation rule in (10) characterizes a one-product deviation from the benchmark sugar vector. In general, however, the reformulation decisions of different products are interdependent because any change in q affects equilibrium prices and market shares for all products through the second-stage Bertrand game.

To compute the equilibrium, we proceed iteratively. Starting from the observed sugar vector q^0, we evaluate for each product $k \in G_f^s$ whether condition (10) is satisfied, taking as given the current sugar levels of all other products. For products for which the condition holds, we update the sugar level to the optimal choice. Given the updated sugar vector, we resolve the second-stage pricing game and recompute profits. This procedure is repeated until the set of reformulated products and the associated sugar levels converge. The resulting fixed point defines the counterfactual equilibrium under the tax.

At convergence, we find a Nash equilibrium: no firm has a profitable unilateral reformulation deviation given the equilibrium sugar vector and the associated price equilibrium.

4.1 Application with linear taxation

We evaluate the effects of a linear tax on sugar that is proportional to the grams of sugar per 100g of product. We consider two policy scenarios: a low tax of 1 cent and a high tax of 10 cents per gram of sugar per 100g.

We now turn to the counterfactual reformulation patterns induced by the tax. In equilibrium, 42 products are reformulated under the low tax and 71 under the high tax, indicating that the extensive margin of reformulation responds strongly to policy intensity.

Tables 5 and 6 summarize the equilibrium reformulation response to a low (1c) and a high (10c) linear tax on sugar. The response is highly uneven across categories. Under the 1c tax, yogurts exhibit no reformulation (reform rate $= 0$) and therefore no change in average sugar

Table 5: Equilibrium reformulation outcomes by category (tax = 1c/g per 100g)

Group	Reform rate	Sugar (base)	Sugar (eq.)	ΔSugar
Yogurt	0.0000	12.2523	12.2523	0.0000
Dessert	0.9775	19.4041	2.7440	-16.6602
Compote	1.0000	21.6857	6.1219	-15.5638
FBPS	0.4509	11.5916	8.7956	-2.7960

Notes: Baseline sugar corresponds to the observed pre-tax equilibrium. Counterfactual sugar levels reflect optimal reformulation under the tax, taking into account fixed reformulation costs. The reformulation rate is the share-weighted fraction of products that adjust their sugar content. Group shares are pre-tax market shares. All sugar levels are share-weighted averages.

Table 6: Equilibrium reformulation outcomes by category (tax = 10c/g per 100g)

Group	Reform rate	Sugar (base)	Sugar (eq.)	ΔSugar
Yogurt	0.7153	12.2523	6.2487	-6.0036
Dessert	0.9775	19.4041	2.7238	-16.6804
Compote	1.0000	21.6857	6.1220	-15.5637
FBPS	0.4509	11.5916	8.7952	-2.7964

Notes: Baseline sugar corresponds to the observed pre-tax equilibrium. Counterfactual sugar levels reflect optimal reformulation under the tax, taking into account fixed reformulation costs. The reformulation rate is the share-weighted fraction of products that adjust their sugar content. Group shares are pre-tax market shares. All sugar levels are share-weighted averages.

content. In contrast, complex desserts and compotes reformulate almost universally (reform rates close to one), implying large reductions in equilibrium sugar levels (about 16.7 and 15.6 grams per 100g, respectively). FBPS display an intermediate response: only about 45% of products are reformulated, leading to a more modest average reduction of roughly 2.8 grams per 100g.

Raising the tax to 10c induces additional reformulation in yogurts: the reformulation rate increases to about 71.5% and average sugar falls by roughly 6.0 grams per 100g. By contrast, the other categories change little between the two tax levels: desserts and compotes remain near full reformulation with almost identical equilibrium sugar levels, and FBPS exhibit essentially the same reformulation rate and average reduction.

The corresponding tables by firm are reported in the Appendix. They reveal additional heterogeneity in reformulation behavior across manufacturers, consistent with meaningful within-category variation at the product level in both baseline sugar content and the incentives to reformulate.

Table 7 summarizes the aggregate equilibrium effects of the linear sugar tax. When reformulation is not taken into account (i.e., product characteristics are held fixed), the low tax has limited impact on market outcomes: the inside share remains close to its pre-tax level (0.893)

Table 7: Policy outcomes under a linear sugar tax

Scenario	Inside share	Price (€)	Margin (€)	Margin (%)	Sugar cons. (tons) (Δ%)
1c (no reform)	0.8929	2.5533	1.0384	45.13	1065.91 (-3.8)
1c (reform)	0.9276	2.5524	1.0327	44.25	517.70 (-53.3)
10c (no reform)	0.6760	3.6006	1.0748	31.83	662.34 (-40.2)
10c (reform)	0.8678	3.0605	1.0595	37.29	294.61 (-73.4)

Notes: The table compares counterfactual equilibria under two linear sugar taxes. Total sugar consumption is reported in metric tons. Percentage changes are relative to the pre-tax equilibrium. All moments are computed using equilibrium inside-good shares. A very small tax (0.01 cent per gram of sugar per 100g) does not trigger any reformulation in equilibrium, as the induced marginal cost change is too small to offset the fixed reformulation cost. This counterfactual can therefore be interpreted as a benchmark in which product characteristics remain effectively unchanged, even though prices adjust slightly. By contrast, a tax of 0.1 cent is sufficient to induce reformulation for one product.

and prices and margins are virtually unchanged, while total sugar consumption declines by 3.8%. When reformulation is taken into account, the equilibrium implications differ markedly. Under the same tax rate, the inside share increases to 0.928 and total sugar consumption falls by 53.3%, more than ten times the reduction obtained when product characteristics are held fixed. Prices and margins remain close across the two scenarios, with only a small decline in the margin rate.

The high tax produces larger adjustments along all dimensions. When reformulation is not taken into account, the inside share drops to 0.676, the average price increases to 3.60 euros, and sugar consumption declines by 40.2%. When reformulation is taken into account, the inside share recovers to 0.868 and the average price decreases to 3.06 euros relative to the fixed-characteristics equilibrium, while sugar consumption falls further to 294.6 tons, a reduction of 73.4% relative to the pre-tax equilibrium. Margins in levels remain close across scenarios, whereas the margin rate varies with the change in prices.

Overall, comparing the two cases at each tax level shows that the predicted reduction in sugar consumption is much larger when equilibrium reformulation is taken into account, and that accounting for reformulation substantially attenuates the contraction of the inside market implied by the fixed-characteristics counterfactual.

Table 8 reports equilibrium outcomes by category under the high tax scenario. Without reformulation, the tax reduces total sugar consumption in all categories, with declines ranging from 20.8% in yogurts to 68.2% in compotes. Allowing for reformulation amplifies these reductions substantially: sugar consumption falls by 74.8% in yogurts, 90.8% in desserts, 64.9% in compotes, and 30.7% in FBPS relative to the pre-tax equilibrium.

These changes are accompanied by large reallocations of market shares across categories. In

Table 8: Category outcomes under a linear sugar tax (10c/g per 100g)

Group	Share			Sugar (tons)		Tax rev. (M€)	
	Observed	no ref	ref	no ref	ref	no ref	ref
Yogurt	0.4006	0.3407	0.1250	320.34 (-20.8)	101.97 (-74.8)	32.03	10.20
Dessert	0.2775	0.1332	0.4132	176.21 (-60.3)	40.99 (-90.8)	17.62	4.10
Compote	0.0474	0.0169	0.0738	26.92 (-68.2)	29.71 (-64.9)	2.69	2.97
FBPS	0.1844	0.1852	0.2551	138.88 (-21.1)	121.94 (-30.7)	13.89	12.19

Notes: Observed denotes the pre-tax market share in the data., while no ref and respectively ref denote our simulated counterfactual without and with reformulation. Sugar consumption is reported in tons; parentheses show percentage changes relative to the pre-tax equilibrium. Tax revenue is reported in million euros.

the absence of reformulation, yogurts lose 6.0 p.p. of market share relative to the observed one, while desserts decline by 14.4 p.p. Compotes also contract slightly (-3.0 p.p.), whereas FBPS remain essentially unchanged (+0.1 p.p.). When reformulation is taken into account, the composition of the market shifts very importantly: yogurts fall to 12.5% (-27.6 p.p.), while desserts expand to 41.3% (+13.6 p.p.). Compotes rise modestly to 7.4% (+2.6 p.p.), and FBPS increase to 25.5% (+7.1 p.p.).

Tax revenues are systematically lower once reformulation is taken into account. At the category level, revenues decline from 32.03 to 10.20 million euros for yogurts and from 17.62 to 4.10 million euros for desserts, reflecting the reduction in the tax base induced by endogenous quality adjustment.

The corresponding firm-level results, reported in Appendix 19, display even larger dispersion, indicating that the aggregate patterns mask substantial heterogeneity in the incidence of the tax and in the scope for reformulation across product portfolios.

The low-tax scenario yields qualitatively similar but much smaller changes (Table 17 in the appendix).

5 Conclusion

This paper studies firms' incentives to reformulate products in response to a tax on sugar in a differentiated-product market. We develop and estimate a structural model in which manufacturers compete in prices and product characteristics, and in which changing the sugar content of a product requires paying a fixed reformulation cost. The model combines rich demand-side substitution patterns with supply-side price competition and allows us to recover product-level lower bounds on reformulation costs from observed equilibrium behavior.

Our estimates reveal substantial heterogeneity across product categories in both markups and reformulation costs. High-margin segments such as yogurts face reformulation costs that are moderate relative to existing margins, whereas in categories such as compotes and FBPS the implied costs represent a much larger share of revenues and are of the same order of magnitude as current margins. These differences translate into sharply uneven incentives to adjust product characteristics in response to policy. In equilibrium, reformulation is nearly universal in some categories even under a low tax, while it remains limited in others unless the policy becomes sufficiently stringent.

Accounting for endogenous reformulation is crucial for evaluating the effects of a sugar tax. When product characteristics are held fixed, the tax primarily operates through demand reallocation and price adjustments. Once reformulation is taken into account, a large share of the reduction in sugar consumption comes from changes in product composition rather than from substitution across existing products. At the same time, allowing for reformulation substantially attenuates the contraction of the inside market that would arise if recipes were fixed. These results highlight that models that abstract from firms' quality responses may mischaracterize both the magnitude and the incidence of policy effects.

The equilibrium adjustment to the tax is highly heterogeneous not only across categories but also across firms and products. The firm-level results reported in the appendix show that manufacturers with different product portfolios face very different incentives to reformulate, even within the same segment. This heterogeneity reflects differences in baseline sugar content, demand elasticities, and the magnitude of the fixed reformulation cost, and implies that the burden of the policy and the scope for quality adjustment are unevenly distributed across the market.

Our analysis focuses on the fixed technological and demand-adjustment costs required to modify product recipes and treats the marginal cost of production as unaffected by reformulation. Under this normalization, the estimated reformulation costs should be interpreted as equilibrium objects that rationalize observed product characteristics rather than as a structural decomposition between fixed and variable cost components. The next subsection assesses the sensitivity of this assumption by allowing for small changes in the marginal cost of sugar.

More broadly, the framework provides a tractable way to study quality adjustment in response to fiscal policies in differentiated-product industries where changing product characteristics is infrequent and costly. It shows that is essential to capture the full set of strategic responses available to firms , incuding endogenous product reformulation into structural models, to obtain a coherent equilibrium evaluation of policies that target product composition.

5.1 On the marginal cost of reformulation

In the baseline specification, reformulation is modeled as a purely fixed cost and we abstract from any change in marginal production costs. This assumption is motivated by the fact that the unit cost difference between sugar and the other ingredients that enter the recipe is quantitatively very small. Here we re-estimate the whole model with an affine transformation of the marginal cost of ± 0.1 cent per gram per 100g.

To calibrate a plausible order of magnitude for the change in marginal production costs induced by recipe adjustments, we use observed input price data for sugar available from the European Commission(European Commission, 2026a). Over our sample period, the industrial price of raw sugar is about €380 per tonne, i.e. roughly 38 cents per kilogram. A change of 1 gram of sugar per 100 grams of product therefore modifies the ingredient cost by approximately 0.38 cents per unit. Reformulation, however, involves replacing sugar with another input. In yogurt for example, the substitute is raw milk. Raw milk prices, obtained from the European Commission's Milk Market Observatory (European Commission, 2026b), range between 30 and 40 cents per liter over the same period, implying a very similar cost.

The relevant marginal cost of reformulation is thus not the cost of sugar itself, but the difference between the cost of sugar and that of the ingredient that replaces it. Given the proximity of these input prices, this differential is on the order of one tenth of a cent per gram of sugar per 100 grams of product. This provides a calibration for the magnitude of the marginal cost associated with recipe adjustments. To assess the quantitative importance of this channel, Table 9 reports a robustness exercise in which we allow for a differential marginal cost of sugar equal to ± 0.1 cent per gram per 100g.

Table 9: Reformulation cost and revenue share by category

Category	Cost (€) base	Cost (€) +0.1c	Cost (€) -0.1c	Rev. (%) base	Rev. (%) +0.1c	Rev. (%) -0.1c
Yaourt	-248798	-252036	-242528	-13.60	-13.78	-13.28
Dessert	-267541	-228910	-280012	-11.39	-10.08	-11.99
Compote	-2186334	-2124008	-2249817	-40.98	-39.79	-42.20
FBPS	-760028	-749702	-770483	-43.88	-43.27	-44.49

Notes: Costs are share-weighted category averages of product-level reformulation costs using our estimated market shares. The percentage columns report the corresponding cost as a share of product revenues. The baseline assumes no change in marginal production costs; the alternative columns allow for a differential marginal cost of sugar of ± 0.1 cent per gram per 100g. Even under a large differential in the marginal cost of sugar, the implied reformulation costs remain close to our baseline estimates, with the exception of complex desserts, which display a larger sensitivity (see Appendix Table 20)..

Introducing this channel reveal modest quantitative effects on the implied total cost of reformulation and on its revenue share. Across all categories, allowing for a marginal cost difference of ± 0.1 cent per gram per 100g leads to limited rescaling of the baseline estimates, and the ranking of categories remains unchanged. For instance, in the yogurt segment the reformulation cost varies only slightly around its baseline value (from about -242,528 € to -252,036 €), corresponding to revenue shares between 13.3 % and 13.8 %. A similar pattern holds in the other segments: desserts fluctuate within a narrow range around 11 % of revenues, while compotes and FBPS remain close to 40–44 %.

These results indicate that, in our setting, plausible variations in the marginal cost of sugar do not materially alter the economic magnitude of the reformulation cost. Allowing for a small differential in the marginal cost of sugar mainly produces a limited rescaling of the estimates without changing the economic conclusions or the relative exposure of the different categories to reformulation costs.

Our approach can be viewed as complementary to Barahona et al. (2023): while they abstract from fixed reformulation costs and focus on marginal cost adjustments, we take the opposite normalization by allowing for fixed costs and remaining agnostic about marginal cost changes. More generally, the assumption of a homogeneous marginal cost difference between sugar and the other ingredients is itself restrictive. In principle, the detailed information on product recipes would allow us to construct product-specific marginal cost shifters that vary with input prices. In practice, however, we do not observe firm-level input prices, which prevents any separate identification of the marginal cost component of reformulation. We therefore remain agnostic about how reformulation affects marginal costs. In any cases different assumptions on marginal costs rescale very slightly the implied reformulation cost, as shown above.

References

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

Allcott, H., B. B. Lockwood, and D. Taubinsky (2019b): "Should we tax sugar-sweetened beverages? An overview of theory and evidence," *Journal of Economic Perspectives*, 33, 202–227.

Barahona, N., C. Otero, and S. Otero (2023): "Equilibrium effects of food labeling policies," *Econometrica*, 91, 839–868.

Bercholz, M., S. W. Ng, N. Stacey, and E. C. Swart (2022): "Decomposing consumer and producer effects on sugar from beverage purchases after a sugar-based tax on beverages in South Africa," *Economics & Human Biology*, 46, 101136.

Bonnet, C. and V. Réquillart (2013): "Tax incidence with strategic firms on the soft drink market," *Journal of Public Economics*, 106, 77–88.

Capacci, S., O. Allais, C. Bonnet, and M. Mazzocchi (2019): "The impact of the French soda tax on prices and purchases. An ex post evaluation," *Plos One*, 14 (10), e0223196.

Crawford, G. S., O. Shcherbakov, and M. Shum (2019): "Quality Overprovision in Cable Television Markets," *American Economic Review*, 109, 956–95.

Draganska, M., M. Mazzeo, and K. Seim (2009): "Beyond plain vanilla: Modeling joint product assortment and pricing decisions," *QME*, 7, 105–146.

Dubois, P., R. Griffith, and M. O. Connell (2018): "The Effects of Banning Advertising in Junk Food Markets," *The Review of Economic Studies*, 85, 396–436.

European Commission (2026a): "EU sugar price monitoring database," Accessed: 23 February 2026.

——— (2026b): "Milk Market Observatory," Accessed: 23 February 2026.

Fan, Y. (2013): "Ownership consolidation and product characteristics: A study of the US daily newspaper market," *American Economic Review*, 103, 1598–1628.

Griffith, R., M. O'Connell, and K. Smith (2017a): "Corrective taxation and internalities from food consumption," *CESifo Economic Studies*, 1–14.

——— (2017b): "Tax design in the alcohol market," .

Koujianou Goldberg, P. and R. Hellerstein (2013): "A structural approach to identifying the sources of local currency price stability," *Review of Economic Studies*, 80, 175–210.

Nevo, A. (2001): "Measuring Market Power in the Ready-To-Eat Cereal Industry," *Econometrica*, 69, 307–342.

Petrin, A. and K. Train (2010): "A Control Function Approach to Endogeneity in Consumer Choice Models." *Journal of Marketing Research (JMR)*, 47, 3 – 13.

Réquillart, V., L.-G. Soler, and Y. Zang (2016): "Quality standards versus nutritional taxes: Health and welfare impacts with strategic firms," *Journal of Health Economics*, 50, 268 – 285.

Scarborough, P., V. Adhikari, R. A. Harrington, A. Elhussein, A. Briggs, M. Rayner, J. Adams, S. Cummins, T. Penney, and M. White (2020): "Impact of the announcement and implementation of the UK Soft Drinks Industry Levy on sugar content, price, product size and number of available soft drinks in the UK, 2015-19: A controlled interrupted time series analysis," *PLoS medicine*, 17, e1003025.

Silver, L., S. Ng, S. Ryan-Ibarra, L. Taillie, M. Induni, D. Miles, and et al. (2017): "Changes in prices, sales, consumer spending, and beverage consumption one year after a tax on sugar-sweetened beverages in Berkeley, California, US: A before-and-after study." *PLoS Medicine*, 14(4), e1002283.

A Appendix for recipes

Table 10: **Technical constraints of formulation**

Constraint	Description	Mathematical transcription
Texture	In order to obtain a satisfying texture, the dry extract of the product has to be in a certain scale	$B^- \leq \frac{(B_m * y_m + B_s * y_s)}{(y_m + y_s)} \leq B^+$ where B_i is the dry extract of ingredient i
Sweetness	In order to obtain a satisfying taste, the sweetness of the product has to be in a certain scale	$S^- \leq \frac{(S_m * y_m + S_s * y_s)}{(y_m + y_s)} \leq S^+$ where S_i is the sweetening power of ingredient i
Quantity	The sum of the proportions of each ingredient must be equal to 100%	$y_m + y_s + y_f = 100\%$
Fermentation	Sweetening ingredients in too high proportion can inhibit growth of bacteria	$\frac{B_s * y_s}{(y_m + y_s)} \leq F^+$ where B_s is the dry extract of the sweetening ingredient
Gelation	Sweetening ingredients in too high proportion can dilute milk proteins	$\frac{y_m * Prot_m}{(y_m + y_s)} \geq G^+$ where $Prot_m$ is the protein content of matrix ingredient
Regulatory	In France, fermented milks (e.g., yogurts) may be supplemented with other ingredients provided they do not exceed 30% of total weight	$y_s + y_f \leq 30\%$

Note: fermentation and gelation constraints could be released in the case of fruit dairy products because part of the sugar can be added after fermentation.

Table 11: Observed purchase distribution by product classification and category (2017)

Classification	Frequency	Percent
Yogurts		
Yaourt aromatisé lait entier	19,381	3.41
Yaourt aromatisé lait demi-écrémé	17,108	3.01
Yaourt édulcoré lait demi-écrémé	4,531	0.80
Yaourt aux fruits lait entier	80,225	14.13
Yaourt aux fruits lait demi-écrémé	31,756	5.59
Yaourt aux fruits lait végétal	5,170	0.91
Yaourt édulcoré fruits	11,180	1.97
Yaourt nature sucré lait entier	38,058	6.70
Yaourt nature sucré lait demi-écrémé	36,142	6.37
Fromages Blancs / Petits Suisses (FBPS)		
FBPS lait écrémé aromatisé	3,784	0.67
FBPS fruits lait entier	25,862	4.55
FBPS fruits lait demi-écrémé	35,489	6.25
FBPS nature sucré lait demi-écrémé	26,249	4.62
FBPS chocolat lait entier	3,672	0.65
FBPS aromatisé lait entier	3,721	0.66
FBPS aromatisé lait demi-écrémé	10,940	1.93
Other Dairy Desserts (ODD)		
Crème aux œufs	5,105	0.90
Crème aux œufs au chocolat	4,695	0.83
Crème aux œufs caramel	3,912	0.69
Crème caramel	3,679	0.65
Crème dessert gélifiée avec fruits	13,733	2.42
Crème dessert gélifiée	75,485	13.29
Mousse chocolat	41,887	7.38
Mousse liégeoise chocolat	17,342	3.05
Mousse liégeoise vanille	7,984	1.41
Riz au lait	11,384	2.00
Compotes		
Compote sans sucre ajouté	6,941	1.22
Compote standard	22,368	3.94
Total	**567,783**	**100.00**

B Appendix for demand

Table 12: First-Stage Regression: Price Equation

Variable	Coefficient	Std. Err.	t	p-value	95% CI
Fat content (g)	0.1062	0.0089	11.98	0.000	[0.0888, 0.1236]
Sugar content (g)	-0.1028	0.0154	-6.68	0.000	[-0.1330, -0.0726]
Category fixed effects (baseline: Outside good)					
Yoghurt	0.7472	0.2030	3.68	0.000	[0.3490, 1.1454]
Complex dessert	1.8886	0.1497	12.61	0.000	[1.5949, 2.1824]
Compotes	3.5696	0.4722	7.56	0.000	[2.6433, 4.4960]
FBPS	2.6524	0.2004	13.23	0.000	[2.2592, 3.0456]
Sugar × category effects (baseline: FBPS)					
Sugar × Yoghurt	0.1482	0.0203	7.31	0.000	[0.1084, 0.1880]
Sugar × Complex dessert	0.0931	0.0164	5.69	0.000	[0.0610, 0.1252]
Sugar × Compotes	0.0319	0.0280	1.14	0.255	[-0.0230, 0.0868]
Inst: Sum of sugar in other (same category)	-0.0025	0.0006	-4.27	0.000	[-0.0037, -0.0014]
Inst: Number of other (same category, aroma)	-0.0433	0.0109	-3.98	0.000	[-0.0647, -0.0220]
Brand fixed effects			Included		
Period fixed effects			Included		

Notes: Category 1 (outside good) is the omitted baseline category. Brand and period fixed effects are included but not reported for brevity. The FBPS category is omitted in the sugar–category interaction terms. The excluded instruments are jointly significant in the first stage ($F = 13.95$, $p < 0.001$), and exhibit moderate correlation ($\rho = -0.25$).

C Appendix for supply

Table 13: Margins by firm

Group	Price (€)	Margin (€)	Margin (%)	Simulated share	Observed share
Firm 1	3.9099	1.0736	28.8516	0.061505	0.061435
Firm 2	2.4512	0.9769	42.0225	0.120603	0.120809
Firm 3	2.3760	1.2074	55.5944	0.294670	0.294457
Firm 4	1.7316	0.8152	47.6888	0.017232	0.013785
Firm 5	1.6274	0.8155	53.1849	0.024985	0.024315
Firm 6	1.8129	0.8983	53.2807	0.095819	0.104415
Firm 7	1.4500	0.8091	58.8824	0.031403	0.030388
Firm 8	1.7538	0.8419	52.1281	0.042633	0.049210
Firm 9	1.8078	0.8186	46.5582	0.014195	0.012894
Firm 10	1.8367	0.8591	49.0177	0.055091	0.046568
Firm 11	3.4816	1.0993	33.7945	0.122004	0.121728
Firm 12	3.3800	0.9673	28.7899	0.024265	0.024391

Notes: Price, margin, and margin (%) are reported as simulated-share–weighted averages. Specifically, within each month t, group-level moments are computed as weighted averages across products in the group using simulated shares S_{jt} as weights, and then averaged over months. Simulated and observed group shares are reported as average monthly shares, computed as $\frac{1}{T}\sum_{t=1}^{T}\sum_{j\in g} S_{jt}$ and $\frac{1}{T}\sum_{t=1}^{T}\sum_{j\in g} \hat{S}_{jt}$, respectively.

Table 14: Change in sugar content by firm

Firm	Mean change	Min change	Max change
Firm 1	-12.58	-20.00	2.70
Firm 2	-0.54	-6.20	7.72
Firm 3	-4.50	-20.80	6.42
Firm 4	-1.71	-3.40	-0.01
Firm 5	-0.54	-3.70	2.10
Firm 6	-8.83	-21.99	5.10
Firm 7	-3.65	-8.30	1.60
Firm 8	-5.11	-29.66	2.30
Firm 9	-1.86	-3.70	-0.02
Firm 10	-8.08	-21.08	2.20
Firm 11	-13.38	-24.80	-0.01
Firm 12	-1.18	-4.06	1.70

Notes: Change in sugar is measured in grams per 100g of product.

D Appendix for counterfactual

Table 15: Equilibrium reformulation outcomes by firm (tax = 1c/g per 100g)

Group	Share	Reform rate	Sugar (base)	Sugar (eq.)	ΔSugar
Firm 1	0.0676	0.8623	19.6532	5.7870	-13.8662
Firm 2	0.1351	0.2100	10.9094	9.7580	-1.1514
Firm 3	0.3269	0.4616	14.7443	7.7581	-6.9861
Firm 4	0.0189	0.0000	11.2824	11.2824	0.0000
Firm 5	0.0277	0.0000	12.2576	12.2576	0.0000
Firm 6	0.1054	0.4704	15.2025	7.4214	-7.7811
Firm 7	0.0345	0.0000	13.8506	13.8506	0.0000
Firm 8	0.0460	0.0968	12.4771	9.6010	-2.8761
Firm 9	0.0155	0.0000	10.4098	10.4098	0.0000
Firm 10	0.0608	0.3944	16.0521	9.3536	-6.6984
Firm 11	0.1348	0.8083	19.0753	6.8204	-12.2548
Firm 12	0.0268	0.6323	9.4191	6.8518	-2.5673

Notes: Baseline sugar corresponds to the observed pre-tax equilibrium. Counterfactual sugar levels reflect optimal reformulation under the tax, taking into account fixed reformulation costs. The reformulation rate is the share-weighted fraction of products that adjust their sugar content. Group shares are pre-tax market shares. All sugar levels are share-weighted averages.

Table 16: Equilibrium reformulation outcomes by firm (tax = 10c/g per 100g)

Group	Share	Reform rate	Sugar (base)	Sugar (eq.)	ΔSugar
Firm 1	0.0676	1.0000	19.6532	4.3825	-15.2707
Firm 2	0.1351	0.6468	10.9094	5.9030	-5.0064
Firm 3	0.3269	0.7281	14.7443	5.2664	-9.4779
Firm 4	0.0189	0.4480	11.2824	7.9673	-3.3151
Firm 5	0.0277	0.6288	12.2576	7.7715	-4.4862
Firm 6	0.1054	0.7285	15.2025	5.3633	-9.8391
Firm 7	0.0345	0.5098	13.8506	10.0720	-3.7786
Firm 8	0.0460	0.6379	12.4771	4.7667	-7.7104
Firm 9	0.0155	0.4216	10.4098	8.3018	-2.1080
Firm 10	0.0608	0.8521	16.0521	5.0407	-11.0114
Firm 11	0.1348	0.9550	19.0753	5.8875	-13.1878
Firm 12	0.0268	1.0000	9.4191	5.2709	-4.1482

Notes: Baseline sugar corresponds to the observed pre-tax equilibrium. Counterfactual sugar levels reflect optimal reformulation under the tax, taking into account fixed reformulation costs. The reformulation rate is the share-weighted fraction of products that adjust their sugar content. Group shares are pre-tax market shares. All sugar levels are share-weighted averages.

Table 17: Category outcomes under a linear sugar tax (1c/g per 100g)

Group	Share		Sugar (tons)		Tax rev. (M€)	
	no ref	ref	no ref	ref	no ref	ref
Yaourt	0.453 (2.8)	0.290 (-34.2)	405.20 (0.2)	269.35 (-33.4)	4.05	2.69
Dessert	0.290 (-5.0)	0.311 (1.9)	409.37 (-7.7)	54.01 (-87.8)	4.09	0.54
Compote	0.048 (-7.9)	0.085 (63.7)	75.70 (-10.6)	40.16 (-52.6)	0.76	0.40
FBPS	0.210 (3.6)	0.314 (55.1)	175.65 (-0.2)	154.18 (-12.4)	1.76	1.54

Notes: Shares are group shares within the inside-good market; parentheses report percentage changes relative to the pre-tax equilibrium. Sugar consumption is reported in tons; parentheses show percentage changes relative to the pre-tax equilibrium. Tax revenue is reported in million euros.

Table 18: Firm outcomes under a linear sugar tax (1c/g per 100g)

Group	Share		Sugar (tons)		Tax rev. (M€)	
	no ref	ref	no ref	ref	no ref	ref
Firm 1	0.064 (-4.8)	0.090 (33.0)	91.73 (-7.9)	39.63 (-60.2)	0.92	0.40
Firm 2	0.140 (4.0)	0.121 (-10.6)	109.87 (-0.5)	77.79 (-29.5)	1.10	0.78
Firm 3	0.328 (0.3)	0.320 (-2.2)	351.40 (-2.7)	153.10 (-57.6)	3.51	1.53
Firm 4	0.020 (3.4)	0.017 (-9.9)	16.25 (1.4)	11.54 (-28.0)	0.16	0.12
Firm 5	0.028 (2.0)	0.023 (-16.4)	25.42 (0.0)	17.85 (-29.8)	0.25	0.18
Firm 6	0.104 (-1.1)	0.107 (1.6)	114.78 (-4.4)	47.31 (-60.6)	1.15	0.47
Firm 7	0.034 (-0.1)	0.046 (32.1)	35.09 (-2.0)	27.82 (-22.3)	0.35	0.28
Firm 8	0.047 (2.3)	0.038 (-17.0)	40.88 (-5.0)	22.71 (-47.2)	0.41	0.23
Firm 9	0.016 (4.7)	0.015 (-5.5)	12.39 (2.7)	8.93 (-25.9)	0.12	0.09
Firm 10	0.059 (-2.4)	0.059 (-3.0)	69.43 (-5.0)	30.71 (-58.0)	0.69	0.31
Firm 11	0.130 (-3.9)	0.138 (2.4)	178.95 (-7.2)	67.84 (-64.8)	1.79	0.68
Firm 12	0.029 (6.4)	0.027 (1.4)	19.72 (4.2)	12.47 (-34.1)	0.20	0.12

Notes: Shares are group shares within the inside-good market; parentheses report percentage changes relative to the pre-tax equilibrium. Sugar consumption is reported in tons; parentheses show percentage changes relative to the pre-tax equilibrium. Tax revenue is reported in million euros.

Table 19: Firm outcomes under a linear sugar tax (10c/g per 100g)

Group	Share		Sugar (tons)		Tax rev. (M€)	
	no ref	ref	no ref	ref	no ref	ref
Firm 1	0.046 (-32.5)	0.096 (41.3)	44.08 (-55.7)	27.75 (-72.1)	4.41	2.78
Firm 2	0.199 (47.6)	0.102 (-24.5)	83.73 (-24.2)	44.03 (-60.1)	8.37	4.40
Firm 3	0.318 (-2.6)	0.344 (5.2)	235.45 (-34.8)	83.96 (-76.8)	23.54	8.40
Firm 4	0.022 (13.9)	0.012 (-36.1)	13.48 (-15.9)	5.76 (-64.1)	1.35	0.58
Firm 5	0.028 (0.5)	0.014 (-49.2)	18.75 (-26.2)	9.20 (-63.8)	1.87	0.92
Firm 6	0.087 (-17.2)	0.117 (10.9)	65.89 (-45.1)	28.08 (-76.6)	6.59	2.81
Firm 7	0.028 (-19.0)	0.036 (4.0)	21.53 (-39.9)	17.03 (-52.4)	2.15	1.70
Firm 8	0.067 (45.4)	0.036 (-21.6)	23.86 (-44.6)	10.19 (-76.3)	2.39	1.02
Firm 9	0.020 (28.0)	0.011 (-27.9)	11.43 (-5.2)	5.25 (-56.4)	1.14	0.53
Firm 10	0.043 (-29.1)	0.061 (0.5)	36.00 (-50.8)	14.93 (-79.6)	3.60	1.49
Firm 11	0.099 (-26.6)	0.144 (6.7)	85.76 (-55.5)	37.89 (-80.3)	8.58	3.79
Firm 12	0.043 (61.4)	0.027 (2.3)	22.40 (18.3)	10.54 (-44.3)	2.24	1.05

Notes: Shares are group shares within the inside-good market; parentheses report percentage changes relative to the pre-tax equilibrium. Sugar consumption is reported in tons; parentheses show percentage changes relative to the pre-tax equilibrium. Tax revenue is reported in million euros.

Table 20: Total reformulation cost and revenue share by category

Category	Cost (€) base	Cost (€) +1c	Cost (€) -1c	Rev. (%) base	Rev. (%) +1c	Rev. (%) -1c
Yaourt	-248798	-283305	-209007	-13.60	-15.56	-11.52
Dessert	-267541	-52346	-462546	-11.39	-1.99	-20.84
Compote	-2186334	-1607689	-2871326	-40.98	-29.91	-54.16
FBPS	-760028	-660789	-868663	-43.88	-38.03	-50.29

Notes: Costs are share-weighted category averages of product-level reformulation costs using our estimated market shares. The percentage columns report the corresponding cost as a share of product revenues. The baseline assumes no change in marginal production costs; the alternative columns allow for a differential marginal cost of sugar of ± 1 cent per gram per 100g.

4 - Are Sugar Taxes Well Designed? Empirical evidence from the UK soft drink market

Are Sugar Taxes Well Designed?

Empirical evidence from the UK soft drink market

Maxime Tranchard* Pauline Leveneur† Céline Bonnet‡ Olivier Allais§

Abstract

Policymakers have increasingly implemented nutritional taxes to influence consumer behavior toward healthier diets. While theoretical and empirical literature suggests that taxes should be proportional to the harm caused, most taxes implemented to date, including sugar taxes, feature tiered rather than linear designs. This discrepancy between theory and practice raises the central question: can tiered sugar taxes, under imperfect competition and market power, be welfare-optimal, and if so, how should their structure be designed? In this paper, we evaluate the economic performance of tiered sugar tax designs compared to the theoretically optimal linear tax. Using a welfare maximization framework, we account for externalities from excess sugar consumption, heterogeneous consumption patterns, and firms' strategic pricing behavior. Our findings reveal that tiered tax designs, when incorporating strategic responses from firms, can lead to significantly greater welfare improvements than linear taxation or the implemented Soft Drinks Industry Levy in the UK. Specifically, the optimal design features higher taxes on high-sugar products, prompting firms to reduce prices on lower-sugar alternatives. This adjustment not only enhances public health outcomes but also increases consumer surplus and preserves firm profitability. These results suggest that tiered sugar taxes can serve as welfare-enhancing policy tools when designed to reflect both consumer heterogeneity and market competition.

Keywords: Tax design, Welfare, Sugar tax

JEL classification: D62, H21, H30, I18, Q18

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1 Introduction

In recent decades, policymakers have implemented "sin taxes" primarily to steer consumer choices toward healthier food options by targeting products considered harmful to society and individuals, such as alcohol, tobacco, and soft drinks. The taxes aim to reduce demand, by increasing their prices, and generate revenue for the government. To date, more than 50 countries have implemented taxes on sugar-sweetened beverages (SSBs).[1] However, the design of these taxes varies significantly from one country to another. Most designs implemented by regulators in the last 20 years include some tiered aspect (*e.g.*, France, UK, Spain, Chile). There has not been a sugar tax implemented that is strictly proportional to sugar content,[2] although it was theoretically and empirically shown to be the optimal design (Allcott et al., 2019a; O'Connell and Smith, 2024).

This raises the central question of whether tiered sugar taxes can be welfare-optimal, and if so, how their structure should be designed. Specifically, should the tax apply only to products exceeding certain sugar content levels? How many thresholds should be introduced, where should they be placed, and what should be the corresponding tax rates?

This paper aims to address the questions by analyzing how tax design affect welfare. Specifically, we provide a regulatory framework that accounts for total welfare, measured as consumer surplus, firm profits, tax revenues, and the costs of externalities resulting from excessive sugar consumption. These sugar costs are associated with treating conditions, such as weight gain, type 2 diabetes, and cardiovascular disease (Allcott et al., 2019b; Bhattacharya and Sood, 2011). Including the cost of externalities allows for a comprehensive measure of welfare that accounts for heterogeneous effects on consumers, firms, the government, and health. Three components of the tax design can vary in our framework: the number of thresholds, the location of these thresholds (in grams of sugar per 100 mL), and the tax rate for each threshold (in euro cents per liter). This setting enables us to cover a large variety of tax designs, from taxes proportional to sugar content to tiered tax designs with varying numbers of thresholds.

We focus on the UK non-alcoholic beverages market, where the consumption of soft drinks has emerged as a notable health concern, prompting the government to enact the Soft Drinks Industry Levy (SDIL) tax in 2018.[3] We use rich scanner data obtained from a representative panel

[1] Obesity Evidence Hub (2022) shows a list of implemented policies and different tax designs.

[2] Quasi-linear sugar taxes have been implemented but all have a threshold. For example, taxes at a rate of approximately 0.15 and 0.40 US cents for each gram of sugar over an initial threshold of 4 g/100 mL have been implemented in South Africa and Sri Lanka, respectively.

[3] The Soft Drinks Industry Levy is designed such that beverages with more than 8 grams of sugar per 100 mL are taxed at a high rate, while those containing 5 to 8 grams of sugar per 100 mL face a lower tax rate. Drinks

of UK households in 2017 to estimate the variations in the four welfare components through a structural counterfactual analysis. Our methodology follows the classic counterfactual evaluation in structural industrial organization originating from the seminal papers of Berry et al. (1995, 2004). We rely on the three-step structural econometric strategy approach used by Bonnet and Réquillart (2013). In the first step, we estimate a random coefficient logit model of demand allowing for substitutions both between and within product's segments of non-alcoholic beverages. By identifying both observed and unobserved heterogeneity in household-level preferences, this estimation generates flexible substitution patterns and non-linear demand curvature. This is crucial for accurately assessing welfare effects and understanding how heterogeneity in consumption patterns can justify the optimality of tiered taxation. In the second step, we model the supply side as an oligopoly proposing differentiated products and competing *à la Nash* in a Bertrand game, in the spirit of Berry et al. (1995) and Nevo (2001). We use the estimated demand curves to identify the price-cost margins for each product and the unit costs of production for firms. Finally, the third step consists in simulating counterfactual market equilibria under alternative tax structures, allowing us to evaluate the welfare implications of each design and to identify the welfare-maximizing tiered tax structure.

We apply our methodology to derive optimal tiered tax designs with one and two thresholds. We find that the optimal one-threshold structure exempts products with up to 12 g/100 mL of sugar and imposes a tax of 0.32€/L above this point. Under an optimal two-threshold design, beverages with 7–13 g/100 mL are taxed at 0.01€/L, while those above 13 g/100 mL are taxed at 0.53€/L. Our results show that optimal sugar tax designs which account for firms' strategic pricing lead to significantly greater welfare improvements than the linear tax, or the implemented SDIL. The optimal tax design, through higher taxes on high-sugar products, creates a new equilibrium where firms lower prices on low-sugar alternatives, resulting in improved public health outcomes and consumer surplus. Additionally, firms are able to preserve profits through strategic price adjustments. Policymakers seeking to maximize the welfare impact of sugar taxes should, therefore, design them to reflect both consumer heterogeneity and market competition.

Related empirical work in industrial organization has studied how taxes operate in markets with market power, pass-through, and product differentiation. Bonnet and Réquillart (2013) analyze soda taxes in a vertical supply context and document the role of strategic pricing. They show that the tax is over-shifted onto consumers in France. Cawley et al. (2021) provide empirical evidence

with less than 5 grams of sugar per 100 mL are exempt. Additionally, pure fruit juices and beverages with high milk content are not subject to the tax.

on the pass-through of beverage taxes in practice, documenting under-shifting of the tax in U.S. soft drink markets. In our setting the tax is over-shifted onto consumers. More importantly, we document that firms respond strategically by reducing the prices of untaxed products. Most recently, Conlon et al. (2024) document that sin-good purchases are highly concentrated across households, implying that the incidence of such taxes falls disproportionately on a small share of consumers. Their results underscore the relevance of accounting for heterogeneity in consumption when evaluating the distributional and welfare effects of alternative tax designs, such as the tiered schedules considered in this paper. Dubois et al. (2020) show that the soft drink tiered sugar-based tax implemented in the UK partially failed to target the groups whose behavior the regulator would most like to influence. Our framework, which integrates the social cost of sugar and accounts for heterogeneity in demand, shows that tiered sugar-based taxes can be optimal.

This paper mostly relates to the literature on the externality of sin goods. Recent work such as Allcott et al. (2019a), extend the theoretical results of Pigou (1934) and Diamond (1975) on the optimality of taxation at the marginal cost of the externality to the particular case of "sin taxes". Allcott et al. (2019a) demonstrate that an optimal tax on sugar-sweetened beverages should depend on sugar content, whereas a purely volumetric tax is comparatively less efficient. While they acknowledge that tiered tax schemes better approximate the theoretical ideal of a sugar-based tax, they argue that such designs fail to incentivize consumers to substitute toward lower-sugar beverages within a given tier. We concur with these observations. However, in this paper we show that once both strategic price responses and consumer substitution patterns are taken into account, tiered taxation can generate equilibrium outcomes that are unachievable under a linear tax design, and that are not considered in their analysis. Griffith et al. (2019) discuss the optimal multiple tax system for alcoholic beverages. They show that in the presence of nonlinear externalities, when heavy consumers differ in their consumption patterns, multi-rate taxes are optimally more efficient than single-rate taxes. Our approach does not focus on the functional form implications of the externality, but aims to determine the optimal number of thresholds, their location, and the optimal tax levels, considering the heterogeneity in consumption patterns. We show that when firms behave strategically, multi-tiered tax structures can yield greater efficiency than either a single uniform tax or a fully linear sugar tax, even in settings where externalities scale linearly with sugar content.

Finally, our paper is closely related to O'Connell and Smith (2024). They show that market power interacts with optimal sin taxation and failing to account for market power when designing sin taxes can lead to substantial welfare losses. While their analysis focuses on the optimal level of a single sin tax, our paper examines the optimal structure of sugar taxation. Specifically, we consider tax design with one or multiple sugar-content thresholds and characterize how the number and location of thresholds, as well as the tax rates applied at each, affect welfare. Importantly, we confirm that their core insight regarding the role of market power extends to more general tax structures: market power continues to shape welfare outcomes under tiered and multi-rate tax designs. To the best of our knowledge, this study is the first to derive the optimal tax structure. In contrast, the existing literature (Dubois et al., 2020; Allcott et al., 2019a; Bonnet and Réquillart, 2013) primarily examines ad hoc scenarios or evaluates tax schemes that are already in place. By estimating demand, cost, and pass-through in the non-alcoholic beverage market, we solve for the welfare-optimal shape of a tiered sugar tax. This allows us to determine when tiered tax designs can outperform linear taxes in practice and provide policy-maker insight to design them.

The paper is organized as follows. Section 2 presents describes the UK non-alcoholic beverage market. Section 3 details our methodology. Section 4 provides the main results. Section 5 concludes.

2 The UK soft drink market

2.1 Data

We use representative consumer panel data from Kantar Worldpanel in the United Kingdom for 2017. These data are collected by the market research firm Kantar Worldpanel and are widely used in the economic literature on industrial organization and food purchases in Europe (Dubois et al., 2022). The dataset covers 24,586 households who are representative of the British population, and includes detailed information on household members, such as age, socio-economic status, income class, and weight status.[4] Households record their daily grocery purchases brought into the home by scanning the bar codes of each item. Thus, the data provide high-frequency details on disaggregated products, including product attributes (*e.g.*, brand, size, sugar content), store of purchase, quantity, and price. This analysis focuses on purchases of non-alcoholic beverages for the year 2017.[5]

[4] Additionally, Kantar Worldpanel provides weights to ensure the panel's representativeness and to correct for reporting biases, including periods when households are away from home.

[5] Note that the SDIL had not yet been implemented in the UK. We assume that consumer preferences remain stable over time.

Demographic characteristics. We categorize households according to their composition (number and age of children), obesity status (proportion of obese or overweight adults), and socio-economic class (see Appendix A.1 for details and Table 3 for summary statistics).

Market & product definition. The non-alcoholic beverage market includes sugar-sweetened beverages (SSBs), fruit juices, flavored waters, and milk-based drinks.[6] We define products by crossing information on the firm (*e.g.*, Coca-Cola Company), the brand (*e.g.*, Coca-Cola, Fanta, Sprite, ...), the 11 drinks sub-categories,[7] and other product characteristics (diet or regular characteristic for SSBs; presence of added sugar and flavor for fruit juices). We get a set of 402 distinct varieties of beverages (hereafter, called alternatives) that we consider in our analysis. Additional details are provided in Appendix A.3.

Prices. The price of each alternative is calculated as the weighted ratio of total expenditure in euros over the total quantities in liters of all items belonging to the alternative in the corresponding four-week period. The weights used are Kantar period-specific household sample weights.[8]

2.2 Descriptive statistics

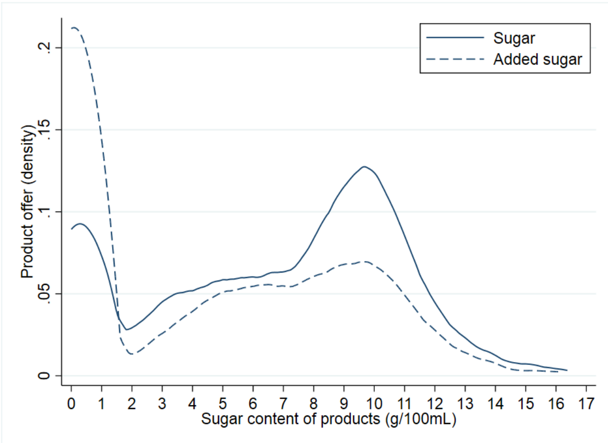
Sugar distribution. The distribution of sugar in the products offered on this market shows two peaks: one for products containing no sugar and one for products containing around 10 grams of sugar per 100ml (Figure 1). 34% of products have less than 5g of sugar per 100 mL, 20% of products have between 5g and 8g of sugar per 100 mL and 46% of products have more than 8g of sugar per 100 mL.

[6]We exclude water and products that are not ready-to-drink (*e.g.* syrup, powdered drinks, cocktail mixers). See Table 4 for a description of the products included in the market.

[7]See Table 6 for descriptive statistics about the different subcategories.

[8]These weights are calculated by Kantar. They ensure that the panel is representative and correct for reporting biases related to periods away from home.

Figure 1: Distribution of the sugar content of the non-alcoholic beverage supply



Notes: This figure plots the distribution of sugar and added sugar content (in grams per 100mL) of the supply of products.

Price. Non-alcoholic beverages have an average price of 0.67 € (Table 5). Products with added sugar are on average less expensive. The most expensive sub-categories are smoothies and energy drinks. There is no unequivocal pattern between price and diet characteristics: depending on the sub-category, diet products can be more or less expensive than regular products (Table 6).

Purchases. Households purchase on average 65 liters per capita per year, among which 44 liters contain added sugar (Table 7). Only 13% of non-alcoholic beverages purchases by households have a sugar content above 8 g per 100 mL. A large proportion of non-alcoholic beverages purchased by households are beverages with a sugar content between 0 and 5 g per 100 mL. 14.5% of Kantar households (7.9% when considering only products containing added sugar) purchase more than the equivalent of one can (330 mL) per day per capita (Figures 6a and 6b). 33.6% of households purchase more than one sugar cube per day per capita (Figure 7).

3 Methodology

3.1 Welfare maximization program

3.1.1 Definition of a tax design

We consider that a tax design is defined by three parameters that the regulator has to pick: i) the number k of thresholds, ii) a vector ρ of dimension k with the location of thresholds (in g/100mL), and iii) a vector ω of dimension k with the tax level for each threshold (in € cents/L). The vector

$\tau(k, \rho, \omega)$ of dimension J contains the resulting tax amount supported by each product j for the tax design defined by (k, ρ, ω).[9]

This definition encompasses all tax designs enacted in various countries and states where the tax rate increases with the sugar content, such as a volumetric tax (by setting the number of thresholds to 1 and the location of the threshold at 0 g/100mL, all products are taxed at a single tax rate, which is equivalent to a volumetric tax) and a linear tax or a tiered tax with proportional tax rate within each tier (by proposing a number of thresholds equal to the number of distinct sugar values in the market).[10]

3.1.2 Theoretical welfare definition

We provide a conceptual framework where a regulator wants to implement a sugar tax. The regulator's objective is to find a design that maximizes total welfare. The welfare encompasses consumers' utility, firms' profits, tax revenue, and the external costs induced by excess sugar consumption, as follows:

$$\text{Welfare} = \text{Consumer surplus} + \text{Firm profit} + \text{Fiscal revenue} - \text{Social cost of sugar} \qquad (1)$$

Consumer surplus. The consumer surplus reflects the benefits consumers derive from purchasing a product. It is measured as the difference between what they are willing to pay and the price they actually pay.[11] Consumer surplus is determined by consumers' preferences for product attributes (*e.g.*, price sensitivity, taste for sugar, or brand loyalty). To quantify these preferences, we will use a demand model (section 3.2.1). Given that the introduction of the tax will likely affect product prices, we need to understand how consumers will react and this depends on their valuation of product attributes. This model will also allow us to estimate price elasticities, which capture how sensitive consumers are to price changes. Both own-price and cross-price elasticities will be required to account for substitution patterns among available alternatives.

[9] We will implement the tax on the same set of products as in the Soft Drink Industry Levy, *i.e.*, all soft drinks except for pure fruit juices and drinks with high milk content.

[10] We simplify the optimization program of the later defined equation 11 by restricting the sugar content to integer values. This approach reduces the dimensionality of the problem, resulting in 17 discrete sugar levels for the products in our market. Figure 5 displays the distribution of the sugar content of products (supply dimension) when discretizing the sugar content.

[11] McFadden (1999) formalized the change in consumer surplus with the "random compensating variation" approach, *i.e.*, the income adjustment required to equalize maximum utility with the tax and without. In other words, how much compensation (in monetary terms) would consumers require for the introduction of the tax to maintain the same level of maximum utility?

Firm profit. A firm's profit is the amount it earns after selling a product, computed as the difference between total revenue and total costs. It depends on the product's price, marginal costs, and the quantity sold. The implementation of a tax will mechanically increase the marginal cost of each product targeted by the tax. In response, firms may decide to adjust their product prices.[12] They might choose to absorb part of the tax, resulting in a price increase that is less than the tax amount, or increase their margins, leading to a price rise that exceeds the tax amount. We will introduce a supply model (section 3.2.2) to capture firms' strategic responses to the tax and calculate the tax pass-through, which indicates how much of the tax is passed on to consumer prices. The new profit will depend on a combination of the adjusted prices and the resulting quantities sold (which in turn will be determined by consumer demand in response to these price changes).

Fiscal revenue. Fiscal revenue refers to the tax income collected by the government. It is primarily driven by demand factors, as it depends on the quantities purchased by consumers. Generating revenue is not the primary intent of the tax, but the funds raised are often allocated to public health programs or other societal benefits.

Social cost of sugar. The social cost of sugar refers to the negative externalities resulting from excess sugar consumption. High levels of sugar intake contribute to various health issues, leading to increased healthcare expenditures for treating sugar-related conditions. This qualifies as an externality because the costs of healthcare are borne by society as a whole, rather than solely by the individuals who consume excessive sugar (Bhattacharya and Sood, 2011; Allcott et al., 2019b). The social cost of sugar is affected by demand factors, as it depends on consumers' choices of products and the quantities they decide to purchase. We obtain the social cost of sugar from the estimate provided by Rischbieth et al. (2020), which is 27€ per kg of sugar. For sensitivity analyses, we consider a lower bound at 10€ per kg of sugar.[13]

3.2 Consumer and firms behaviors

We represent consumers' and firms' behavior using a flexible discrete-choice model of demand for differentiated products and a supply model of oligopolistic competition. The estimation method is in two steps. First, we estimate demand to recover household preferences for non-alcoholic

[12] Firms may also respond by modifying their offer of products (introducing new products or reformulating existing ones). However, we exclude these adjustments from our analysis.

[13] See section 4.2.2 for a discussion on the implications of the choice of the value of the healthcare externality.

beverage purchases. Second, using the estimated consumers' substitution patterns, we model the supply side to determine pricing strategies and alternatives' marginal costs.

3.2.1 Demand model

We consider a flexible discrete-choice model to estimate consumer. Specifically, we use a random coefficient logit model (RCLM) (Berry et al., 1995; McFadden and Train, 2000). In this model, preferences over product characteristics are specified in a flexible manner, as it allows for both observed and unobserved heterogeneity in the slopes of the utility function and allow for flexible consumer substitution and curvature patterns.

Following Revelt and Train (1998), let t denote the index of time ($t = 1, \dots, T$), i the index of the household in the sample ($i = 1, \dots, N$) and j the index of the product inside the choice set of differentiated products ($j = 1, \dots, J_t$) at time t.[14]

Utility. The indirect utility function V_{ijt} for household i buying product j in period t is given by

$$V_{ijt} = \alpha_i p_{jt} + \beta_i X_{jt} + \epsilon_{ijt} \tag{2}$$

where p_{jt} is the price of product j in period t, α_i is the marginal disutility of the price for household i, X_{jt} is a vector of observed product characteristics, β_i is the vector of associated parameters that capture the individual taste for product characteristics, and ϵ_{ijt} is an individual error term.

We assume that parameter α_i varies across households, with some unobserved heterogeneity. Indeed, households can have a different price disutility. It can be rewritten as

$$\alpha_i = \alpha + \pi^\alpha D_i + \sigma \nu_i \tag{3}$$

where α is the mean marginal disutility of the price for all households, π the vector of parameters associated with demographic characteristics D_i (family composition, obesity status and socio-economic class of the household), and ν_i measures the unobserved heterogeneity of the households. We denote $P_\nu(.)$ the distribution of parameter ν.

Additionally, the parameter β_i also depends on household characteristics. It can be rewritten as $\beta_i = \beta + \pi^\beta H_i$ where β includes brand and category fixed effects and π^β are the coefficients

[14] Here t corresponds to a four-week period ($t = 1 \dots, 13$).

associated with a dummy for diet products and the sugar content of fruit juices and SSBs, interacted with household composition characteristic H_i.

We can divide the indirect utility between a mean utility $\delta_{jt} = \alpha p_{jt} + \beta X_{jt} + \xi_{jt}$ where ξ_{jt} captures all unobserved product characteristics and a deviation from this mean utility $\mu_{ijt} = (\sigma\nu_i + \pi^{\alpha} D_i)p_{jt} + \pi^{\beta} H_i X_{jt}$. Hence the indirect utility is given by

$$V_{ijt} = \delta_{jt} + \mu_{ijt} + \epsilon_{ijt} \tag{4}$$

A household is defined by the vector $(\nu_i, D_i, \varepsilon_{i0t}, ..., \varepsilon_{iJt})$.

Outside option. The household can decide not to buy any of the considered products. The utility of this option is normalized to zero. The indirect utility of choosing the outside option is written as $V_{i0t} = \epsilon_{i0t}$.

Market share. We assume that ϵ_{ijt} is independently and identically distributed as an extreme value type I distribution. The conditional probability that household i chooses product j in period t is:

$$s_{ijt}(\nu) = \frac{exp(\delta_{jt} + \mu_{ijt})}{1 + \sum_{k=1}^{J_t} exp(\delta_{kt} + \mu_{ikt})} \tag{5}$$

The market share of product j in period t is (Nevo, 2001):

$$s_{jt} = \int_{A_{jt}} \left(\frac{\exp(\delta_{jt} + \mu_{ijt})}{1 + \sum_{k=1}^{J_t} \exp(\delta_{kt} + \mu_{ikt})} \right) dP_{\nu}(\nu) \tag{6}$$

where A_{jt} is the set of households who have the highest utility for product j in period t and P_ν is the cumulative distribution function of ν which is typically assumed to be standard normal.

Elasticity. The random coefficient logit model generates a flexible pattern of substitutions between products. We can then write the own-price and cross-price elasticities of the market share s_{jt} as:

$$\theta_{jkt} = \frac{\partial s_{jt}}{\partial p_{kt}} \frac{p_{kt}}{s_{jt}} = \begin{cases} \frac{p_{jt}}{s_{jt}} \int \alpha_i s_{ijt}(1 - s_{ijt}) \phi(\nu_i) \mathrm{d}\nu_i & \text{if } j = k \\ -\frac{p_{kt}}{s_{jt}} \int \alpha_i s_{ijt} s_{ikt} \phi(\nu_i) \mathrm{d}\nu_i & \text{otherwise} \end{cases} \tag{7}$$

where $\phi()$ is the density function of $P_\nu(.)$.

Identification. This method relies on the assumption that all product characteristics X_{jt} are independent of the error term ϵ_{ijt}, which can be decomposed into a product-specific error term and an individual error term, $\epsilon_{ijt} = \xi_{jt} + e_{ijt}$. However, there is empirical evidence that unobserved factors included in ξ_{jt} can be correlated with P_{jt}, producing endogeneity problems (Berry, 1994). Such unobserved characteristics can be promotions or advertising, for example. For instance, promoted products are often moved to the front of the shelf, advertised, and sold at a lower price at the same time. Since we do not have any information on advertising expenditure spent by firms, the estimated impact of observed prices on demand will then capture both a true price effect and the effect of unobserved marketing efforts. Prices may also be endogenous if some unobserved characteristics are positively valued by consumers, who are thus ready to pay a premium for them.

We use a control function approach as in Petrin and Train (2010) to account for price endogeneity. We use the price index for glass which is used in the production of non-alcoholic beverages.[15] This instrument is not likely to be correlated with unobserved determinants of demand for non-alcoholic beverages because this industry only represents a very small share of the demand for those inputs. We also have two BLP instruments: the number of competing products offered by other firms within the product category and the total sugar content of competing products within the sugar-based category.[16] The instruments are not weak, the F-test for the joint test of the nullity of the instrumental variables is superior to 10 (Table 8).

Estimation. We estimate the demand model using the simulated maximum likelihood method as in Revelt and Train (1998). Details are provided in section C.2.

3.2.2 Supply model

We consider F firms that compete in prices on the considered market, sell products to consumers and set prices. At each period, the firm maximizes its profit, conditional on the demand parameters and other firms' prices, holding the set of products offered and every other observed and unobserved characteristics as given:

$$\Pi_{ft} = \sum_{j \in G_{ft}} [M_t(p_{jt} - c_{jt})s_{jt}(p_t)] \tag{8}$$

[15] Cost shifters are Office for National Statistics price production indices (https://www.ons.gov.uk/economy/inflationandpriceindices).

[16] The nutritional category refers to the regular or diet characteristic for SSBs and milk-based drinks and to the three levels of sugar content for fruit juices "Low sugar-sweet", "Sugar-sweet" and "High sugar-sweet" (these three sugar levels are based on the terciles of the sugar content distribution and are computed for each category separately).

where G_{ft} is the set of products sold by firm f in period t, M_t is the size of the market in period t, p_{jt} is the price of product j in period t, c_{jt} is the constant marginal cost to produce and sell product j in period t, $s_{jt}(p_t)$ is the market share of product j in period t given the vector of product price p_t.

The equation of prices of products $j \in G_{ft}$ is determined with the first order conditions:

$$s_{jt}(p_t) + \sum_{k \in G_{ft}} [M_t(p_{kt} - c_{kt}) \frac{\partial s_{kt}}{\partial p_{jt}}] = 0 \ \forall j \in G_{ft} \tag{9}$$

We recover estimates of firms' margins $\gamma_{jt} = p_{jt} - c_{jt}$ for each product using the first-order conditions and estimates of the demand model. Using equation (9), the vector of margins $\gamma_t = (p-c)_t$ can be written in matrix notation.

$$\gamma_t = (p-c)_t = -\Big(\sum_{f=1}^{F} I_{ft} S_{pt} I_{ft}\Big)^{-1} \Big(\sum_{f=1}^{F} I_{ft} s_t(p_t)\Big) \tag{10}$$

where I_{ft} is the ownership diagonal matrix $(J_t \times J_t)$ of firm f in period t with elements $I_{ft}(j,j)$ equal to 1 if product j is produced by firm f in period t and zero otherwise, S_{pt} is the matrix $(J_t \times J_t)$ of the first derivatives of all market shares with respect to all prices in period t, *i.e.*, $S_{pt} = (\frac{\partial s_{kt}}{\partial p_{jt}})_{(j=1,\ldots,J_t;k=1,\ldots,J_t)}$ and $s_t(p_t)$ is the vector of product market shares in period t. We then derive estimates of marginal costs, given observed prices.

3.2.3 Results of the model

We present the main results of the demand model, price elasticities and firms' margins in this section.

Demand estimates. The estimates from the random coefficient logit model are presented in Table 9. Price has a significant and negative impact on utility for all populations. Price unobserved heterogeneity is also substantial. Households from the poor and average classes are more sensitive to price than rich households. Households prefer diet products to regular products. Households have high brand loyalty and the choice of the brand prevails over the taste for sugar (brand fixed effect estimates, not displayed in the Table, ranging from 0.05 to 14.2 in absolute terms, are large compared to the other preferences parameter estimates).

Elasticities and demographic characteristics. When comparing the elasticities by household characteristics, we found that the demand for non-alcoholic beverages is the most elastic for households with 7-16 years old children, households with all adults overweight or obese and poor households (Table 10). We find that the sweeter the non-alcoholic beverage, the more elastic the demand for products; and it is also interesting to note that the elasticities of non-alcoholic beverages with a sugar content above 10 g per 100 mL remain almost constant (Table 11). The results are valid for all household characteristics considered. Furthermore, all previous results in Table 10 are still valid for all sugar content considered.

Supply. The estimated margins and own-price elasticities are presented by firm in Table 12 and by sugar content in Table 13. Margins, expressed as a percentage of price, vary from 8.7% to 28.4% for national brands and are higher for private labels (52.3%). Own-price elasticities, range from -3.5 to -12.5 for national brands and are quite low for private labels (-4.4). Firms with less price-sensitive demand (lower absolute elasticity) are able to maintain higher profit margins. The margins are quite similar across all sugar categories, ranging from 17.7% to 22.5%, except for the category of sugar-sweetened products with less than 5 grams of sugar, which has a significantly higher margin of 49.9%.

3.3 Counterfactual simulations

We now describe the methodology to obtain the optimal parameters of a tax design to enhance total welfare.

3.3.1 Objective function

Total welfare. The regulator wants to maximize the theoretical welfare defined in equation 1. In practice, maximizing the theoretical welfare is equivalent to maximizing the change in welfare induced by the implementation of a tax.[17,18]

For a given number of thresholds k, we look for the optimal combination of thresholds location $\rho^\star$ and tax rates $\omega^\star$ that maximize the increase in total welfare. In other words, for any fixed $k \in \mathbb{N}$,

[17] Indeed, the observed welfare is a constant so it is equivalent to maximizing the difference between the welfare post-tax and the observed welfare.

[18] Note that for computational reasons, we only run the counterfactual simulations for a fixed period of 4 weeks. We picked the first period and we will perform robustness checks on other periods.

the optimal tax design $\tau^{\star}(k, \rho^{\star}, \omega^{\star})$ is obtained from the following maximization program.

$$(\rho^{\star}, \omega^{\star}) = \underset{(\rho,\omega)}{\text{arg max}}\ \Delta W_t(k, \rho, \omega) \tag{11}$$

where

$$\Delta W_t(k, \rho, \omega) = \Delta W_t^C(k, \rho, \omega) + \Delta W_t^{\pi}(k, \rho, \omega) + \Delta W_t^{\text{tax}}(k, \rho, \omega) + \Delta W_t^{SC}(k, \rho, \omega) \tag{12}$$

Welfare changes arise from potential price adjustments, driven by shifts in the marginal cost of products following the introduction of a tax. These new prices following the implementation of the tax (k, ρ, ω) are denoted $p_t^{post(k,\rho,\omega)}$. The method used to calculate the new price equilibrium is detailed in section 3.3.2.

Welfare components. The change in total welfare (equation 12) is the sum of the changes in consumer surplus (equation 13), firm profit (equation 14), fiscal revenue (equation 15) and externalities after the implementation of a tax (equation 16).[19]

Consumer surplus. Following McFadden (1981) and Small and Rosen (1981), we compute the change in consumer surplus as:

$$\Delta W_t^C(k, \rho, \omega) = M_t \int \frac{ln[\sum_{j=0}^{J} exp(V_{ijt}(p_t^{post(k,\rho,\omega)}))] - ln[\sum_{j=0}^{J} exp(V_{ijt}(p_t))]}{\alpha_i} \mathrm{d}P_{\nu}(\nu)\mathrm{d}P_D(D) \tag{13}$$

where $V_{ijt}(p_t^{post(k,\rho,\omega)})$ is the utility where the consumer price $p_t^{post(k,\rho,\omega)}$ is adjusted by the introduction of the tax (k, ρ, ω).

Firm profit. The change in firms' profit is defined by:

$$\Delta W_t^{\pi}(k, \rho, \omega) = M_t \Big(\sum_{f=1}^{F} (\sum_{j \in G_{ft}} \gamma_{jt}(p_t^{post(k,\rho,\omega)}) s_{jt}(p_t^{post(k,\rho,\omega)})) - \sum_{f=1}^{F} (\sum_{j \in G_{ft}} \gamma_{jt}(p_t) s_{jt}(p_t)) \Big) \tag{14}$$

where $s_{jt}(p_t^{post(k,\rho,\omega)})$ and $\gamma_{jt}(p_t^{post(k,\rho,\omega)})$ are the market shares and margins respectively of product j after the implementation of the tax (k, ρ, ω), $s_{jt}(p_t)$ and $\gamma_{jt}(p_t)$ are the estimated pre-tax market shares and margins of product j.

[19] We give equal weights to each welfare component.

Tax revenue. The amount raised by the implementation of the sugar tax is defined as follows:[20]

$$\Delta W_t^{\text{tax}}(k,\rho,\omega) = M_t\Big(\sum_{j=0}^{J} \tau_j \cdot s_{jt}(p_t^{post(k,\rho,\omega)})\Big) \tag{15}$$

where τ_j is the tax level of product j.

Externality. The change in the externality is computed as:

$$\Delta W_t^{SC}(k,\rho,\omega) = M_t\Big(\sum_{j=0}^{J} \kappa \cdot (\lambda_{jt} \cdot s_{jt}(p_t^{post(k,\rho,\omega)}) - \lambda_{jt} \cdot s_{jt}(p_t))\Big) \tag{16}$$

where κ is the social cost of sugar (in euros per kilogram) and λ_{jt} is the quantity of sugar per kilogram of product j.

3.3.2 New price equilibrium

The introduction of a tax will change the marginal cost of each product, which will lead to a potential change in their price. From the firms' profit maximization program defined in section 3.2.2, we estimate a vector of marginal costs that we denote $\hat{c}_t = p_t - \gamma_t = (\hat{c}_{1t}, \ldots, \hat{c}_{j_t}, \ldots, \hat{c}_{J_t})$. For any tax design (k,ρ,ω), we retrieve a new cost vector $c_t^{(k,\rho,\omega)}$ by adding the tax cost to the estimated marginal cost ($c_t^{(k,\rho,\omega)} = \hat{c}_t + \tau$).
We then find the new equilibrium prices vector in period t, denoted $p_t^{post(k,\rho,\omega)} = (p_{1t}^{post(k,\rho,\omega)}, \ldots, p_{J_t}^{post(k,\rho,\omega)})$, using the following optimizing program:

$$\min_{\{p_{jt}^{post(k,\rho,\omega)}\}_{j=1,\ldots,J_t}} || \underbrace{p_t^{post(k,\rho,\omega)} - \gamma(p_t^{post(k,\rho,\omega)})}_{\hat{c}_t(p_t^{post(k,\rho,\omega)})} - c_t^{(k,\rho,\omega)} || \tag{17}$$

which minimizes the difference between the marginal cost derived from the new price equilibrium and the marginal cost estimated from the model and shocked by the tax.

[20] The tax is not subject to VAT in the UK so we only consider the amount raised through the implementation of the sin tax.

4 Results

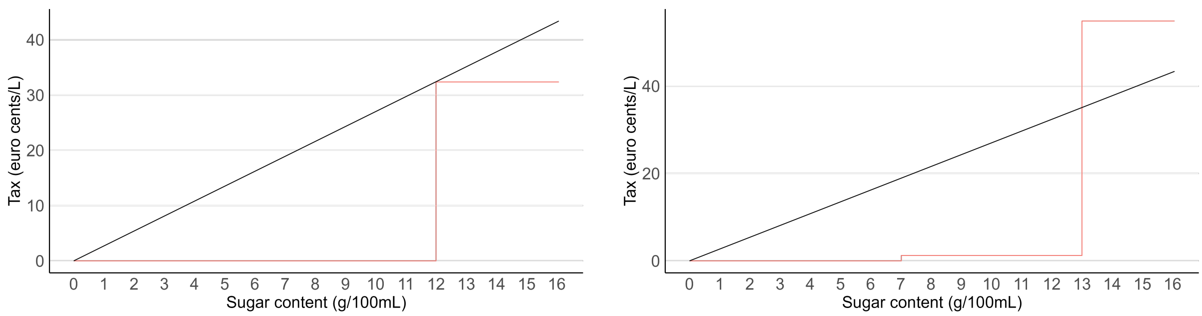
In this section, we provide evidence on the optimal design of tiered taxes. We derive and compare optimal designs for one-tiered and two-tiered taxes against linear taxes and the SDIL, accounting for firms' strategic price reactions.[21] Furthermore, we investigate the impact of accounting for firms' strategic price reaction in designing sugar taxes. Lastly, we conduct robustness checks.

4.1 Optimal design of sugar taxes

Description of the designs. We obtain the optimal taxation scheme as a result of the regulator's maximization program (Figure 2). In the one-threshold design, products with sugar content exceeding 12 grams per 100 mL are taxed at a flat rate of 0.32 € per liter, while those below this threshold are exempt from the tax. In the two-threshold design, products with sugar content between 7 and 13 grams per 100 mL are taxed at 0.01 € per liter, whereas those with more than 13 grams per 100 mL face a higher tax of 0.53 € per liter.

Figure 2: Comparison of tiered tax designs

(a) One tier $(k = 1)$ (b) Two tiers $(k = 2)$



Notes: The two figures plot the optimal tiered tax design with one and two thresholds (in red) where we account for firms' strategic behavior. The optimal tax rates and location of thresholds are obtained empirically from the maximization program presented in section 3.3.1. The black line corresponds to the theoretical optimal linear tax design where the tax rate is set at the value of the social cost (27 euros per kg of sugar). The y-axis plots the tax rate (in euros per L) and the x-axis displays the sugar content of products (in grams per 100 mL).

Welfare decomposition. To better understand the efficiency of these designs, we decompose the welfare effects into their key components: firms' profit, consumer surplus, tax revenue, and externalities. Table 1 presents the results of this decomposition, comparing the welfare effects of

[21]We limit the regulator's welfare maximization program to designs with one or two thresholds for the sake of computation time. This limitation does not impede our methodology to enlighten tiered designs that perform largely better than the linear tax.

the one-threshold and two-threshold optimal designs with a linear tax design, which is identified as the optimal design in the theoretical literature.

The linear tax design leads to a total welfare gain of 7.91 million €, largely driven by a reduction in externalities (11.65 million €) and an increase in tax revenue (5.80 million €). However, the significant decrease in consumer surplus (-8.91 million €) and a reduction in firm profits (-0.63 million €) offset these gains. In contrast, the one-threshold optimal tax design results in a much larger welfare gain of 20.53 million €. This is primarily driven by an increase in consumer surplus (+11.61 million €) and a reduction in externalities (6.73 million €). Firm profits also see a positive increase (+2.15 million €), while tax revenue changes only marginally (+0.04 million €).

The two-threshold design yields the highest total welfare improvement, amounting to 21.15 million €. This design achieves an externality reduction of 7.48 million € while significantly increasing consumer surplus (+11.19 million €). Firm profits also rise by 2.16 million €, and tax revenue increases slightly by 0.32 million €. These results indicate that the two-threshold design outperforms both the one-threshold and linear designs in terms of total welfare and consumer benefits, while still achieving substantial externality reduction.

Table 1: Welfare variation decomposition

	Change (millions euros) in				
Counterfactual	**Total welfare** ΔW_t	**Firm profit** ΔW_t^{π}	**Consumer surplus** ΔW_t^{C}	**Tax revenue** ΔW_t^{tax}	**Externality** ΔW_t^{SC}
Linear design					
27€per kg of sugar	7.91	-0.63	-8.91	5.80	11.65
Tiered design					
1 threshold	**20.53**	2.15	11.61	0.04	6.73
2 thresholds	**21.15**	2.16	11.19	0.32	7.48
SDIL	7.80	-0.65	-6.70	4.02	11.13

Notes: This table plots the changes in total welfare (column 2) and in the different components of total welfare: firms' profit (column 3), consumer surplus (column 4), tax revenue (column 5) and externality (column 6). The linear and SDIL designs are already existing. The tiered designs with 1 and 2 thresholds are empirically derived from the procedure detailed in section 3.3.1 when we take into account firms' strategic behavior.

Mechanisms. Figure 3a illustrates the strategic price adjustments made by firms following the implementation of the two-threshold optimal design. For products with sugar content exceeding 13 grams per 100 mL, firms choose to increase prices by more than the imposed tax. This pricing behavior results in a nearly 100% loss in market share for these high-sugar products (Figure 3b). In this context, the optimal design operates as a corner solution, where the tax at the second threshold is set high enough to mostly drive high-sugar products out of the market.

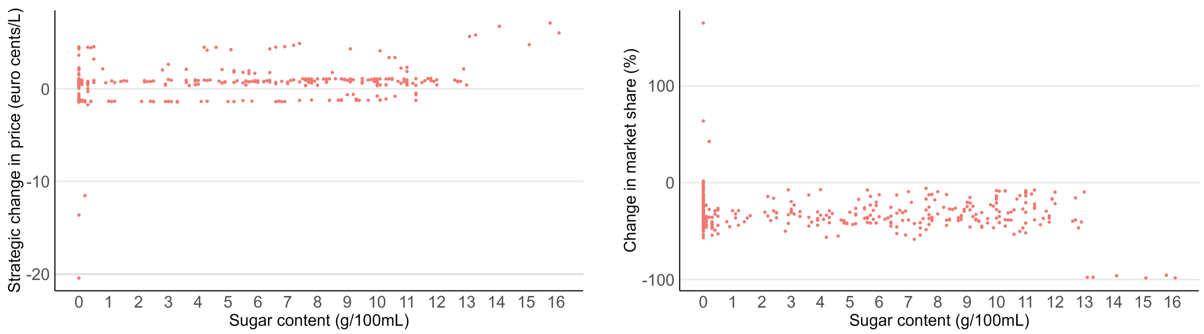
For other products, we do not observe any clear differences between those with 7 to 13 grams of sugar per 100 mL, which are taxed at 1 cents, and those with less than 7 grams, which are exempt from the tax. Interestingly, some products without sugar see an important decrease in price.

By lowering prices on low-sugar products, firms make these healthier options more accessible to consumers, thereby improving consumer surplus. Importantly, this strategic price reduction does not come at the expense of firm profits for these products. Rather, as shown in Figures 3a and 3b, firms' adjustments increase the market share of low-sugar products.

Figure 3: Effects on prices and market shares

(a) Strategical change in price

(b) Change in market share



Notes: These figures plot the change in price and market share along the sugar content distribution following the implementation of the tax. The y-axis plots the price change (in euro cents per L, after removing the tax amount) in Figure (a) and the market share change (in %) in Figure (b). The x-axis displays the sugar content of products (in grams per 100 mL). The difference in price is deflated from the value of the tax, in order to highlight how firms strategically adapts.

4.2 Validity of our methodology

We propose a design that outperforms the linear design, which is theoretically considered the best, as it taxes each product according to its marginal externality. This surprising result arises from the fact that the theoretical optimal linear design does not account for the competitive environment, which leads to a new equilibrium. In the next section, we will study the role of incorporating strategic pricing into the regulator's maximization program. We will also emphasize the importance of carefully estimating the social cost of sugar in designing taxes.

4.2.1 Comparison of strategic vs. non-strategic tax designs

The comparison between tax designs with and without firms' strategic responses illustrates the critical importance of accounting for firm behavior in achieving optimal welfare outcomes.

Description of the design. We derive the optimal designs for one-tiered and two-tiered taxes under the assumption that firms fully pass on the tax to consumers. In the one-threshold design, only products with sugar content above 4 grams per 100 mL are taxed at a flat rate of 0.21 €. In the two-threshold design, products with less than 2 grams of sugar per 100 mL are exempt from the tax, products with sugar content between 2 and 7 grams per 100 mL are taxed at 0.12 €, and products with more than 7 grams of sugar per 100 mL are taxed at 0.26 € (Figure 14). The tax levels are significantly lower and more in line with those implemented in practice when strategic firm behavior is not taken into account.

Welfare decomposition. In the absence of strategic pricing responses, where firms fully pass the tax onto consumers, the welfare gains from taxation are notably smaller (Table 2). Without strategic adjustments, the tax is less effective in changing consumption patterns, as consumers are not sufficiently incentivized to shift towards lower-sugar products in response to price changes. It is also important to note that without firms' strategic responses, the linear design performs better than the optimal tiered designs with one or two thresholds.

In contrast, when firms react strategically by adjusting their prices, several important dynamics arise. First, consumer surplus increases as firms reduce prices on low-sugar products, which would not occur in a non-strategic environment. This price reduction makes healthier products more attractive to consumers, thereby enhancing welfare in a way that would be unattainable under non-strategic assumptions. Second, despite the tax, firms can maintain or even improve profits by decreasing the prices of low-sugar products, compensating for any potential losses in high-sugar product sales. Firms that strategically adjust their pricing are able to sustain profits through increased demand for lower-sugar alternatives. Thus, incorporating strategic firm behavior into the design of sugar taxes is key to finding optimal design.

Table 2: Welfare variation decomposition without firms' strategic behavior

Counterfactual	Change (millions euros) in Total welfare ΔW_t	 Firm profit ΔW_t^{π}	 Consumer surplus ΔW_t^{C}	 Tax revenue ΔW_t^{tax}	 Externality ΔW_t^{SC}
Linear design					
27€per kg of sugar	6.33	-0.34	-10.78	6.09	11.37
Tiered design					
1 threshold	5.77	-0.35	-9.29	4.99	10.43
2 thresholds	6.14	-0.37	-9.84	5.44	10.91
SDIL	5.79	-0.26	-8.94	4.26	10.73

Notes: This table plots the changes in total welfare (column 2) and in the different components of total welfare, assuming no firms' price strategic behavior: firms' profit (column 3), consumer surplus (column 4), tax revenue (column 5) and externality (column 6). The tiered designs with 1 and 2 thresholds are empirically derived from the procedure detailed in section 3.3.1 when we disregard firms' strategic behavior.

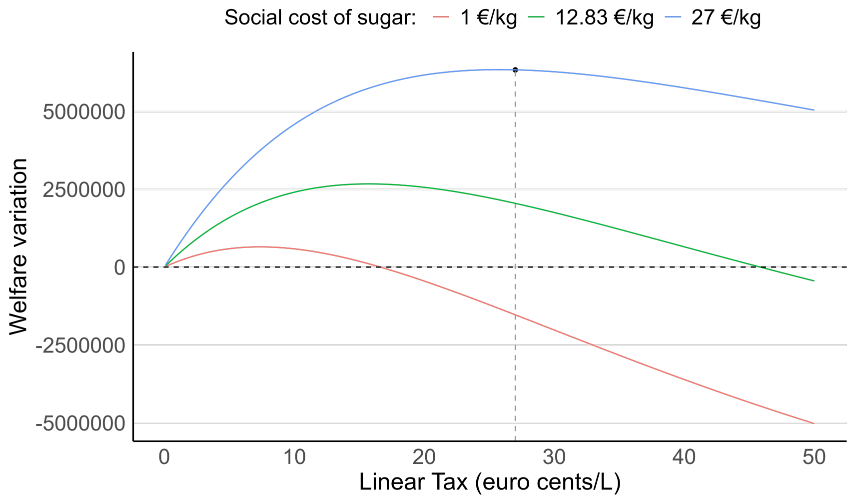
4.2.2 Discussion on the value of the social cost of sugar

In this subsection, we examine how our calibration of social costs influences the results. We consider three levels of social costs: 1 euros per kg (lower bound), 12.83 euros per kg and 27 euros per kg.[22]

We begin by comparing the welfare variations associated with our estimates in a linear design. As the social cost of sugar rises from 1 to 27 € per kg, the highest welfare gain also increases from nearly 0.7 to a bit more than 6.3 million € (Figure 4). Additionally, we observe that the range of tax rates resulting in welfare improvements significantly expands with an increase in the social cost of sugar. While only tax rates below 20 € cents lead to welfare improvements with a social cost of 1 euros per kg, this range extends to tax rates up to 40 € cents with a social cost of 12.83 € per kg and remain high in the positive value at 50 cents for an estimated social cost at 27 € per kg. Therefore, the magnitude of the externality cost plays a critical role in determining the optimal design and the potential necessity for intervention.

[22]We disregard here firms' strategic behaviors because we focus on the opportunity of tax implementation and not the optimal designs.

Figure 4: Welfare change in linear taxation with tax rate



Notes: This figure plots the variation in welfare that would result from implementing a linear tax according to different tax rates for several values of the social cost of sugar. The y-axis plots the variation in welfare (in millions of euros) and the x-axis displays the different tax rates for a linear tax (in euros cents per liter). The red line corresponds to the social cost estimated at 1 euros per kg, the blue line corresponds to the social cost estimated at 27 euros per kg, whereas the green line correspond to our second estimates of the social cost of sugar at 12.83 euros per kg

4.3 Comparison with the SDIL

The Soft Drinks Industry Levy. In 2018, the United Kingdom took a significant step in addressing the public health concerns surrounding excessive sugar consumption by implementing the Soft Drinks Industry Levy on sugar-sweetened beverages. This tax was part of the government's broader strategy to tackle rising rates of obesity and related health issues, particularly among children. The design of the tax is characterized by a two-tiered approach based on the total sugar content of products. Beverages with sugar content above 8 grams of sugar per 100 mL face a high tax rate (24 pounds per liter), while those with a sugar content between 5 to 8 grams per 100 mL are subject to a lower rate (18 pounds per liter) and those with less than 5 grams of sugar per 100 mL are exempt from the tax (Figure 8).[23] Pure fruit juices and drinks with high milk content are exempt from the tax.

Assessment. We now assess the welfare effects of the implemented SDIL. The SDIL, when evaluated under the assumption that firms do not engage in strategic pricing, results in a welfare gain of 4.10 million €, a result that is close to the 4.51 million € gain associated with a linear tax design (Table 2). However, when strategic responses from firms are considered, the welfare

[23] The following conversion rate is used: 1 pound = 1.15 euros.

performance of the SDIL improves slightly, closing the gap with the linear tax design. The SDIL achieves a welfare gain of 5.63 million €, while the linear tax results in a gain of 5.64 million € (Table 14).

Although the SDIL performs reasonably well compared to the linear tax, it lags behind the welfare gains achieved by the two optimal tax designs in the presence of strategic pricing. The SDIL's structure, while effective at raising tax revenue and moderately shifting consumption patterns, could be improved by better targeting higher-sugar products. These results suggest that while the SDIL provides a good baseline for sugar taxation, more optimal designs can be achieved by incorporating strategic pricing behavior to reach better welfare outcomes. Indeed, the choice of threshold locations has little impact on welfare when not considering firms' price reactions, unlike in the more realistic case where firms respond to prices (Figure 15).

5 Conclusion

Many sugar taxes have been implemented in the form of tiered taxes, contradicting what is advocated by theoretical and empirical literature. In this paper, we investigate how tiered tax designs would perform compared to the theoretical optimal linear tax. We introduce a comprehensive framework for evaluating the effect of tax designs on total welfare, accounting for the externality generated by excess sugar consumption, the heterogeneity in patterns of consumption and firms' strategic behavior. Our analysis shows that optimal sugar tax designs which account for firms' strategic pricing lead to significantly greater welfare improvements than non-strategic designs or the implemented SDIL. The optimal tax design, by imposing higher taxes on high-sugar products and creating a new equilibrium where firms reduce prices on low-sugar products, results in both better public health outcomes and higher consumer surplus. Additionally, firms are able to preserve profits through strategic price adjustments. Policymakers seeking to maximize the welfare impact of sugar taxes should, therefore, carefully consider firms' strategic responses when designing their taxation policies.

In future work, we aim to extend this analysis in several ways. First, we will explore the heterogeneous effects of sugar taxes across demographics, allowing for a more nuanced understanding of the policy's impact. We also plan to investigate the heterogeneous effects across firms to better capture industry-level responses to taxation. Additionally, we will replicate this analysis in other European countries, such as France and Spain, which have also implemented tiered taxes on soft drinks. Lastly, we intend to assess whether our findings can be generalized to other markets, such as the biscuit industry, which remains untaxed despite its considerable contribution to sugar consumption.

References

ALLCOTT, H., B. B. LOCKWOOD, AND D. TAUBINSKY (2019a): "Regressive Sin Taxes, with an Application to the Optimal Soda Tax," *The Quarterly Journal of Economics*, 134, 1557–1626.

——— (2019b): "Should We Tax Sugar-Sweetened Beverages? An Overview of Theory and Evidence," *Journal of Economic Perspectives*, 33, 202–227.

BERRY, S. (1994): "Estimating discrete-choice models of product differentiation," *RAND Journal of Economics*, 25, 242–262.

BERRY, S., J. LEVINSOHN, AND A. PAKES (1995): "Automobile Prices in Market Equilibrium," *Econometrica*, 63, 841–890.

——— (2004): "Differentiated products demand systems from a combination of micro and macro data: The new car market," *Journal of political Economy*, 112, 68–105.

BHATTACHARYA, J. AND N. SOOD (2011): "Who Pays for Obesity?" *Journal of Economic Perspectives*, 2, 139–158.

BONNET, C. AND V. RÉQUILLART (2013): "Tax incidence with strategic firms in the soft drink market," *Journal of Public Economics*, 77–88.

CAWLEY, J., D. FRISVOLD, D. JONES, AND C. LENSING (2021): "The pass-through of a tax on sugar-sweetened beverages in Boulder, Colorado," *American Journal of Agricultural Economics*, 103, 987–1005.

CONLON, C., N. RAO, AND Y. WANG (2024): "Who pays sin taxes? understanding the overlapping burdens of corrective taxes," *Review of Economics and Statistics*, 106, 1719–1729.

DIAMOND, P. A. (1975): "A many-person Ramsey tax rule," *Journal of Public Economics*, 4, 335–342.

DUBOIS, P., R. GRIFFITH, AND M. O'CONNELL (2020): "How well targeted are soda taxes?" *American Economic Review*, 110, 3661–3704.

——— (2022): "The Use of Scanner Data for Economics Research," *Annual Review of Economics*, 14, 723–745.

Griffith, R., M. O'Connell, and K. Smith (2019): "Tax design in the alcohol market," *Journal of Public Economics*, 172, 20–35.

Heiss, F. and V. Winschel (2008): "Likelihood approximation by numerical integration on sparse grids," *Journal of Econometrics*, 144, 62–80.

McFadden, D. (1981): "Econometric models of probabilistic choice," *Structural analysis of discrete data with econometric applications*, 198272.

——— (1999): "Computing Willingness-to-Pay in Random Utility Models," in *Trade, Theory and Econometrics: Essays in Honor of John S. Chipman*, ed. by J. Melvin, J. Moore, and R. Riezman, London: Routledge, 253–274.

McFadden, D. and K. Train (2000): "Mixed MNL models for discrete response," *Journal of Applied Econometrics*, 15, 447–470.

Nevo, A. (2001): "Measuring market power in the ready-to-eat cereal industry," *Econometrica*, 69, 307–342.

Obesity Evidence Hub (2022): "Countries that have taxes on sugar-sweetened beverages (SSBs)," Tech. rep., available online at https://www.obesityevidencehub.org.au/collections/prevention/countries-that-have-implemented-taxes-on-sugar-sweetened-beverages-ssbs, accessed March, 2024.

O'Connell, M. and K. Smith (2024): "Optimal Sin Taxation and Market Power," *American Economic Journal: Applied Economics*, 34—-70.

Petrin, A. and K. Train (2010): "A Control Function Approach to Endogeneity in Consumer Choice Models," *Journal of Marketing Research*, 47, 3–13.

Pigou, A. (1934): *The economics of welfare*, Macmillan, 4th ed.

Revelt, D. and K. Train (1998): "Mixed Logit with Repeated Choices: Households' Choices of Appliance Efficiency Level," *Review of Economics and Statistics*, 80, 647–657.

Rischbieth, A., G. Serafeim, and K. Trinh (2020): "Accounting for product impact in the consumer-packaged foods industry," *Harvard Business School Working Paper*, 21-051.

Small, K. A. and H. S. Rosen (1981): "Applied welfare economics with discrete choice models," *Econometrica*, 105–130.

Appendix

A Data

A.1 Demographics

Definition of obese and overweight. Adults with BMI, defined as weight (in kg) divided by the square of the height (in m), above 30 are considered as obese, and individuals with BMI ranging between 25 and 30 are considered as overweight. The final dataset contains only households with no missing value on adults' BMI in the analysis. We exclude 6,353 households (21%).

Definition of socio-economic class. It is based on the socio-professional categories.

Table 3: Household characteristics in Kantar panel

	N	%
Household composition		
Without children	16,093	65
With children below 6 years old	2,960	12
With children 7-16 years old	3,668	15
With children both below 6 and 7-16 years old	1,865	8
Obesity status		
No overweight or obese adults	5,972	24
Some overweight or obese adults	8,184	33
All overweight or obese adults	10,430	43
Socio-economic class		
Rich	5,262	21
Average	13,912	57
Poor	5,412	22
All	**24,586**	

Notes: This table shows the characteristics of households in the panel according to their family composition, obesity status and socio-economic class.

A.2 Market definition

Table 4: Summary of the market definition

Sub-categories	**Included?**
Sugar-sweetened beverage	yes
(cola, iced tea, lemonade, fruit-flavored drink, sport and energy drink, tonic, other)	
Fruit juice	yes
(pure fruit juice, nectar, smoothie, fruit juice with milk)	
Flavoured water	yes
Milk-based drink	yes
Water	no
Syrup, powdered drink, cocktail mixer	no

Notes: This table summarizes which products are included in our analysis.

A.3 Products

A.3.1 Details on the definition of products

Sub-categories. The sugar-sweetened beverage category is made up of colas, iced tea, fruit-flavored drinks, flavored water, tonic water, lemonade, energy drinks, and other SSBs. The fruit juice category includes nectar, fruit juice made from concentrate, pure fruit juices and smoothies. Milk-based drinks are made up of flavored milk.

Added sugar. The dataset flags products containing added sugar.

Additional details on the product definition. Beverages of a given sub-category with a small purchase occurrence are aggregated either with similar products of the same firm or in a hypothetical product defined as other firm/other brand of the sub-category. Additionally, private labels are aggregated into one firm and one brand.

A.3.2 Market structure

Table 5 presents a summary of the market structure with the definition of alternatives. The UK market is characterized by a high number of national brands, resulting in a high number of non-alcoholic beverage alternatives. Mean prices in Table 5 are calculated as the weighted ratio of total expenditure in euros over the total quantities in liters of all drinks purchased.

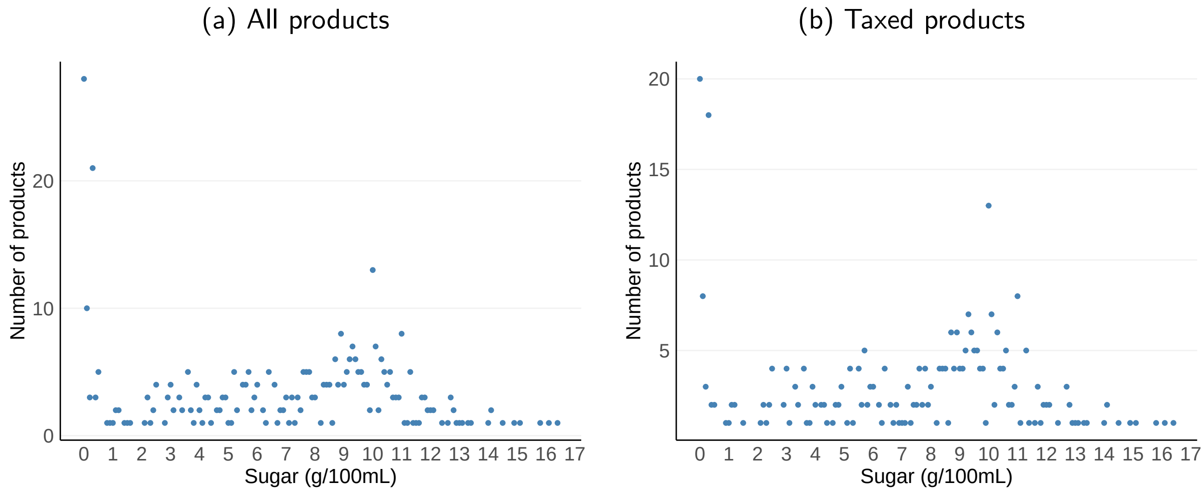
Table 5: Market structure

Number of firms	78
Number of national brands	151
Number of sub-categories	11
Number of alternatives	402
Number of observations	1,319,069
Mean price (per liter)	0.78 €
Mean price of non-alcoholic beverages with added sugar (per liter)	0.67 €

Notes: This table provides some descriptive statistics about the market structure in our analysis. The number of observations refers to the number of Kantar references purchased per household, date and store. If on a given date and in a given store, a household buys 3 bottles of 1L of Coke, this is an observation, but if a household buys 2 bottles of 1L of Coke and 1 bottle of 1.5L, this is 2 observations.

A.3.3 Distribution of the sugar content

Figure 5: Distribution of the sugar content of the non-alcoholic beverage supply



Notes: These figures show the distribution of sugar content for all products and for only taxed products (supply dimension). Specifically, they display the number of products every 0.1 grams of sugar per 100mL.

A.3.4 Descriptive statistics

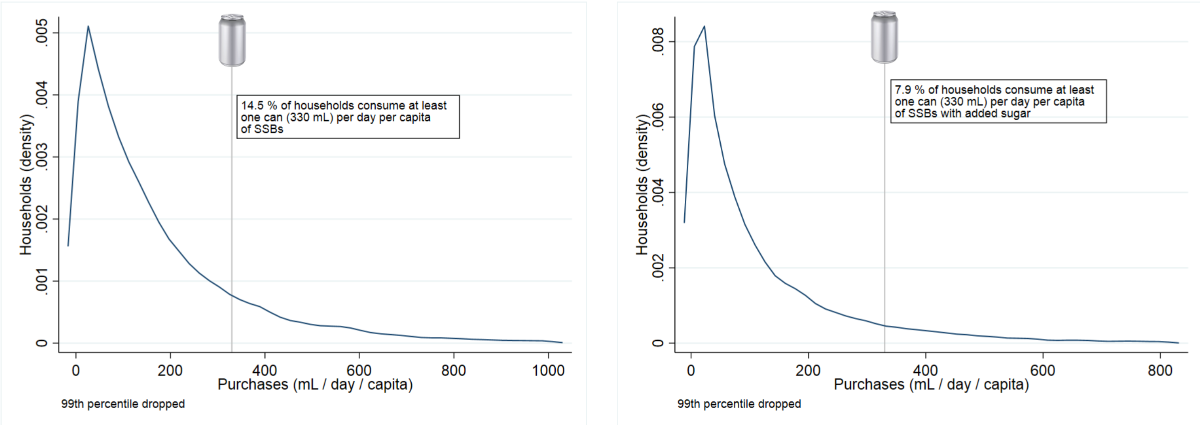
Table 6: Average market share, price and sugar content of each sub-category

	Share %	Price €/l	Sugar g/100ml
Sugar-sweetened beverages			
Colas	**26.8**	**0.8 (1.0)**	**3.1 (5.0)**
Regular	29.6	0.8 (1.3)	10.3 (1.5)
Diet	70.4	0.8 (0.4)	0.0 (0.0)
Fruit-flavoured drinks	**12.2**	**0.9 (0.8)**	**3.4 (3.8)**
Regular	73.2	1.2 (0.6)	6.1 (3.2)
Diet	26.8	0.5 (1.1)	0.4 (2.3)
Flavoured waters	**22.2**	**0.4 (0.7)**	**0.3 (1.3)**
Regular	1.4	0.8 (1.1)	4.7 (1.6)
Diet	98.6	0.4 (0.6)	0.2 (0.1)
Tonic waters	**3.1**	**0.9 (1.2)**	**1.8 (2.7)**
Regular	45.8	1.2 (1.3)	4.3 (1.8)
Diet	54.2	0.7 (1.3)	0.3 (1.4)
Lemonades	**5.0**	**0.4 (1.1)**	**1.8 (4.2)**
Regular	40.0	0.5 (1.3)	4.9 (3.3)
Diet	60.0	0.3 (0.3)	0.1 (0.1)
Energy drinks	**5.8**	**1.4 (0.9)**	**5.4 (5.2)**
Regular	74.5	1.4 (0.9)	7.0 (3.1)
Diet	25.5	1.5 (1.0)	0.2 (0.2)
Other SSBs	**3.5**	**0.7 (1.1)**	**3.6 (4.4)**
Regular	46.7	1.0 (1.1)	9.4 (2.5)
Diet	53.3	0.6 (1.2)	0.1 (1.6)
Fruit juices			
Nectars	**5.6**	**1.1 (0.6)**	**7.2 (3.5)**
Regular	70.9	1.1 (0.6)	7.2 (3.5)
Diet (no added sugar)	29.1	0.9 (0.4)	2.5 (2.2)
Pure fruit juice	**11.7**	**1.2 (0.9)**	**9.8 (2.7)**
Smoothies	**1.5**	**2.9 (0.9)**	**10.7 (1.2)**
Regular	72.7	2.7 (0.7)	10.5 (1.1)
Diet (no added sugar)	27.3	3.6 (0.9)	11.2 (1.5)
Milk-based drinks			
Flavoured milks	**2.6**	**1.7 (1.3)**	**9.2 (2.5)**
Diet	92.9	1.7 (1.4)	9.4 (2.3)
Regular	7.1	2.0 (1.1)	5.6 (2.5)

Notes: This table provides descriptive statistics for the different sub-categories or products. Column 2 displays the market share, column 3 the average price (in euros per liter) and column 4 the average sugar content (in grams per 100mL). Standard deviation are in parentheses.

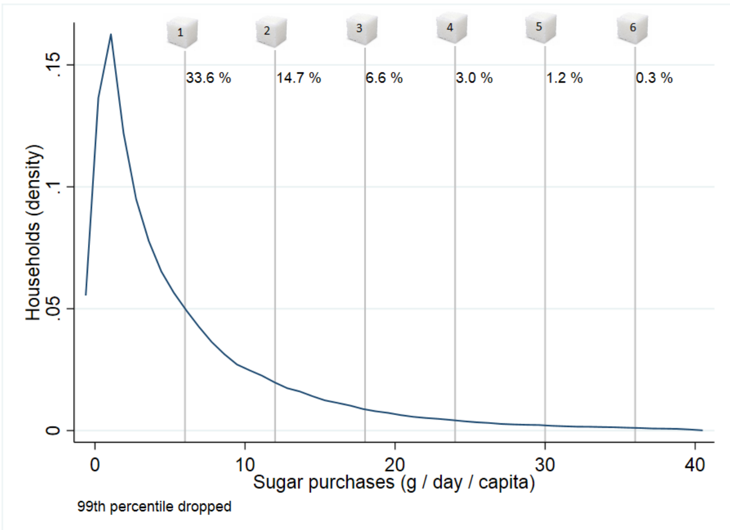
Figure 6: Purchase of non-alcoholic beverages across Kantar households

(a) All SSBs (b) SSBs with added sugar



Notes: These figures show the distribution of households according to their purchases of non-alcoholic beverages (in mL per day per capita). Figure (a) is made on the purchases of all beverages and Figure (b) only on beverages containing added sugar.

Figure 7: Sugar purchases across Kantar households



Notes: This figure shows the distribution of households according to the sugar content of their purchases of non-alcoholic beverages (in grams per day per capita). 33.6 % of households purchase more than one sugar cube per day per capita.

Table 7 provides a comparison of the purchase of non-alcoholic beverages per capita per year across households with respect to household composition, obesity status, and socio-economic class. Households with children between 7 and 16 years old are the highest consumers and households with children between 0 and 6 years old are the lowest consumers. The mean purchase increases gradually with the proportion of adults who are overweight or obese within the household.

Furthermore, poor households buy more than rich households.

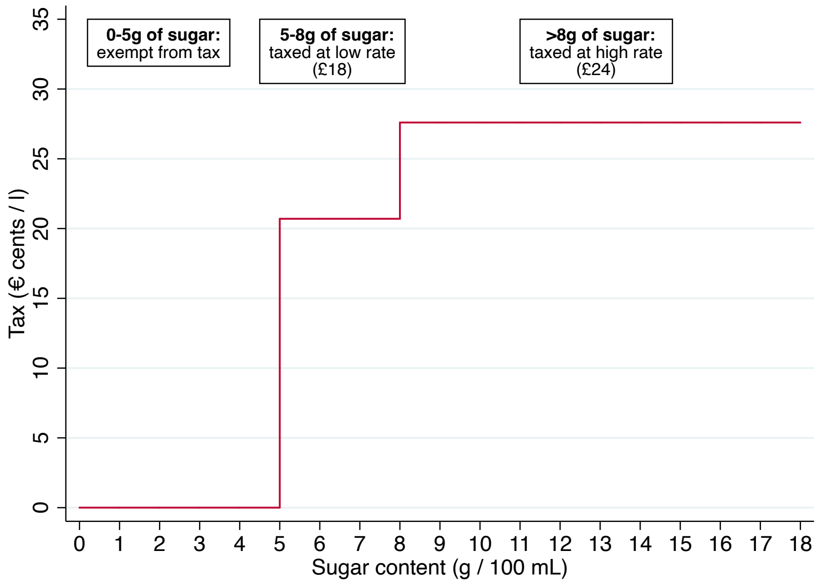
Table 7: Household purchases

Mean quantity (l/capita/year)	All beverages	Added sugar
Household composition		
No children	67 (85)	46 (68)
Children below 6	45 (54)	30 (44)
Children 7-16	76 (74)	53 (60)
Children both below 6 & 7-16	53 (57)	36 (46)
Obesity status		
None overweight or obese	53 (73)	37 (61)
Some overweight or obese	63 (71)	44 (58)
All overweight or obese	73 (87)	50 (68)
Socio-economic class		
Rich	59 (68)	38 (55)
Average	65 (79)	45 (62)
Poor	70 (88)	51 (73)
All	65 (79)	44 (64)

Notes: This table shows the purchases of non-alcoholic beverages (in liters per capita per year) for the different types of households. Column 2 displays the quantities for all beverages and column 3 for products containing added sugar. Standard deviations are in parentheses.

B Institutional background (SDIL)

Figure 8: Design of the SDIL



Notes: This figure describes the design of the SDIL tax implemented in the UK. The y-axis plots the tax rate (in euro cents per L) and the x-axis represents the sugar content of products (in grams per 100 mL).

Tax implementation. Manufacturers are responsible for measuring and reporting the sugar content of their products to the tax authorities. The tax authorities then apply the relevant tax rate based on the sugar content reported by the manufacturer. Regulatory agencies may perform audits or random checks to verify the accuracy of the reported sugar content. If discrepancies are found (for example, if a manufacturer underreports the sugar content to avoid higher tax rates), penalties may be imposed.

C Demand

C.1 Price equation

Table 8: Results on price equation

	Coefficient (se)
Instrumental variables	
BLP instruments	
Number of competing products offered by other firms within the product category	-0.01*** (0.00)
Total sugar content of competing products within the nutritional category	-0.00*** (0.00)
Cost shifter (input prices)	
Glass	-0.00*** (0.00)
Exogenous variables	
Diet	0.11*** (0.04)
Sugar (Soft drinks)	0.07*** (0.01)
Sugar (Fruit juices)	0.28*** (0.01)
Brand fixed effects	yes
Category fixed effects	yes
IV joint significance test	F(3,5035) = 35.97 Prob > F = 0.0000
Observations	5,182
R^2	0.944

Notes: This table displays the coefficients of the price equation where we regress prices on instrumental variables and exogenous variables of the demand equation. Estimators' standard errors (se) are in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

C.2 Estimation

We estimate the demand model using individual data. We use the simulated maximum likelihood method as in Revelt and Train (1998). In our model, as purchases are independent considering household and period, the likelihood function for purchase i can be written as:

$$L_i = \int \prod_{t=1}^{T} \prod_{j=0}^{J_t} [\frac{exp(\delta_{jt} + \mu_{ijt})}{1 + \sum_{k=1}^{J_t} exp(\delta_{kt} + \mu_{ikt})}]^{Y_{ijt}} \mathrm{d}P_{\nu}(\nu) \tag{18}$$

where Y_{ijt} is a dummy variable equal to 1 if purchase i involves product j in period t and 0 otherwise.

We estimate the vector of demand parameters by maximizing the simulated log-likelihood function given by:

$$SLL = \sum_{i=1}^{N} W_i \times ln[\hat{s}_{ijt}] \tag{19}$$

where N is the total number of purchases registered by Kantar for a given market and $W_i = N_i \times W_i^{ht}$ is the weight associated to the purchase i. N_i is the number of units purchased at the i^{th} purchase, used to take into account multiple choices of the same type of product (*i.e.*, buying three bottles of the same product at the same time). This is then multiplied by Kantar period-specific household sample weights associated to the household h that made the i^{th} purchase W_i^{ht}.

$\hat{s}_{ijt}$ stands for the individual simulated market share of product j in period t:

$$\hat{s}_{ijt} = \frac{1}{R}\sum_{r=1}^{R} w_r \prod_{j=0}^{J_t} [\frac{exp(\alpha_i^r p_{jt} + \beta_i X_{jt} + \upsilon \hat{\eta}_{jt})}{\sum_{k=1}^{J_t} 1 + exp(\alpha_i^r p_{kt} + \beta_i X_{kt} + \upsilon \hat{\eta}_{kt})}]^{Y_{ijt}} \tag{20}$$

where R is the number of draws, w_r is the r^{th} entry in the vector of weights and $\alpha_i^r = \alpha + \pi^\alpha D_i + \sigma \nu_i^r$ with $\nu^r \sim \mathcal{N}(0,1)$.[24] $\hat{\eta}_{jt}$ is the estimated error term of product j in period t from the price equation (Table 8).

C.3 Results

We found that households with young children are less sensitive to price and households with children above 7 years of age are more sensitive to price than households without children. Households with overweight or obese individuals are more sensitive to price than households with no overweight or obese individuals. Results also suggest that households prefer diet to regular products. The preference for diet products is stronger for households with children. Households with children have a higher taste for sugar. For a given brand and a given regular or diet characteristic,

[24] To address the curse of dimensionality, we use a sparse grid method as it is developed in Heiss and Winschel (2008). The choice for the number of simulations is explained on http://www.sparse-grids.de/. Integration on sparse grids has low computational costs compared to other methods. The number of draws is especially reduced because each draw is associated with a weight. Let R be the number of simulations which depends on the type of integration rule, the number of dimensions and the chosen accuracy. Let x_r and w_r be the r^{th} entries respectively in the vector of draws and the vector of weights. We want ν^r to follow a standard normal distribution so we apply a transformation (inverse of the standard normal cumulative distribution function) to x_r ($x_r \in [0,1]\ \forall r$) so that $\nu^r = \Phi^{-1}(x_r)$ and $\nu^r \sim \mathcal{N}(0,1)$.

households prefer products with more sugar both for SSBs and fruit juices.[25].

Table 9: Estimates of the random coefficient logit model

Price (p_{jt})	
Mean (α)	-6.84
$\times$ children below 6 years old	0.13
$\times$ children 7-16 years old	-0.03
$\times$ average class	-0.24
$\times$ poor class	-0.35
$\times$ at least one obese	-0.12
$\times$ all obese	-0.15
Standard deviation (σ)	1.64
Diet	1.02
$\times$ children below 6 years old	0.13
$\times$ children 7-16 years old	0.07
Sugar (SSBs)	0.16
$\times$ children below 6 years old	0.03
$\times$ children 7-16 years old	0.02
Sugar (fruit juices)	0.03
$\times$ children below 6 years old	0.05
$\times$ children 7-16 years old	0.04
Fixed effects	
Sub-category	yes
Brand (NBs & PLs)	yes
Error ($\hat{\eta}_{jt}$)	4.09
Observations: 1,364,000	
Log-likelihood: -2.32081e+10	

Notes: This table displays the results from the demand estimation detailed in section 3.2.1. Standard errors of coefficient estimates are in parentheses.

[25] The sugar coefficients do not represent the absolute preference for sugar but rather the preference between products for a given brand. Indeed, when controlling for brand fixed effects, the remaining variation in sugar content comes from the different products sold by the same brand (especially products from different categories, *e.g.*, "fruit-flavored drinks" and "other SSBs").

Table 10: Own-price elasticities by household characteristics

	Own-price elasticities
Household composition	
Without children	-8.93
With children below 6 years old	-8.84
With children 7-16 years old	-9.01
With children below 6 and 7-16 years old	-8.92
Obesity status	
No overweight or obese	-8.84
At least one overweight or obese	-8.95
All overweight or obese	-8.98
Socio-economic class	
Rich	-8.73
Average	-8.96
Poor	-9.08

Notes: This table displays the average own-price elasticities by household characteristics. Own-price elasticities are calculated at the alternative level. For a given household characteristic, it is the mean elasticity computed across all the alternatives' own-price elasticities.

Table 11: Own-price elasticities by sugar content and household characteristics

	Sugar content (g/100mL)					
	0	] 0 ; 5 [	[5 ; 8 [	[8 ; 10 [	[10 ; 12 [	≥ 12
All households	**-7.17**	**-6.90**	**-9.53**	**-10.18**	**-10.13**	**-10.12**
Household composition						
Without children	-7.16	-6.89	-9.54	-10.19	-10.14	-10.13
With children below 6	-7.11	-6.84	-9.44	-10.08	-10.03	-10.03
With children 7-16	-7.23	-6.95	-9.62	-10.27	-10.22	-10.21
With children below 6 & 7-16	-7.18	-6.90	-9.52	-10.16	-10.11	-10.11
Obesity status						
No overweight or obese	-7.11	-6.84	-9.44	-10.07	-10.03	-10.03
At least one overweight or obese	-7.19	-6.91	-9.56	-10.21	-10.16	-10.15
All overweight or obese	-7.22	-6.94	-9.60	-10.24	-10.19	-10.19
Socio-economic class						
Rich	-7.03	-6.76	-9.32	-9.95	-9.90	-9.91
Average	-7.20	-6.92	-9.57	-10.22	-10.17	-10.16
Poor	-7.29	-7.01	-9.71	-10.36	-10.31	-10.30

Notes: This table displays the own-price elasticities for different brackets of sugar content according to household characteristics.

D Supply

Table 12: Elasticities and margins by firms

Firms	**Own-price elasticities**	**Margins (% price)**
National brands		
Firm 1	-6.5	19.2
Firm 2	-6.6	17.6
Firm 3	-8.2	12.6
Firm 4	-4.2	27.2
Firm 5	-5.6	19.5
Firm 6	-3.5	28.4
Firm 7	-4.8	21.4
Firm 8	-12.5	8.7
Firm 9	-10.8	9.8
Firm 10	-6.4	16.5
Small firms	-7.9	18.9
Very small firms	-7.5	15.3
Private labels	-4.4	52.3

Notes: This table displays the own-price elasticities and the margins (as a percentage of price) for national brands and private labels. Firm 1 to Firm 10 are the ten firms with the highest market shares.

Table 13: Margins by sugar content

Sugar content (g/100mL)	**Margins (% price)**
0	19.2
] 0 ; 5 [	49.9
[5 ; 8 [	20.1
[8 ; 10 [	17.7
[10 ; 12 [	22.5
$\geq$ 12	19.1

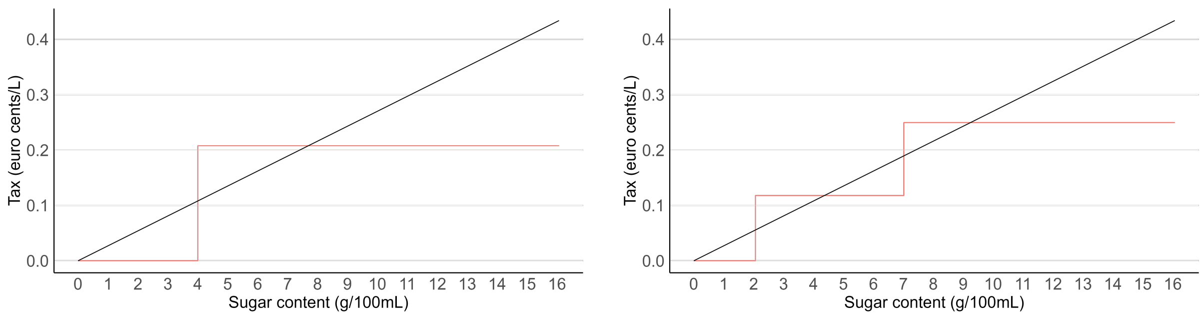
Notes: This table displays the margins (as a percentage of price) for different brackets of sugar content.

E Counterfactual simulations

E.1 Optimal designs without firms' strategic behavior

Figure 9: Comparison of tiered tax designs (without firms' strategic behavior)

(a) One tier $(k = 1)$ (b) Two tiers $(k = 2)$



Notes: The two figures plot the optimal tiered tax design with one and two thresholds respectively (in red) where we ignore firms' strategic behavior. The optimal tax rates and location of thresholds are obtained empirically from the maximization program presented in section 3.3.1. The black line corresponds to the theoretical optimal linear tax design where the tax rate is set at the value of the social cost (27 euros per kg of sugar). The y-axis plots the tax rate (in euros per L) and the x-axis displays the sugar content of products (in grams per 100 mL).

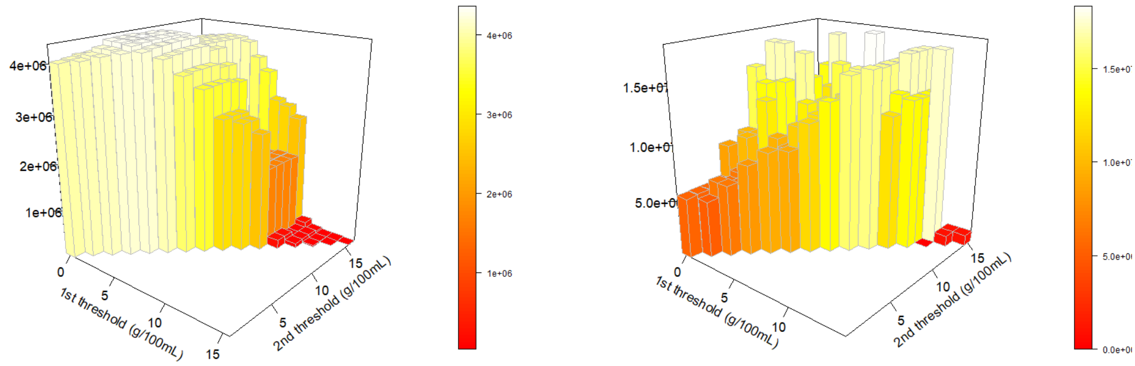
E.2 Optimization

The regulator's choice of thresholds becomes crucial when firms' strategic pricing behavior is considered. Figure 15 plots the maximum achievable welfare across different threshold locations for two-tiered designs.[26] When considering non-strategic firms, welfare variation remains relatively stable around the optimal threshold (Figure 15b). However, when considering firms' strategic responses, the variations become more pronounced (Figure 15a).

[26]See Figures 16 and 19 for similar graphs with one threshold and with two thresholds in 2D.

Figure 10: Welfare variation according to the location of thresholds

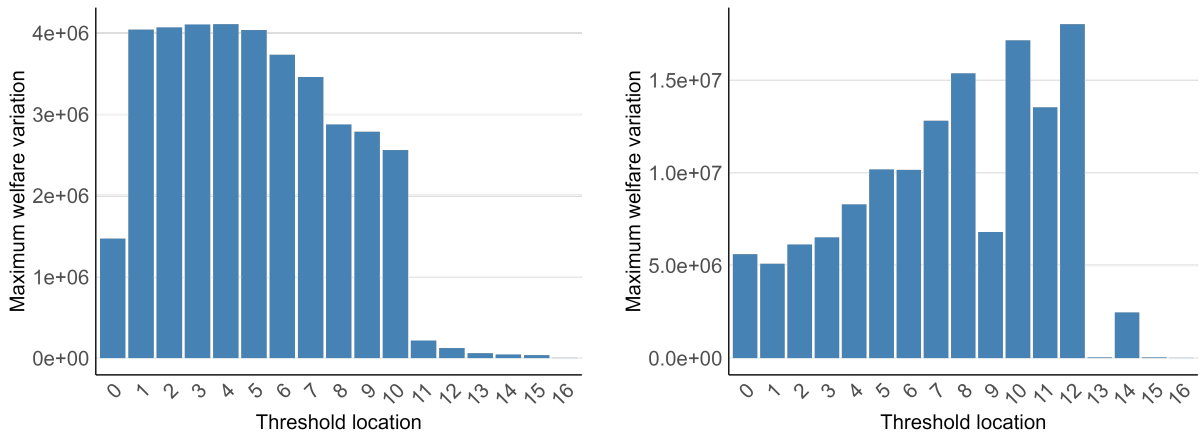
(a) No strategic pricing (b) Strategic pricing



Notes: These figures plot the variation in welfare (in euros) according to the location of the two thresholds (in grams per 100 mL). The lighter the colors, the higher the welfare gains. Figure (a) disregards firms' strategic behavior and Figure (b) accounts for it.

Figure 11: Welfare variation according to the location of threshold $(k = 1)$

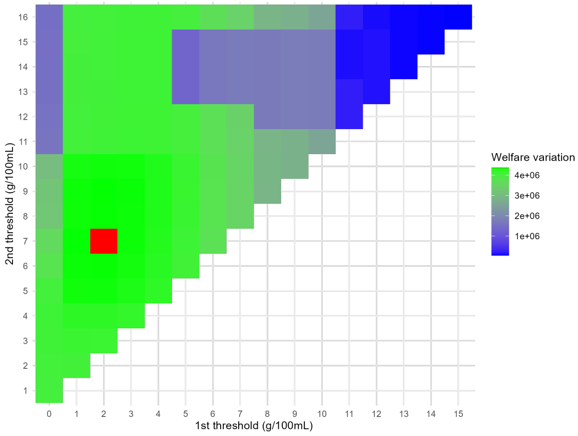
(a) No strategic pricing (b) Strategic pricing



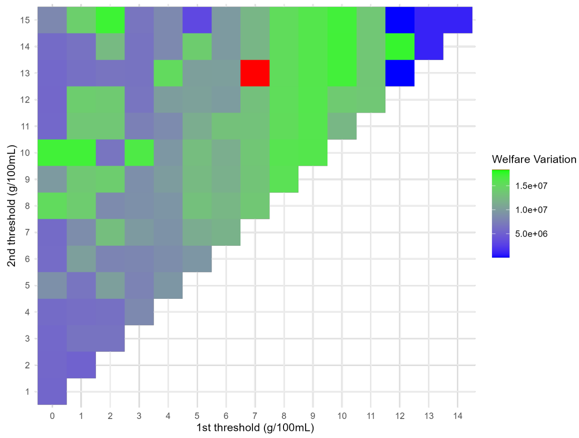
Notes: These figures plot the variation in welfare (in euros) according to the location of the threshold (in grams per 100 mL). Figure (a) disregards firms' strategic behavior and Figure (b) accounts for it.

Figure 12: Welfare variation according to the location of thresholds $(k = 2)$

(a) No strategic pricing



(b) Strategic pricing



Notes: These figures plot the variation in welfare (in euros) according to the location of the two thresholds (in grams per 100 mL). The red square corresponds to the threshold location that achieves the highest welfare gains. Figure (a) disregards firms' strategic behavior and Figure (b) accounts for it.

F Counterfactual simulations with estimated social cost of sugar at 12.833 €

Table 14: Welfare variation decomposition

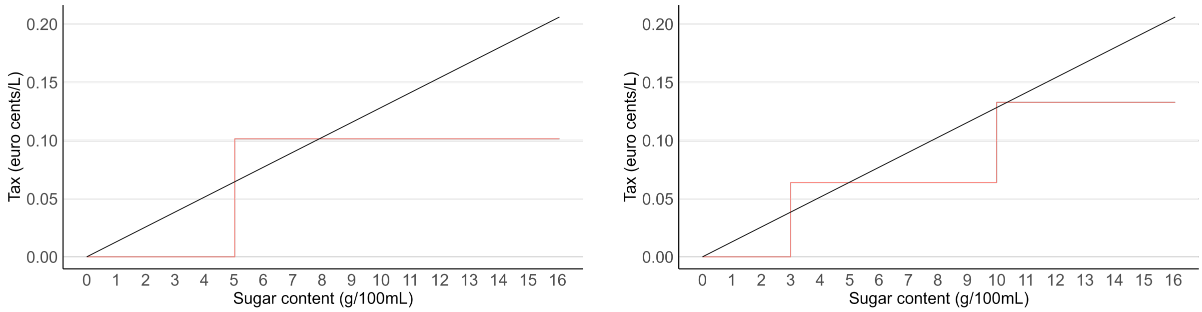
	Change (millions euros) in				
Counterfactual	**Total welfare** ΔW_t	**Firm profit** ΔW_t^{π}	**Consumer surplus** ΔW_t^{C}	**Tax revenue** ΔW_t^{tax}	**Externality** ΔW_t^{SC}
			Without firms' strategic behaviour		
Linear design					
12.83€per kg of sugar	1.57	-0.19	-6.54	4.96	3.34
Tiered design					
1 threshold	1.41	-0.12	-5.07	3.80	2.80
2 thresholds	1.51	-0.16	-5.51	4.18	2.99
SDIL	0.15	-0.26	-8.94	4.26	5.10
			With firms' strategic behaviour		
Linear design					
12.83€per kg of sugar	2.95	-0.17	-5.18	4.80	3.49
Tiered design					
1 threshold	21.62	2.15	16.23	0.04	3.20
2 thresholds	19.93	1.63	14.63	1.10	2.57
SDIL	1.96	-0.65	-6.70	4.02	5.29

Notes: This table plots the changes in total welfare (column 2) and in the different components of total welfare: firms' profit (column 3), consumer surplus (column 4), tax revenue (column 5) and externality (column 6). The linear and SDIL designs are already existing. The tiered designs with 1 and 2 thresholds are empirically derived from the procedure detailed in section 3.3.1.

F.1 Optimal designs without firms' strategic behavior

Figure 13: Comparison of tiered tax designs (without firms' strategic behavior)

(a) One tier $(k = 1)$ (b) Two tiers $(k = 2)$

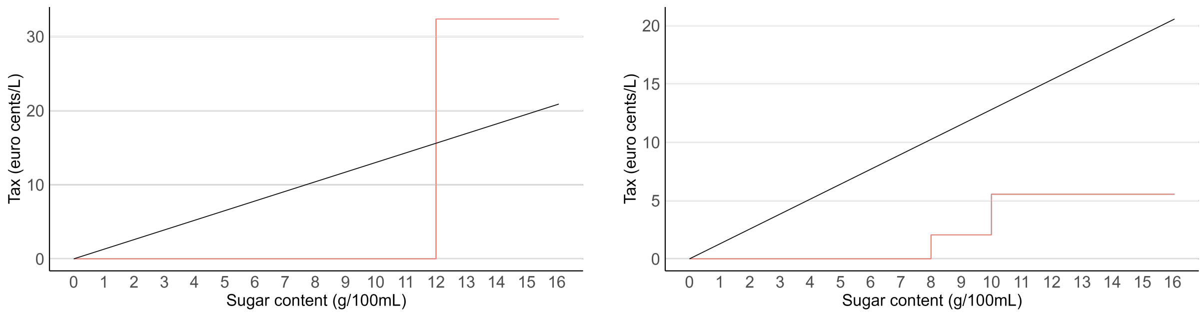


Notes: The two figures plot the optimal tiered tax design with one and two thresholds respectively (in red) where we ignore firms' strategic behavior. The optimal tax rates and location of thresholds are obtained empirically from the maximization program presented in section 3.3.1. The black line corresponds to the theoretical optimal linear tax design where the tax rate is set at the value of the social cost (12.833 euros per kg of sugar). The y-axis plots the tax rate (in euros per L) and the x-axis displays the sugar content of products (in grams per 100 mL).

F.2 Optimal designs with firms' strategic behavior

Figure 14: Comparison of tiered tax designs

(a) One tier $(k = 1)$ (b) Two tiers $(k = 2)$



F.3 Optimization

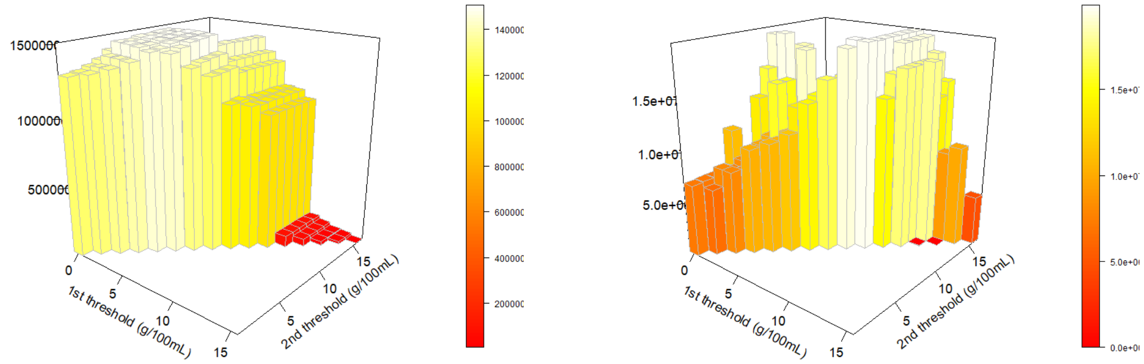
The regulator's choice of thresholds becomes crucial when firms' strategic pricing behavior is considered. Figure 15 plots the maximum achievable welfare across different threshold locations for two-tiered designs.[27] When considering non-strategic firms, welfare variation remains relatively

[27] See Figures 16 and 19 for similar graphs with one threshold and with two thresholds in 2D.

stable around the optimal threshold (Figure 15b). However, when considering firms' strategic responses, the variations become more pronounced (Figure 15a).

Figure 15: Welfare variation according to the location of thresholds

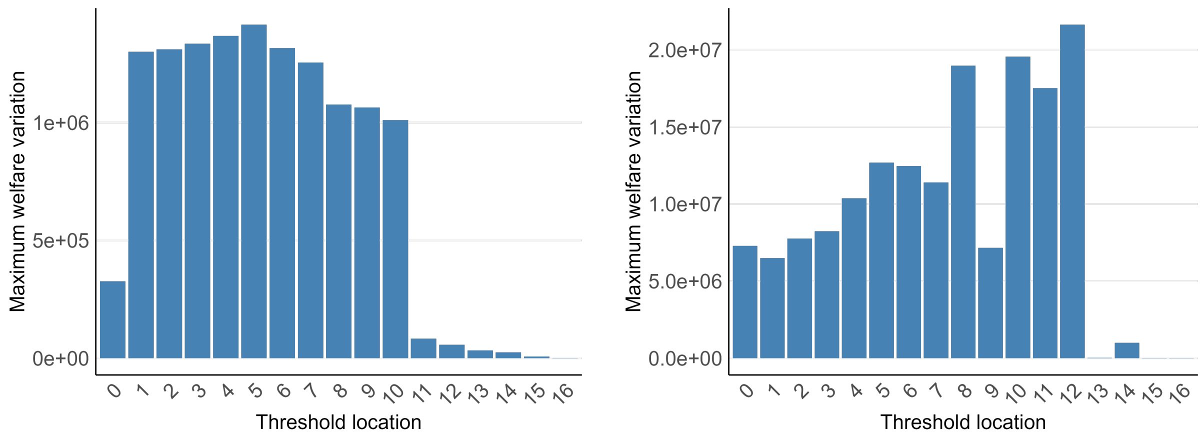
(a) No strategic pricing (b) Strategic pricing



Notes: These figures plot the variation in welfare (in euros) according to the location of the two thresholds (in grams per 100 mL). The lighter the colors, the higher the welfare gains. Figure (a) disregards firms' strategic behavior and Figure (b) accounts for it.

Figure 16: Welfare variation according to the location of threshold $(k = 1)$

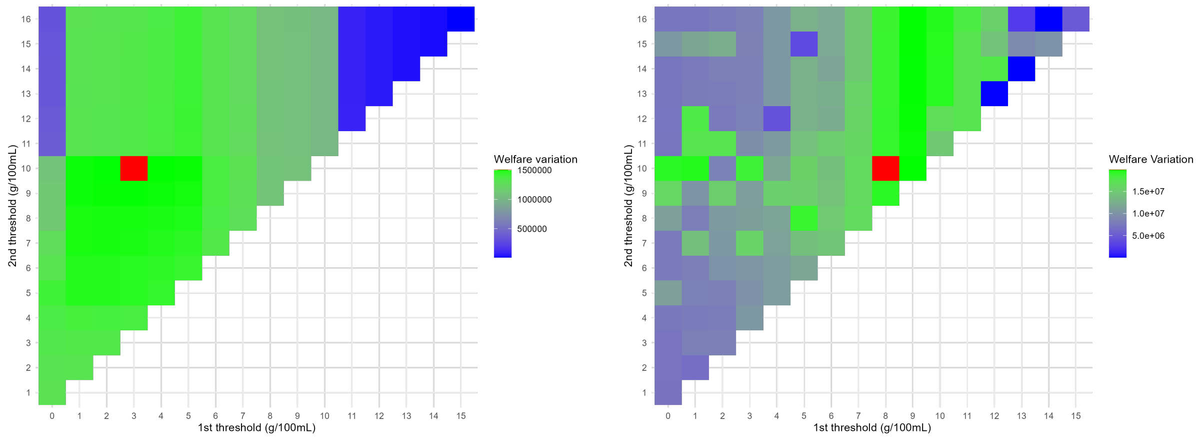
(a) No strategic pricing (b) Strategic pricing



Notes: These figures plot the variation in welfare (in euros) according to the location of the threshold (in grams per 100 mL). Figure (a) disregards firms' strategic behavior and Figure (b) accounts for it.

Figure 17: Welfare variation according to the location of thresholds $(k = 2)$

(a) No strategic pricing (b) Strategic pricing

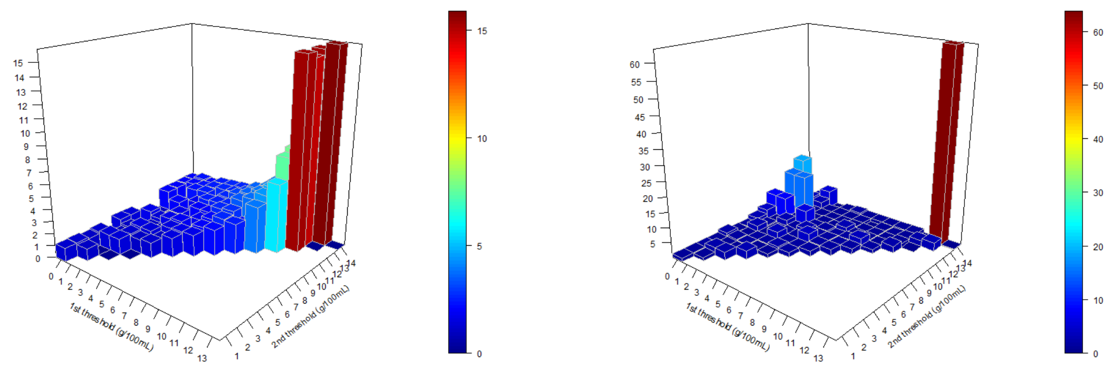


Notes: These figures plot the variation in welfare (in euros) according to the location of the two thresholds (in grams per 100 mL). The red square corresponds to the threshold location that achieves the highest welfare gains. Figure (a) disregards firms' strategic behavior and Figure (b) accounts for it.

F.4 Overview of the types of optimal solutions for each couple of threshold

Figure 18: Structure of the tax $(k = 2)$

(a) 1st threshold value (b) 2nd threshold value

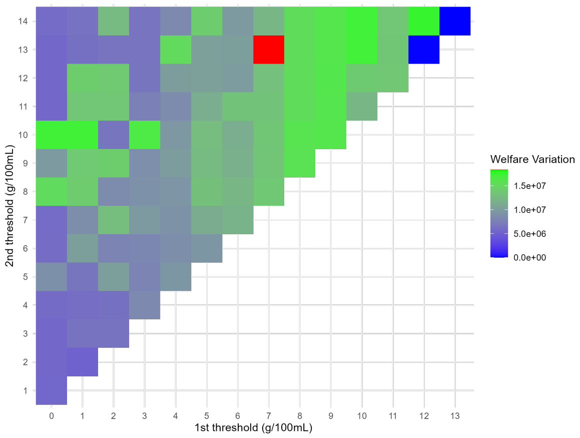


Notes: These figures show the value of the tax (in € cents) at each couple of threshold (in grams of sugar per 100mL of product). Figure (a) shows the value for the first threshold and Figure (b) for the second.

G Supplementary figures on optimal solutions (with a social cost of €27, as used in the paper's main application)

Figure 19: Solution with 27 cs $(k = 2)$

(a) heatmap



(b) Solution

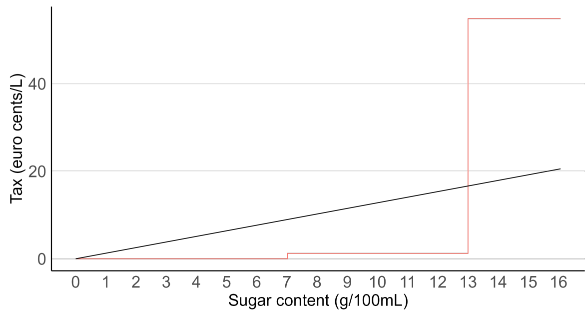
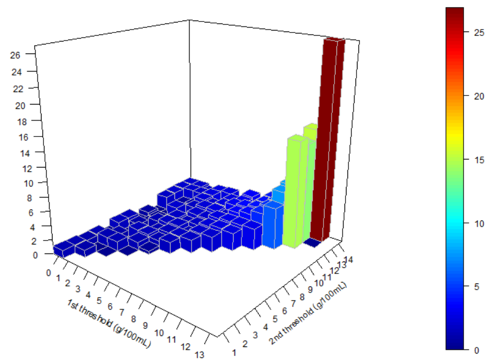
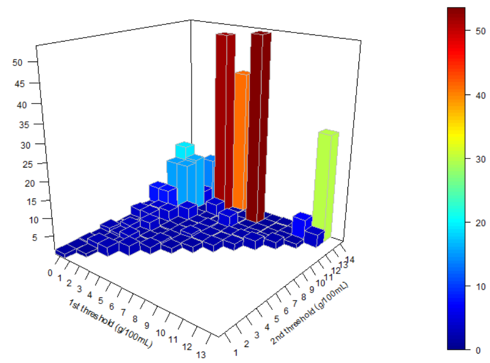


Figure 20: Structure of the tax $(k = 2)$

(a) 1st threshold value



(b) 2nd threshold value



Notes: These figures show the value of the tax (in € cents) at each couple of threshold (in grams of sugar per 100mL of product). Figure (a) shows the value for the first threshold and Figure (b) for the second.

5 - The UK Soft Drinks Industry Levy

The UK Soft Drinks Industry Levy

Maxime Tranchard *

Abstract

The Soft Drinks Industry Levy (SDIL), implemented in the United Kingdom in 2018, introduced a tiered tax on beverages based on their sugar content. This policy was explicitly designed to encourage manufacturers to reformulate products by reducing sugar concentrations. This paper studies how such incentives affect firms' product design and pricing decisions in a differentiated-product market.

Using household scanner data on soft drink purchases, I estimate a random-coefficients demand system that allows consumers to value both price and sugar content while accounting for heterogeneous substitution patterns across products. The demand estimates are combined with a multiproduct Bertrand pricing model to recover marginal costs and equilibrium markups. The analysis then incorporates endogenous reformulation decisions by firms, modeled as discrete adjustments in sugar content that require paying a fixed reformulation cost.

I show that the implied reformulation costs vary systematically across products and are larger for products located at the extremes of the sugar distribution. Using the estimated model, I simulate counterfactual equilibria under the SDIL and show that observed reformulation patterns can be partly predicted by the structural model using ex ante information on demand and cost conditions.

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1 Introduction

Taxes on sugar-sweetened beverages have become a central policy instrument in efforts to reduce sugar consumption and address rising rates of obesity and diet-related diseases. As a growing number of countries have implemented such policies, a rapidly expanding empirical literature has studied their effects(Aguilar et al., 2021; Cawley et al., 2019; Griffith et al., 2019; Silver et al., 2017; Capacci et al., 2019) and motivation Allcott et al. (2019). In April 2018, the United Kingdom introduced the Soft Drinks Industry Levy (SDIL), a tiered tax applied to soft drinks according to their sugar concentration. Beverages containing less than 5 grams of sugar per 100 millilitres are exempt, drinks containing between 5 and 8 grams face a lower tax rate, and products exceeding 8 grams per 100 millilitres are subject to a higher rate. Unlike standard excise taxes that aims to operate primarily through prices, the SDIL was explicitly designed and publicized with the objective of inducing product reformulation by manufacturers. Because tax liability depends directly on the sugar concentration of beverages, firms can reduce or entirely avoid the tax by lowering the sugar content of their products. This feature places firms' product design decisions at the center of the policy.

This paper studies how UK manufacturers respond to the SDIL, with a focus on endogenous product reformulation and its implications for consumer sugar exposure, using a structural model of demand and multiproduct firm supply. The analysis combines Kantar Worldpanel household scanner data with a structural model of differentiated-product demand and multiproduct firm pricing. The demand system allows consumers to have heterogeneous preferences for both prices and sugar content, capturing realistic substitution patterns across beverages. Modeling such heterogeneity is crucial for evaluating taxation policies in soft drink markets Etilé et al. (2021).

The empirical framework is extended to incorporate endogenous reformulation decisions by manufacturers. Firms are modeled as choosing the sugar content of their products in a first stage, before competing in prices in a second stage. Changing a product's formulation requires paying a fixed reformulation cost. Observed reformulation and non-reformulation decisions therefore contain information about the magnitude of these costs. I use this information to recover bounds on product-level reformulation costs. These bounds are then used to evaluate counterfactual equilibria.

The results highlight the importance of accounting for endogenous product characteristics when evaluating corrective taxes. While the SDIL directly affects prices through marginal costs, its ultimate impact on sugar exposure depends crucially on manufacturers' incentives to redesign their products. I show that the implied reformulation costs vary systematically across products and are larger for products located at the extremes of the sugar distribution. Using the estimated model, I simulate counterfactual equilibria under the SDIL and show that observed reformulation patterns can be partly predicted by the structural model using ex ante information on demand and cost conditions.

This paper contributes to the literature on corrective taxation of sugar-sweetened beverages and to the broader literature on taxation in markets with imperfect competition. A central motivation for soda taxes is that beverage choices generate social costs through diet-related disease risks and associated healthcare expenditures, and may also reflect internalities when consumers misperceive or underweight the health consequences of sugar consumption (Allcott et al., 2019; Griffith et al., 2018). In such environments, the effectiveness of corrective taxation depends not only on consumer responses but also on how firms adjust prices and product characteristics.

A large reduced-form literature documents that soda taxes can affect beverage prices and consumption. Evidence from Mexico shows substantial declines in purchases of taxed beverages following the introduction of a national excise tax (Colchero et al., 2017, 2016). In the United States, city-level taxes have been found to increase prices and reduce consumption of taxed beverages, although their effects may be attenuated by cross-border shopping and tax avoidance (Rogers et al., 2023; Seiler et al., 2021). While these studies provide important evidence on consumer responses, they typically abstract from supply-side adjustments in product characteristics.

Empirical evaluations of this policy show that sugar purchased from soft drinks declined after its introduction, even if overall beverage consumption did not fall proportionally (Dickson et al., 2025; Rogers et al., 2023; Bandy et al., 2020; Scarborough et al., 2020). These patterns suggest that reformulation played a central role in shaping the policy's effects. The importance of reformulation has been similarly documented in other markets (Griffith et al., 2017). However, existing evidence does not recover the structural determinants of reformulation decisions, such as the costs firms incur when modifying product recipes or the loss, or pontential loss, of demand due to change in product taste.

This paper complements the reduced-form evidence by developing a structural framework that links consumer demand, oligopolistic pricing, and endogenous product reformulation. The demand system follows the random-coefficients discrete-choice framework commonly used in differentiated-product markets (Berry et al., 2004; Nevo, 2001; Berry et al., 1995). These models allow the recovery of substitution patterns, markups, and marginal costs, and have been widely used to evaluate tax policies in imperfectly competitive markets (Dubois et al., 2020; Bonnet and Réquillart, 2013).

Most structural evaluations of beverage taxes treat product characteristics as fixed and focus on price responses and consumer substitution. An exception is the recent work of Barahona et al. (2023), which incorporates firms' product reformulation decisions in a structural framework. However, the literature on endogenous product reformulation in response to corrective taxes remains very limited, with only a small number of applications. This paper contributes to this emerging area by providing a structural analysis of product reformulation in the context of soda taxation and the UK Soft Drinks Industry Levy.

The framework developed in this paper is closely related to the methodology proposed by Koujianou Goldberg and Hellerstein (2013), who recover unobserved fixed costs of price adjustment from observed equilibrium pricing behavior. In a similar spirit, reformulation costs are interpreted here as a difference between two equilibrium that rationalize the product characteristics observed in the market, rather than as structural technological parameters that would need to be separately measured or decomposed.

The empirical strategy also exploits the timing of reformulation and retail inventory adjustments to identify consumer preferences over alternative formulations. Because reformulation occurs at the manufacturer level while products are sold through existing retail inventories, old and reformulated versions of a product may temporarily coexist in the market during the inventory clearance period. As a result, two households may purchase what appears to be the same product in the same period while consuming beverages with different sugar contents depending on which formulation remains available in the retailer's inventory. Following the approach suggested by Conlon and Mortimer (2013), this variation in product availability provides additional identifying variation for estimating demand.

2 The consumption of soft drink in the UK

2.1 Presentation of the data

This section examines the consumption of soft drinks in the United Kingdom. To conduct the analysis, we rely on household scanner data drawn from the Kantar Worldpanel. This dataset provides detailed information on grocery purchases recorded at the household level and is widely used in empirical studies of consumer behavior.

The empirical analysis focuses on the years 2017 and 2018. 2015 consumption is also exploit in order to observe a clean state of the market pre-annoucement and pre-taxation. Time is structured into four-week periods, leading to a total of 26 observed purchase periods over the sample 2017-2018. For each purchase occasion, the data include detailed product-level information, such as brand identifiers, prices, and key product characteristics, most notably the sugar content of beverages.

The panel consists of 36,000 households. For each household, we observe a rich set of sociodemographic characteristics, including income class, the obesity status of adult individuals , and the age composition of household members. These variables allow for an in-depth analysis of heterogeneity in consumption behavior across population groups.

Descriptive statistics indicate an overall increase in soft drink consumption between 2015 and 2018, accompanied by a general rise in prices over the same period. However, this aggregate pattern masks important distributional differences. In particular, a decline in consumption is observed for one specific social group: households belonging to the lowest income class. For all other social classes, consumption increase between the two years.

Table 1: Comparison of Total volume by Household Income in 2015 and 2018

	Volume (Million L)	
Household Income	**2015**	**2018**
£0 - £9,999 per annum	128.15	119.72
£10,000 - £19,999 per annum	334.56	358.23
£20,000 - £29,999 per annum	306.29	337.19
£30,000 - £39,999 per annum	250.56	267.41
£40,000 - £49,999 per annum	171.80	186.82
£50,000 - £59,999 per annum	116.52	133.72
£60,000 - £69,999 per annum	61.29	75.66
£70,000 +	87.43	118.47

Note: Rows highlighted in red indicate that the total volume in 2015 was greater than in 2018. Household are affected to their income category at the initial period in the sample, hence there is no change in the composition of these category. Observed change are not coming from change in the composition.

Given that one the primary objective of this paper is to evaluate the impact of the Soft Drinks Industry Levy, this preliminary evidence already suggests a potential behavioral response to the tax. The observed reduction in consumption among lower-income households, contrasted with rising consumption in other groups, is consistent with the hypothesis that the tax may have had a regressive effect across the income distribution.

Table 2: Comparison of Total Sugar Volume by Household Income in 2015 and 2018

	Sugar volume consumption in Tonne (t)	
Household Income	**2015**	**2018**
£0 - £9,999 per annum	545.66	336.93
£10,000 - £19,999 per annum	1407.97	994.55
£20,000 - £29,999 per annum	1178.91	916.43
£30,000 - £39,999 per annum	913.32	679.54
£40,000 - £49,999 per annum	575.64	466.28
£50,000 - £59,999 per annum	375.07	304.48
£60,000 - £69,999 per annum	191.33	161.82
£70,000 +	266.12	244.55

Note: Rows highlighted in green indicate that the total sugar volume in 2015 was greater than in 2018.

The analysis of sugar intake presented in Table 2 complements these findings by documenting changes in the volume of sugar consumed through soft drink purchases. While total beverage consumption increases for most segments of the population, this pattern does not extend to sugar intake. On the contrary, a consistent decline in sugar consumption is observed over the period 2015–2018.

This reduction is unsurprising for the subgroup of households whose overall soft drink consumption decreases. However, the magnitude of the decline is particularly striking among the remaining population groups, for which beverage consumption continues to rise.

Taken together, these results suggest that changes in market composition may have occurred over the period under study. In particular, they point to a potential reduction in the sugar content of available products, consistent with widespread reformulation by manufacturers in response to the Soft Drinks Industry Levy.

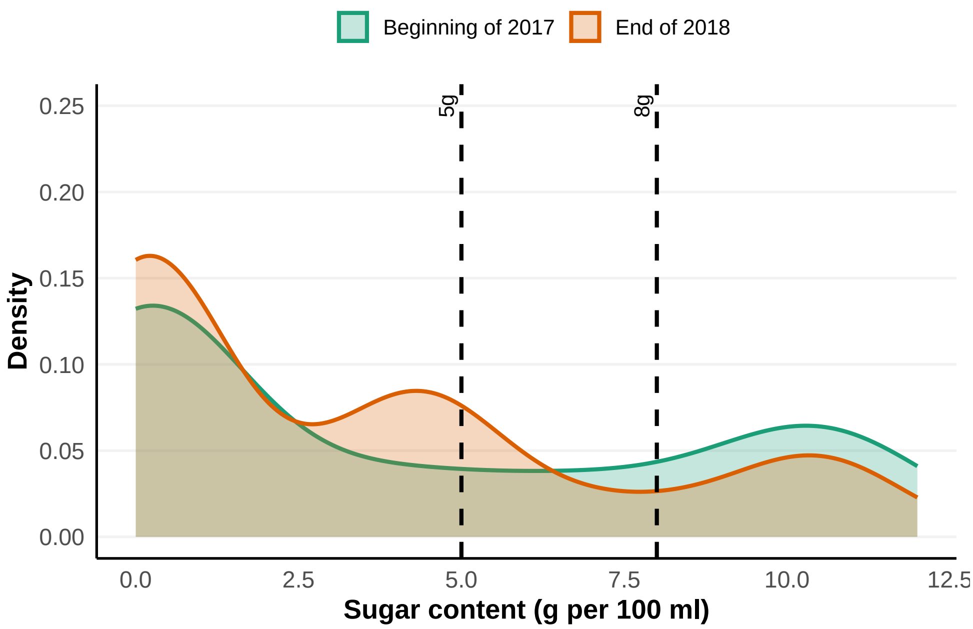

Figure 1: Sugar content distribution

Notes: The figure compares the distribution of sugar content across products before any reformulation and at the end of the data. Vertical dashed lines indicate the SDIL thresholds at 5g and 8g of sugar per 100ml.

Figure 1, which depicts the distribution of sugar concentration across soft drinks, provides strong support for the hypothesis of widespread product reformulation in response to the Soft Drinks Industry Levy. Importantly, this provides a first indication that the adjustment occurred through changes in product characteristics rather than through substitution across existing products. The distribution is constructed from product-level sugar content and therefore reflects the characteristics of the products offered in the market, rather than their market shares. As a result, shifts in this distribution cannot arise from changes in consumer substitution patterns and instead point only to changes in the supply of product formulations. The figure reveals a substantial increase in the mass of products with very low sugar content. In addition, there is a noticeable rise in the concentration of beverages located just below the first policy threshold, that is, below 5 grams of sugar per 100 millilitres. By contrast, the concentration of products with sugar content above the second threshold declines.

Taken together, these shifts in the distribution of sugar concentration indicate a clear bunching pattern around the tax thresholds. Such patterns are consistent with strategic reformulation by manufacturers aiming to reduce their tax liability under the levy.

Table 3: Manufacturer's shares, prices, and sugar content

	Market share		Mean price (£)		Mean sugar (g/100ml)	
Top manufacturer	**2015**	**2018**	**2015**	**2018**	**2015**	**2018**
Coca Cola Enterprises	0.304	0.273	0.816	0.960	4.418	3.240
Britvic / Pepsico	0.226	0.202	0.722	0.854	2.369	1.337
Lucozade Ribena Suntory	0.038	0.033	1.288	1.259	10.178	7.035
A.G.Barr Plc	0.028	0.035	0.728	0.722	5.050	2.139
J.N.Nichols (Vimto) PLC	0.017	0.020	1.118	1.020	3.834	2.534
Merrydown Wine Plc	0.006	0.005	1.692	1.543	10.507	8.405
Refresco Beverages Ltd	0.005	0.003	0.965	1.070	11.210	8.095
Friesland Campina	0.002	0.004	1.497	1.313	9.483	9.229
Outside goods	0.373	0.425	0.934	1.011	4.769	3.569

Note: The category labelled *outside goods* aggregates products supplied by very small producers as well as private-label beverages. Market's share are computed in volume.

Table 3 reports descriptive statistics on manufacturers' market shares and average sugar content between 2015 and 2018. The analysis focuses on products marketed by large national manufacturers, for which consistent information on pricing strategies and reformulation decisions is available over time.[1] Several important patterns emerge from these descriptive statistics. First, the market structure remains highly concentrated, with Coca-Cola Enterprises and Britvic/Pepsico

[1]Definition of outside goods could seem peculiar. Private-label products commercialized by retail distributors are included in this group. As a result, the empirical analysis restricts attention to branded products produced by major national manufacturers. This restriction allows us to examine firms' strategic responses to the Soft Drinks Industry Levy in terms of reformulation and pricing decisions, abstracting from heterogeneous behavior among small-scale producers and retailer-owned brands.

accounting for a substantial share of total soft drink sales in both years, although their market shares decline slightly over the period. By contrast, smaller manufacturers exhibit relatively stable or modestly increasing market shares.

Second, average prices increase for most major manufacturers between 2015 and 2018. This price growth is particularly pronounced among leading firms, consistent with the possibility that part of the tax burden was passed through to consumers. However, the magnitude of price changes varies across producers, suggesting differences in firms' exposure to the levy or heterogeneous pricing responses.

Third, and most strikingly, the table documents a substantial reduction in average sugar content across nearly all major manufacturers. For high-sugar producers such as Lucozade Ribena Suntory and A.G. Barr Plc, mean sugar levels decline sharply between 2015 and 2018. Similar, though more moderate, reductions are observed for other national brands.

Overall, the joint evolution of market shares, prices, and sugar content indicates that manufacturers primarily responded to the policy through adjustments in product characteristics rather than through large-scale market exit. This descriptive evidence supports the hypothesis that reformulation played a central role in reducing sugar intake from soft drinks in the United Kingdom.

2.2 Definition of product alternatives

To characterize competition in the soft drink market, we define a discrete set of product alternatives available to consumers. The analysis focuses on the largest national brands in order to capture manufacturers' strategic behavior in terms of pricing and product reformulation.

Products are defined at the level of a specific brand–flavor combination. In this context, the term *brand* refers to the precise product identity as perceived by consumers, rather than to the umbrella manufacturer name. For instance, *Coca-Cola Original* and *Coca-Cola Zero* are treated as distinct products. Similarly, flavored beverages such as *Fanta Orange* and *Fanta Lemon* are considered separate alternatives, even though they belong to the same parent brand.

Based on this definition, the choice set consists of 46 differentiated product alternatives. These products correspond to the main national brand–flavor combinations observed in the data and represent the strategic products marketed by large manufacturers.

Despite this restriction, the modeled choice set captures a substantial share of total market activity. In 2015, the 46 product alternatives account for approximately 63% of total soft drink purchases, while in 2018 they still represent around 58% of the market. Hence, even after excluding private-label beverages and products supplied by smaller producers, the analysis retains the majority of observed consumer demand.

All remaining products, namely private-label beverages, drinks produced by smaller manufacturers and smaller alternatives from the main ones, are excluded from the analyis. This modeling choice allows the analysis to focus on the behavior of major national products.

Table 4: Reformulated products and changes in sugar content

Product	Sugar content (pre) (g/100 ml)	Sugar content (post) (g/100 ml)	Change (g/100 ml)
7UP	11.0	7.0	-4.0
Irn-Bru	10.3	4.7	-5.6
Dr Pepper	7.2	4.9	-2.3
Fanta Orange	6.4	4.8	-1.6
Lucozade Energy Orange	12.0	4.5	-7.5
Ribena Blackcurrant	10.0	4.6	-5.4
Sprite	6.6	3.3	-3.3
Vimto	9.1	4.6	-4.5

Notes: Sugar content is expressed in grams per 100 millilitres. The table reports discrete reformulation events observed during the sample period, whereby products move from a high-sugar formulation subject to taxation under the Soft Drinks Industry Levy to a lower-sugar formulation falling below one of the tax thresholds (7UP) or outside the scope of the levy.

Table 4 summarizes the reformulation events observed in the data. Among the 46 product alternatives, eight products undergo reformulation during the sample period. For these products, the data reveal discrete changes in sugar content over time. Specifically, each of these products is observed in two distinct sugar states.

The first state corresponds to a high-sugar formulation, which is subject to the higher tax rate under the Soft Drinks Industry Levy. The second state corresponds to a lower-sugar formulation, which places the product either below the first tax threshold or entirely outside the scope of the levy.

These reformulated products therefore experience a transition from a taxed to a less-taxed, or untaxed, sugar category over the observation period. As such, they constitute the primary objects of interest when analyzing manufacturers' reformulation decisions. Focusing on these products allows to directly examine how firms adjust product characteristics in response to the incentives created by the levy.

2.3 Inventory dynamics and product availability

A key feature of the data for the analysis of reformulation is the timing of the Soft Drinks Industry Levy, which was implemented in April 2018. Within the four-week structure of the dataset, this date corresponds approximately to period 17. Periods 1–16 therefore constitute the pre-implementation window, while periods 17–26 form the post-implementation window.

Reformulation does not occur simultaneously across products. For the eight reformulated products, the transition from the high-sugar to the low-sugar formulation takes place at different points in the sample. Moreover, for several products, both formulations are observed to coexist within the same period. This overlap is consistent with inventory dynamics in the retail supply chain: distributors may continue to sell remaining stocks of the pre-reformulation product while the newly reformulated version is progressively introduced. In contrast, for other products, inventories of the pre-reformulation formulation appear to be depleted rapidly, leading to a sharp transition in observed sales once the new formulation becomes available.

These dynamics generate heterogeneous patterns of product availability across time. For some products, reformulation occurs around the time of policy implementation, with a period during which both formulations are simultaneously observed. For others, the transition takes place later in the post-implementation window. For instance, the 7UP product is observed in both sugar states in period 16, after which the high-sugar formulation exits the market and the lower-sugar version remains available for the remainder of the sample. By contrast, for Dr Pepper, the transition occurs substantially later, between periods 23 and 25, such that only the low-sugar formulation is observed by the final period.

From an econometric perspective, the temporary coexistence of old and new formulations could, in principle, introduce noise and complicate the identification of causal effects. In the present setting, however, this feature of the data proves to be highly informative. Importantly, the data never record simultaneous purchases of both formulations of the same product within a given household and period. This pattern is consistent with a retail mechanism in which, once inventories of the pre-reformulation product are exhausted, retailers replace them with deliveries of the reformulated version.

As a result, the observed availability of the old formulation reflects inventory decisions made upstream and prior to the introduction of the new formulation by manufacturers. These stockpiling decisions are therefore largely predetermined and not actively chosen in response to contemporaneous demand conditions. Under this interpretation, the residual availability of the pre-reformulation product can be treated as plausibly exogenous with respect to current demand shocks.

This interpretation is closely related to the framework developed by Conlon and Mortimer (2013), who study demand estimation under incomplete product availability and show that stock-out events may bias demand estimates when availability is systematically correlated with unobserved demand shocks. While such concerns are not central in our empirical setting, given that the products under study correspond to major national brands that are continuously stocked and rarely subject to complete stock-outs, their analysis provides a useful conceptual foundation.

In particular, their discussion of inventory-driven variation in choice sets offers a natural lens through which to interpret the temporary coexistence of product formulations observed in the data. Here, this coexistence arises from stockpiling and inventory clearance rather than from endogenous supply responses to demand fluctuations. We therefore exploit this inventory-driven variation not as a source of concern, but as an informative feature of the data. The staggered availability of the two sugar formulations for the eight reformulated products generates within-product variation that can be used to identify consumer preferences over sugar content, while remaining plausibly exogenous to contemporaneous demand shocks.

3 Model

This section describes the demand and supply framework used to analyze consumer choices and firms' pricing responses. A key feature of the model is that some products may be observed under two alternative formulations ("states") during the sample period, reflecting reformulation. In periods where the formulation of a subset of products is uncertain due to inventory clearance and coexistence of old and new stock, the likelihood integrates over the corresponding set of possible product-state configurations.

3.1 Demand

Consider markets indexed by four-week periods $t = 1, \dots, T$. Consumers choose among J inside goods $j = 1, \dots, J$ and an outside option $j = 0$. Let p_{jt} denote the observed price and s_{jt} the observed sugar content (in grams per 100ml) associated with the formulation sold in period t. Let τ_t denote a period fixed effect capturing common shocks (e.g. seasonality and macroeconomic conditions).

Utility of consumer i from choosing product j in period t is

$$u_{ijt} = \alpha_i p_{jt} + \mu_i s_{jt} + \tau_t + \beta_j \mathbb{1}\{j \text{ is in state 2 at } t\} + \beta_j^0 \mathbb{1}\{j \text{ as two states in the data }\} + \varepsilon_{ijt}, \quad (1)$$

where ε_{ijt} is i.i.d. Type I extreme value. Heterogeneity in price and sugar preferences is modeled via random coefficients:

$$\alpha_i = \alpha + \sigma \nu_{ip}, \quad (2)$$

$$\mu_i = \mu + \sigma_\mu \nu_{is}, \quad (3)$$

with (ν_{ip}, ν_{is}) independent standard normal draws.

The terms β_j^0 and β_j are estimated only for products that are ever observed in two states during the sample. β_j captures a product-specific shift in mean utility when product j is sold under the reformulated formulation (state 2).

Conditional on consumer-specific coefficients, demand follows the standard multinomial logit structure, and aggregate market shares are obtained by integrating individual choice probabilities over the distribution of random coefficients.

3.2 Reformulation states over product-state configurations

For a subset of products, reformulation implies two feasible formulations (states): a baseline formulation (state 1) and a reformulated (state 2). Let $k_{jt} \in \{1, 2\}$ denote the formulation of product j in period t.

When the formulation is observed deterministically, k_{jt} is known and the corresponding sugar content and price enter utility directly. In periods affected by inventory clearance, however, the formulation of a small number of products may be uncertain. For each such product j, the data provide a period-specific probability $\pi_{jt} \in (0, 1)$ that the product is sold in state 1 (with probability $1 - \pi_{jt}$ it is sold in state 2). In these periods, demand is modeled as a mixture over all feasible formulation configurations.

Formally, let $\mathcal{U}_t$ denote the set of products whose formulation is uncertain in period t, and let k_t denote the number of such products. A demand state $\omega \in \Omega_t$, with $\Omega_t \subseteq \{1, 2\}^{k_t}$, assigns a formulation to each product in $\mathcal{U}_t$.

The probability weight associated with demand state ω is given by

$$\pi_{\omega t} = \prod_{j \in \mathcal{U}_t} [\pi_{jt}]^{\mathbb{1}\{\omega_{jt}=1\}} [1 - \pi_{jt}]^{\mathbb{1}\{\omega_{jt}=2\}} . \tag{4}$$

Conditional on a given demand state ω, each product is assigned a formulation: deterministically for products $j \notin \mathcal{U}_t$, and according to ω for products $j \in \mathcal{U}_t$. This assignment uniquely determines the vectors of prices and sugar contents, denoted respectively by $p_{jt}(\omega)$ and $s_{jt}(\omega)$.

Let $S_{jt}(\omega)$ denote the model-implied market share of product j under demand state ω. Let y_{jt} denote the observed purchase counts for products available in period t. The period-t log-likelihood contribution conditional on state ω is

$$\ell_t(\omega) = \sum_{j \in \mathcal{A}_t} y_{jt} \log S_{jt}(\omega), \tag{5}$$

where $\mathcal{A}_t$ denotes the set of available alternatives, including the outside option.

The unconditional likelihood contribution in period t integrates over all feasible demand states:

$$\ell_t = \log \left(\sum_{\omega \in \Omega_t} \pi_{\omega t} \exp\{\ell_t(\omega)\} \right), \tag{6}$$

When $k_t = 0$, the set Ω_t contains a single element and the likelihood reduces to the standard simulated logit likelihood with deterministically observed product characteristics.

3.3 Supply

Supply is modeled using a standard static Bertrand framework with multiproduct firms. In each period t, the market is normalized to have unit mass of consumers, so that equilibrium quantities coincide with market shares. In particular, if product j is chosen with probability s_{jt}, the corresponding quantity is given by

$$q_{jt} = S_{jt}. \tag{7}$$

This normalization is adopted for convenience and does not affect the equilibrium conditions.

Let $\mathcal{F}$ denote the set of firms and $\mathcal{J}_f$ the set of products owned by firm f. Firms choose prices simultaneously in each period to maximize static profits,

$$\Pi_{ft}(p_t) = \sum_{j \in \mathcal{J}_f} (p_{jt} - c_{jt})\, S_{jt}(p_t), \tag{8}$$

where c_{jt} denotes marginal cost and demand shares $s_{jt}(p_t)$ are determined by the demand system described above.

The first-order condition associated with product j owned by firm f is:

$$S_{jt}(p_t) + \sum_{m \in \mathcal{J}_f} (p_{mt} - c_{mt}) \frac{\partial S_{mt}(p_t)}{\partial p_{jt}} = 0. \tag{9}$$

Stacking these conditions across products yields the standard markup equation. Let s_t denote the $J \times 1$ vector of inside-good shares, and let Δ_t denote the $J \times J$ matrix of demand derivatives, with generic element

$$(\Delta_t)_{jm} \equiv \frac{\partial S_{mt}(p_t)}{\partial p_{jt}}. \tag{10}$$

Let Ω denote the $J \times J$ ownership matrix, where $\Omega_{jm} = 1$ if products j and m are produced by the same firm and $\Omega_{jm} = 0$ otherwise. The system of first-order conditions can then be written compactly as

$$p_t - c_t = -\left(\Omega \odot \Delta_t\right)^{-1} S_t, \tag{11}$$

where $\odot$ denotes the Hadamard (element-by-element) product.

Supply under formulation uncertainty. Reformulation states are realized at the retail level through inventory clearance, so manufacturers do not observe the exact formulation configuration faced by consumers at the time prices are set. Instead, firms are assumed to know the distribution of possible demand states and to form expectations over formulation availability.

Consistent with this timing, the model abstracts from the explicit vertical structure of the market and contractual interactions between manufacturers and distributors. Manufacturers are assumed to set formulation-specific prices prior to the resolution of retail inventory clearance. In particular, when a product undergoes reformulation, firms choose distinct prices for the baseline formulation ($k = 1$) and the reformulated formulation ($k = 2$), but cannot condition these prices on the realized availability of formulations at the retail level.[2]

Let Ω_t denote the set of feasible demand states in period t, where each state $\omega \in \Omega_t$ specifies which formulation of each product is available. Let $\pi_{\omega t}$ denote the probability associated with demand state ω.

[2]Allowing prices to adjust after the realization of formulation availability would effectively correspond to local retail pricing, which is outside the scope of the manufacturer-level pricing behavior modeled in this paper.

Expected profits for firm f in period t are given by

$$\mathbb{E}[\Pi_{ft}] = \sum_{\omega \in \Omega_t} \pi_{\omega t} \sum_{(j,k) \in \mathcal{J}_f} \mathbb{1}\{k = \omega_{jt}\} \left(p_{jkt} - c_{jkt}\right) S_{jkt}(\omega), \tag{12}$$

where p_{jkt} and c_{jkt} denote respectively the price and marginal cost of formulation k of product j, and $s_{jkt}(\omega)$ denotes the demand share of formulation (j,k) conditional on demand state ω.

Define expected formulation-level shares as

$$\bar{S}_{jkt} = \sum_{\omega \in \Omega_t} \pi_{\omega t} \mathbb{1}\{k = \omega_{jt}\} S_{jkt}(\omega). \tag{13}$$

The first-order condition associated with the price of formulation k_{jt} can then be written as

$$\bar{S}_{jkt} + \sum_{(m,\ell) \in \mathcal{J}_f} (p_{m\ell t} - c_{m\ell t}) \frac{\partial \bar{S}_{m\ell t}}{\partial p_{jkt}} = 0. \tag{14}$$

This system yields formulation-specific markups that depend on expected substitution patterns across demand states. When formulation availability is deterministic, the expressions collapse to the standard Bertrand pricing equations. The summation therefore captures the fact that a change in the price of formulation (j,k) affects not only its own expected demand, but also the expected demand of all other formulations owned by the same firm. As in the standard multiproduct Bertrand model, firms internalize these substitution effects when choosing formulation-specific prices.

In particular the formulation is deterministic in two parts of the data that is used in this paper, prior to any reformulation and when all products have been reformulated. In other terms if we consider first the state where all products are untouched from prior equilibrium and then the equilibrium where all products reformulated are reformulated we are able to recover two standard bertrand pricing equations.

4 Estimation strategy

This section describes the estimation procedure, based on a control-function approach.

A central challenge in demand estimation is that prices may be correlated with unobserved demand shocks (e.g. advertising, unobserved quality, or local demand conditions). To address this concern, a control-function approach is implemented.

Hence the demand specification become

$$u_{ijt} = \alpha_i p_{jt} + \mu_i s_{jt} + \lambda_p \eta_{jt} + \beta_j \mathbb{1}\{j \text{ is in state 2 at } t\} + \beta_j^0 \mathbb{1}\{j \text{ as two states in the data}\} + \tau_t + \xi_{jt} + \varepsilon_{ijt}, \tag{15}$$

As previously, p_{jt} is the price of product j in period t, s_{jt} is sugar content, τ_t denotes period fixed effects, and η_{jt} is a control-function term capturing the endogenous component of price. The terms β_j^0 and β_j are estimated only for products that are ever observed in two states during the sample. β_j captures a product-specific shift in mean utility when product j is sold under the reformulated formulation (state 2).

The coefficient λ_p measures the extent to which the control function absorbs correlation between p_{jt} and the unobserved demand shock ξ_{jt}.

First stage. The control function η_{jt} is constructed as the residual from a reduced-form price equation:

$$p_{jt} = Z_{jt}'\pi + \tau_t + \nu_{jt}, \tag{16}$$

where Z_{jt} includes excluded instruments and other exogenous controls. A key excluded source of variation is provided by the Soft Drinks Industry Levy itself, which generates discontinuous cost pressure as a function of sugar content. Concretely, Z_{jt} includes indicators for whether product j falls above the relevant SDIL sugar thresholds in period t, which shift equilibrium prices through marginal costs but are assumed not to directly affect utility conditional on observed sugar content and period fixed effects.

The estimated residual $\hat{\nu}_{jt}$ is then used as the control function:

$$\eta_{jt} \equiv \hat{\nu}_{jt}. \tag{17}$$

Second stage. The demand parameters are estimated by simulated methods maximum likelihood, treating η_{jt} as an additional regressor in utility. Intuitively, conditional on the control function, price variation is purged of the component correlated with the unobserved demand shock, allowing consistent identification of price sensitivity.

4.1 Results on demand

The demand specification includes random coefficients on price and sugar content, as well as a control-function term constructed from the first-stage price equation. In addition, product-specific reformulation fixed effects are included to capture average shifts in demand associated with reformulated products. Four-week period fixed effects are also included to absorb aggregate demand shocks but are not reported for brevity.

Table 5 reports the estimated parameters of the demand system.

Table 5: Demand Estimates

	(1) Post only	(2) Product + Post
Preference parameters		
Price mean (α)	-2.656	-2.634
Price heterogeneity (σ_α)	0.283	0.608
Sugar mean (μ)	-0.192	-0.189
Sugar heterogeneity (σ_μ)	0.344	0.366
Product reformulation indicators		
7UP Regular	–	-1.499
Irn-Bru Regular	–	-0.277
Dr Pepper Regular	–	0.261
Fanta Orange	–	-0.377
Lucozade Energy Orange	–	-0.435
Ribena Blackcurrant	–	0.056
Sprite Regular	–	-0.519
Vimto Regular	–	-0.627
Post-reformulation indicators		
7UP Regular	-1.360	-0.119
Irn-Bru Regular	0.680	0.840
Dr Pepper Regular	0.111	-0.119
Fanta Orange	0.947	0.979
Lucozade Energy Orange	0.688	1.157
Ribena Blackcurrant	0.361	0.388
Sprite Regular	0.905	1.000
Vimto Regular	-0.011	0.516
Period fixed effects	Yes	Yes
Control function (λ_p)	2.617	2.277

Notes: Column (1) includes post-reformulation indicators only and therefore captures average demand shifts following reformulation. Column (2) additionally includes product-specific reformulation indicators, allowing baseline differences between reformulating and non-reformulating products to be separated from within-product changes. All specifications include four-week period fixed effects.

The reformulation fixed effects display substantial heterogeneity across products. While some reformulated products exhibit positive shifts in utility relative to their pre-reformulation versions, others show negative or negligible changes. These estimates indicate that reformulation affects consumer demand through channels beyond sugar content alone, motivating the richer structural framework developed in the next section.

Comparing columns (1) and (2) highlights the importance of accounting for selection into reformulation. In the first specification, post-reformulation coefficients combine baseline product differences with reformulation-induced changes. Once product-specific reformulation indicators are included, post-reformulation effects reflect within-product shifts in utility relative to each product's pre-reformulation baseline.

5 Taking into account endogenous reformulation

The analysis developed in the previous sections characterizes consumer demand, equilibrium pricing, and marginal cost determination conditional on observed product formulations. This approach allows the empirical evaluation of the Soft Drinks Industry Levy through its effects on prices, market shares, and sugar purchases, while taking reformulation behavior as given.

This subsection presents now the full model underlying the empirical analysis, in which reformulation itself arises endogenously from firms' optimization problems. Importantly, this extension does not modify the demand system, pricing behavior, or identification strategy developed above. Rather, it nests the empirical framework within a broader model of two-stage product design.

Timing. Firms interact over two stages. In the first stage, manufacturers choose the sugar content of their products. In the second stage, conditional on these choices, firms compete in prices. Consumers then make purchase decisions.

Formally, let q_t denote the vector of sugar contents in period t. Given q_t, equilibrium prices are determined by the Bertrand pricing system:

$$p_t^*(q_t) = \arg\max_{p_t} \Pi_t(p_t, q_t),$$

where profits are defined as in the baseline model.

Firm problem. Firm f chooses sugar content to maximize expected profits:

$$\Pi_t^f(q_t) = \sum_{j \in G_f} \left(p_{jt}^*(q_t) - c_{jt}(q_{jt})\right) \bar{S}_{jt}(p_t^*(q_t), q_t) \tag{18}$$

Firms internalize how changes in sugar content affect demand directly through consumer preferences, indirectly through equilibrium price adjustments, and mechanically through marginal costs due to policy exposure.

Optimal reformulation. Let $\tilde{q}_t$ denote the observed vector of sugar contents in period t, corresponding to the status-quo formulation of all products. Firms may adjust the sugar content of a product by paying a fixed reformulation cost. For product k, define the optimal sugar choice as

$$q_{kt}^* \in \arg\max_{q_{kt}} \Pi_t^f(q_{kt}, \tilde{q}_{-k,t}), \tag{19}$$

where $\tilde{q}_{-k,t}$ denotes the sugar levels of all other products, which are held fixed.

Observed reformulation decisions provide inequality restrictions on the magnitude of reformulation costs. When reformulation does not occur, the firm prefers to keep the existing formulation rather than incur the fixed reformulation cost. Profit maximization therefore implies

$$A_{kt} \;\geq\; \Pi_t^f(q_{kt}^*, \tilde{q}_{-k,t}) - \Pi_t^f(\tilde{q}_t), \tag{20}$$

where A_{kt} denotes the fixed cost of reformulating product k. Intuitively, if the profit gain from switching to the optimal formulation were larger than the reformulation cost, the firm would have chosen to reformulate. The absence of reformulation therefore provides a lower bound on the reformulation cost.

Conversely, when reformulation is observed, the inequality is reversed. In that case the profit gain generated by the reformulated product must exceed the associated reformulation cost:

$$\Pi_t^f(q_{kt}^*, \tilde{q}_{-k,t}) - \Pi_t^f(\tilde{q}_t) \;\geq\; A_{kt}. \tag{21}$$

Taken together, observed reformulation choices provide upper and lower bounds on the magnitude of reformulation costs.

Prior any reformulation Consider first the equilibrium state preceding any product reformulation. In this initial configuration, all products are sold in their original formulation and no alternative states are available in the market. Consequently, the demand system corresponds to the baseline product characteristics observed prior to reformulation, and the supply-side pricing problem reduces to the standard static Bertrand competition described in Section 3.3.

Importantly, this period also precedes the implementation of the Soft Drinks Industry Levy. As a result, firms do not face any tax-related cost component, and marginal costs correspond solely to the standard sum of production and distribution costs. Under these conditions, firms set prices to maximize profits given the demand system and the portfolio of products they own.

In this environment, the absence of reformulation decisions provides information about the magnitude of reformulation costs. From the inequality derived above, profit maximization implies that the fixed cost of reformulating product k must be at least as large as the profit gain that would be generated by switching from the observed formulation $\tilde{q}_t$ to the optimal formulation q^*_{kt}.

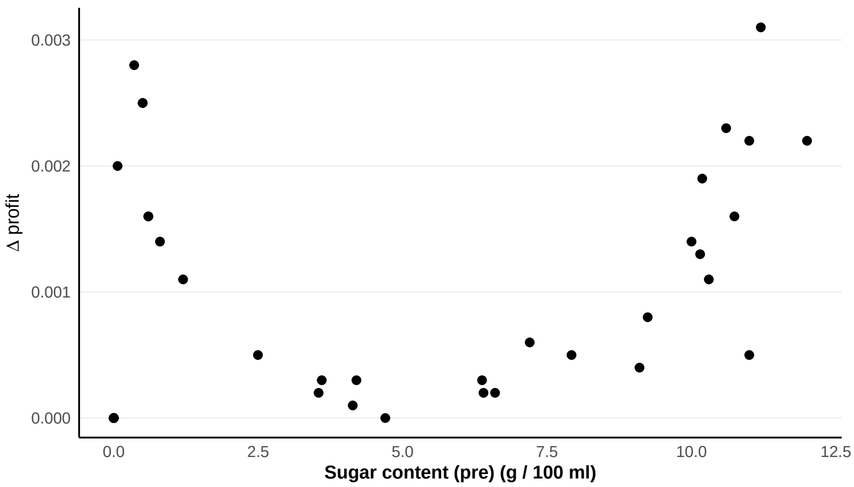

Figure 2: Estimated variation in profit due to reformulation

Notes: The figure reports the estimated profit differences $\Pi^f_t(q^*_{kt}, \tilde{q}_{-k,t}) - \Pi^f_t(\tilde{q}_t)$ as a function of the pre-reformulation sugar content. Each point corresponds to the counterfactual change in equilibrium profits obtained by replacing the observed formulation with the profit-maximizing sugar level while holding the formulations of other products fixed. According to the inequality derived above, these profit gains provide lower bounds on the reformulation costs A^q_{kt}.

Figure 2 reports the estimated profit differences $\Pi^f_t(q^*_{kt}, \tilde{q}_{-k,t}) - \Pi^f_t(\tilde{q}_t)$ as a function of the pre-reformulation sugar content. These profit gains correspond to the counterfactual increase in profits that would result from reformulating product k while keeping the formulations of other products fixed.

According to the inequality derived above, the absence of reformulation implies that the fixed reformulation cost must be at least as large as these potential profit gains. The values reported in Figure 2 therefore provide empirical lower bounds on the reformulation costs A^q_{kt} for the corresponding products.

A notable feature of Figure 2 is that the implied reformulation incentives vary systematically with the initial sugar content of the product. In particular, the profit gains from reformulation appear relatively small for products located near the center of the sugar distribution, while they increase for products with either very low or very high sugar content.

To better understand this pattern, we examine how these cost of reformulation relate to the distance between a product's initial sugar level and the average sugar content observed in the market.

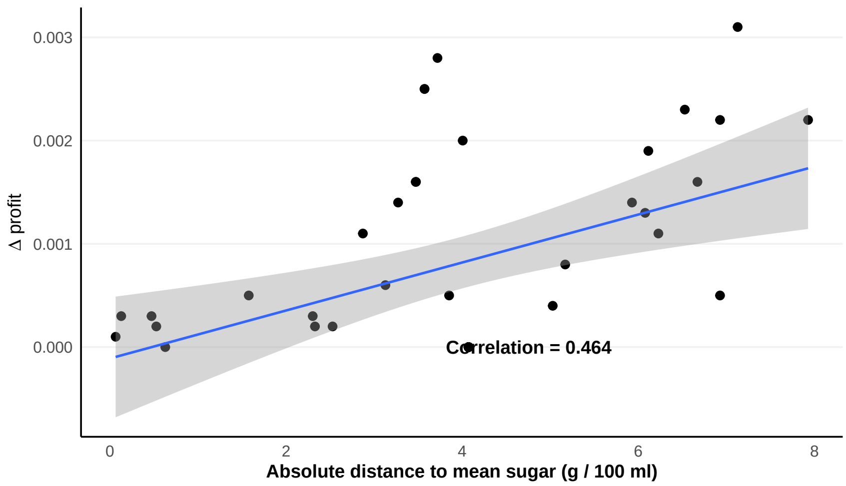

Figure 3: Profit variation from reformulation

Notes: The figure plots the estimated profit gains from reformulation, $\Pi^f_t(q^*_{kt}, \tilde{q}_{-k,t}) - \Pi^f_t(\tilde{q}_t)$, against the absolute distance between a product's initial sugar content and the mean sugar level in the market. Each point corresponds to a product in the sample. The correlation between the two variables is 0.464.

Figure 3 provides additional insight into the pattern observed in the previous figure. The profit gains from reformulation are plotted against the absolute distance between a product's initial sugar content and the average sugar level in the market. A clear positive relationship emerges: products whose initial formulation lies further away from the center of the sugar distribution tend to exhibit larger potential profit gains from reformulation.

The correlation between the two variables is 0.464, indicating a moderate but meaningful relationship between the distance to the mean sugar content in the market and the estimated reformulation cost.

Taken together, these results suggest that implied reformulation costs are not uniform across products, but vary systematically with a product's position in the sugar distribution. Products located further from the center of the distribution are associated with larger values of the counterfactual profit gain from reformulation, and therefore with higher implied lower bounds on reformulation costs.

After reformulation In the final periods of the sample, all products that undergo reformulation appear exclusively in their reformulated state, and the Soft Drinks Industry Levy (SDIL) is fully implemented. As a result, the sugar levels observed in the data correspond directly to the reformulated choices q^*_{kt} selected by firms.

In this case, the optimal sugar level does not need to be recovered through the profit maximization problem, since the reformulated formulation is directly observed in the data. The profit associated with the reformulated state can therefore be computed directly using the estimated demand system and the corresponding equilibrium product characteristics.

Firms set prices to maximize profits given the vector of product characteristics, including the reformulated sugar levels. The only modification relative to the pre-reformulation environment is that the SDIL enters marginal costs for products whose sugar content exceeds the relevant tax thresholds. Formally, marginal costs can be written as

$$c_{jt} = c^0_{jt} + \tau(q_{jt}), \tag{22}$$

where c^0_{jt} denotes the baseline production cost and $\tau(q_{jt})$, represents the tax component implied by the product's sugar content.

Using the estimated demand system, these conditions allow the recovery of equilibrium profits under the observed reformulated formulations q^*_{kt}. These profits can then be compared with the counterfactual profits associated with the pre-reformulation formulation, providing the complementary inequality that yields an upper bound on the reformulation cost A_{kt}, but only for reformulated products.

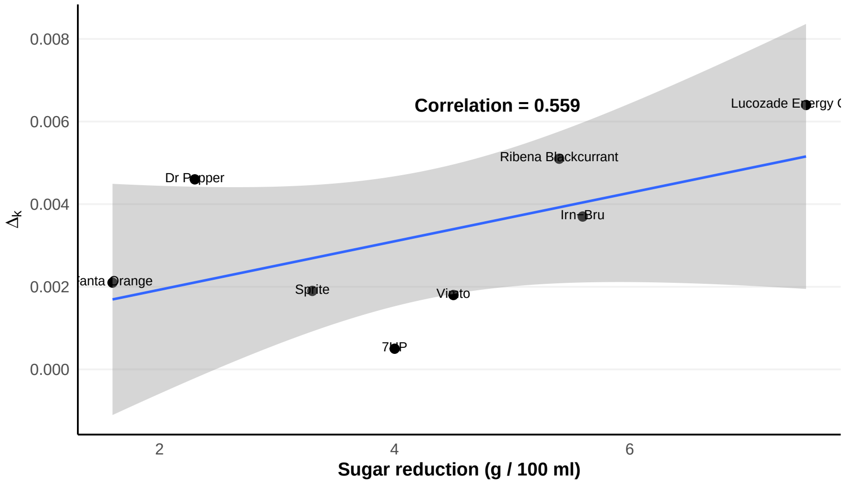

Figure 4: Profit gains and sugar reductions for reformulated products.

Notes: The figure plots the estimated profit change from reformulation, $\Delta\Pi_{kt} = \Pi_t^f(q_{kt}^*, \tilde{q}_{-k,t}) - \Pi_t^f(\tilde{q}_t)$, against the change in sugar content between the pre- and post-reformulation states for products that are observed to reformulate.

Figure 4 relates the estimated profit change from reformulation to the magnitude of the sugar reduction implemented by firms. Since reformulation is observed for these products, the profit differences $\Delta\Pi_{kt}$ provide the empirical counterpart of the upper bound on the reformulation cost A_{kt}^q.

Beyond this identification role, the figure also provides insight into the economic consequences of reformulation for firms. The positive relationship indicates that larger reductions in sugar content are associated with larger profit differences. This pattern may suggest that firms undertaking large reformulations were also those for which the cost of not reformulating would have been the highest.

6 Counterfactual reformulation under a sugar tax

Using the estimated bounds on reformulation costs A_j, the incentives for firms to adjust sugar content in response to a tax on sugar can be evaluated. Let τ denote the tax per gram of sugar.

The tax enters the model as a marginal cost shifter, so that for any vector of sugar contents q the post-tax marginal cost becomes

$$\tilde{c}^{\tau}(q) = \hat{c} + \tau q,$$

where $\hat{c}$ denotes the estimated baseline marginal cost vector.

Conditional on a given sugar vector q, firms compete in prices in the second stage according to the Bertrand pricing game described in Section 3.3. Let $p^*(q,\tau)$ denote the vector of equilibrium prices that solves the pricing first-order conditions under the tax. Market shares follow from the estimated demand system.

Firm f's profit under the tax is therefore

$$\Pi^f(q,\tau) = \sum_{j \in G_f} M \left(p_j^*(q,\tau) - \tilde{c}_j^{\tau}(q) \right) S_j(p^*(q,\tau), q)\,. \tag{23}$$

The tax creates incentives for firms to adjust the sugar content of their products. For each product $k \in G_f^s$, s indicating the subset of products that can adjust sugar, the firm compares the profit obtained when the product is reformulated to the profit obtained when its sugar content is kept at the pre-tax level. Let q^0 denote the observed sugar vector in the absence of reformulation. Let q_k^* denote the optimal product k sugar level while the sugar content of all other products remains fixed. Product k is reformulated if and only if

$$\Pi^f(q_k^*, q_{-k}, \tau) - A_k \;\geq\; \Pi^f(q^0, \tau). \tag{24}$$

This condition characterizes a discrete adoption decision at the product level: reformulation occurs when the gain in variable profits generated by the reduction in the tax burden exceeds the fixed reformulation cost. Because prices are determined endogenously in the second stage, both $\Pi^f(q_k^*, q_{-k}), \tau)$ and $\Pi^f(q^0, \tau)$ incorporate the equilibrium adjustment of prices and market shares induced by the tax and by the change in product characteristics.

A stylized reformulation cost function is therefore introduced:

$$A_k = A_0 + \gamma \Delta q_k,$$

where Δq_k denotes the reduction in sugar content for product k. The slope parameter γ is calibrated using the estimated relationship between the reformulation cost proxy Δ_k and the magnitude of sugar reduction. The corresponding regression yields a slope coefficient of approximately 7.8×10^{-4}, indicating that larger reductions in sugar content are associated with higher reformulation costs.

Operationally, for a given tax level τ, the post-tax equilibrium is first computed while holding the observed sugar vector fixed. This delivers the benchmark profit level $\Pi^f(q^0, \tau)$. The counterfactual profit associated with reformulating each product $k \in G_f^s$ is then evaluated while holding the formulations of all other products fixed. Whenever condition (24) is satisfied, the product is assumed to reformulate.

In general, however, reformulation decisions are interdependent because any change in q affects equilibrium prices and market shares for all products through the Bertrand pricing equilibrium. To account for these interactions, the equilibrium is computed iteratively. Starting from the observed sugar vector q^0, the reformulation condition is evaluated for each product given the current sugar vector. For products satisfying the condition, the sugar level is updated to the optimal reformulated value. Given the updated sugar vector, equilibrium prices and profits are recomputed. This procedure is repeated until the set of reformulated products and the associated sugar levels converge.

At convergence, the resulting configuration constitutes a Nash equilibrium in reformulation decisions: no firm has a profitable unilateral deviation in sugar content given the equilibrium sugar vector and the associated pricing equilibrium.

6.1 Counterfactual evaluation of the SDIL

As stated previously, the policy introduced a tiered tax structure based on the sugar content of beverages. Products containing less than 5 grams of sugar per 100ml are exempt from the tax. Drinks with sugar content between 5 and 8 grams per 100ml are subject to a lower tax tier, while beverages exceeding 8 grams per 100ml face a higher tax rate. The tax is levied on manufacturers and therefore enters the model as a marginal cost component that depends directly on the sugar content of each product.

Using the estimated demand system, pricing equilibrium, and the calibrated reformulation cost function, counterfactual equilibria can be computed under the SDIL. The simulation allows firms to adjust the sugar content of their products when doing so increases profits net of the fixed reformulation cost. For each product, the decision to reformulate follows the adoption rule described in equation (24), while prices adjust endogenously according to the Bertrand pricing equilibrium.

The resulting equilibrium therefore incorporates both channels through which the tax affects market outcomes: the direct impact of the tax on marginal costs and prices, and the endogenous reformulation response of firms that adjust the sugar content of their products in order to reduce tax exposure.

The full equilibrium is achieved after four iterations of the procedure, after which no firms have an incentive to move their products characteristics.

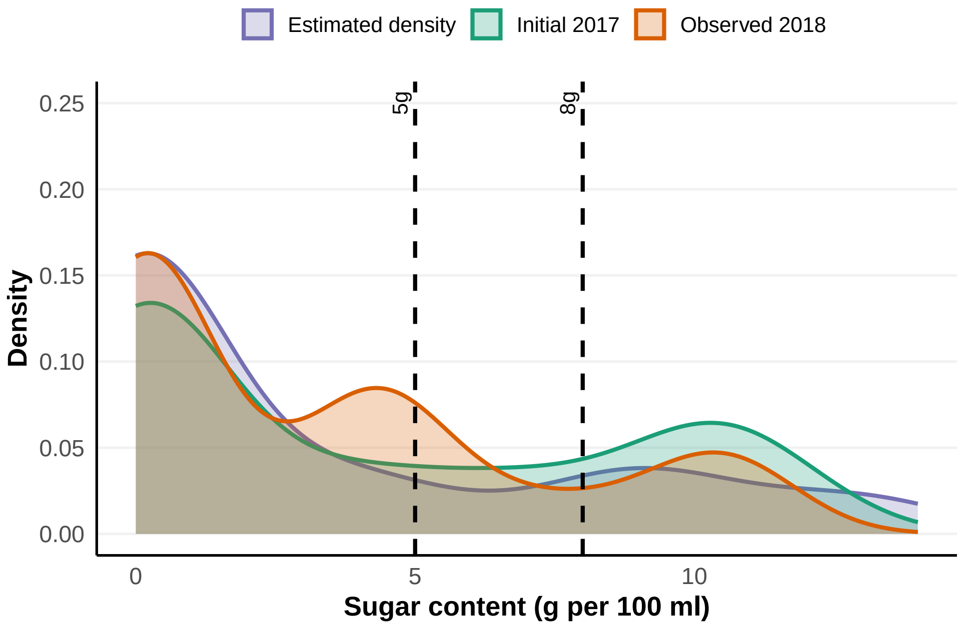

Figure 5: Sugar content distribution.

Notes: The figure compares the distribution of sugar content across products before reformulation, after the reformulation observed in the data, and under the counterfactual reformulation outcomes implied by the model. Vertical dashed lines indicate the SDIL thresholds at 5g and 8g of sugar per 100ml.

Figure 5 compares the distribution of sugar content across products before reformulation, after the reformulation observed in the data, and under the counterfactual reformulation outcomes implied by the model. The observed 2018 distribution shows a substantial reduction in high-sugar products relative to the 2017 baseline.

The counterfactual distribution predicted by the model captures part of this shift, but it does not reproduce the bunching of products just below the 5g threshold that appears in the data. Instead, the simulated distribution remains smoother around the tax thresholds and even predicts a slight increase in sugar content for some products located at the upper end of the distribution.

This discrepancy suggests that the model captures the general incentives to adjust sugar content in response to the tax, but it may miss additional mechanisms that generate sharp bunching behavior around policy thresholds in practice.

7 Limitations and directions for future research

The framework developed in this paper provides a first step toward understanding how firms strategically respond to the Soft Drinks Industry Levy. Several extensions are currently being developed in order to better capture the mechanisms that are only partially addressed in the present application.

First, the demand specification can be enriched to better capture consumer preferences. In the current model, preferences for diet products and alternative sweeteners are not explicitly modeled, even though these products represent an important margin of substitution in the soft drink market. Incorporating these alternatives would allow the analysis to better capture consumer responses to changes in sugar content and to distinguish between reformulation toward lower sugar levels and substitution toward diet beverages.

Second, the current specification does not fully exploit the richness of the household panel data. In particular, the demographic characteristics of consumers observed in the Kantar Worldpanel dataset could be incorporated. Accounting for demographic heterogeneity would provide a more detailed characterization of substitution patterns and improve the identification of consumer responses to sugar content.

Finally, future research could extend the empirical framework toward a fully structural estimation of the model. The objective is to estimate consumer demand, firms' pricing behavior, and the cost structure of the market within a single unified framework. The estimation combines the demand-side restrictions implied by the discrete-choice model with the pricing first-order conditions implied by multiproduct Bertrand competition.

In this structural specification, firms compete in prices while taking product characteristics as given. At the same time, the policy enters the model through the marginal cost function, since the Soft Drinks Industry Levy directly increases the cost of supplying beverages with high sugar content. Estimating the demand and supply sides jointly therefore allows the model to capture both consumer substitution and firms' pricing responses to the policy.

Demand moments. Let $\xi_{jt}(\theta)$ denote the unobserved demand shock associated with product j in period t, implied by the demand system for a given parameter vector θ. This term captures product attributes that affect consumer utility but are not observed by the econometrician.

Identification relies on the standard orthogonality condition between these unobserved demand shocks and a set of instruments Z_{jt}:

$$\mathbb{E}\left[Z_{jt}\,\xi_{jt}(\theta)\right] = 0. \tag{25}$$

The instrument set includes several sources of exogenous variation. First, cost shifters and policy exposure variables provide instruments for prices. In particular, variables related to the SDIL, such as indicators capturing whether a product is subject to the levy after its implementation, generate variation in marginal costs that is independent of product-level demand shocks.

Second, the instrument set includes standard differentiation instruments used in the random-coefficients logit literature. Following Berry et al. (1995), these instruments are constructed from functions of the characteristics of rival products within the same market. Intuitively, they capture variation in the competitive environment faced by each product, such as the number and attributes of competing beverages. Because these variables are determined by firms' product portfolios rather than by idiosyncratic demand shocks, they provide useful exogenous variation for identifying demand parameters.

Supply-side moments. Given estimates of the demand parameters, firms' pricing behavior can be used to recover marginal costs. Firms are assumed to compete in prices according to a multiproduct Bertrand equilibrium. In this setting, each firm chooses prices to maximize profits taking the prices of rival products as given.

Let Ω denote the ownership matrix indicating which products are owned by the same firm, and let $\Delta_t(\theta)$ denote the matrix of derivatives of market shares with respect to prices implied by the demand system. The Bertrand pricing equilibrium implies the following relationship between prices, marginal costs, and demand elasticities:

$$p_t - c_t = -\left(\Omega \odot \Delta_t(\theta)\right)^{-1} S_t, \tag{26}$$

where s_t denotes the vector of market shares in period t, and the Hadamard product $\odot$ accounts for multiproduct ownership. When demand is integrated over formulation states, both market shares and demand derivatives are replaced by their expectations across those states.

This pricing system allows marginal costs to be recovered from observed prices and estimated demand elasticities. Let $\hat{c}_{jt}(\theta)$ denote the marginal cost implied by the pricing equilibrium for product j in period t.

Marginal cost is decomposed into two components. The first component captures baseline production and distribution costs, while the second component captures the policy-induced cost wedge created by the SDIL:

$$\hat{c}_{jt}(\theta) = \tilde{c}_{jt} + \mathsf{SDIL}_{jt}. \tag{27}$$

The baseline marginal cost is parameterized as

$$\tilde{c}_{jt} = w_{jt}'\kappa + \omega_{jt}, \tag{28}$$

where w_{jt} collects observed cost shifters, κ is a vector of cost parameters, and ω_{jt} denotes an unobserved cost shock.

The SDIL component captures the fact that the policy increases marginal costs for products with sugar content above the statutory thresholds. Because this cost variation is determined by the policy design rather than by firms' pricing decisions, it provides additional variation that helps identify the supply side of the model.

Supply-side moment conditions exploit the orthogonality between cost instruments and the unobserved cost shock:

$$\mathbb{E}\left[W_{jt}\left(\hat{c}_{jt}(\theta) - w_{jt}'\kappa - \mathsf{SDIL}_{jt}\right)\right] = 0, \tag{29}$$

where W_{jt} denotes a set of instruments that are assumed to be uncorrelated with ω_{jt}. These instruments typically include observed cost shifters as well as additional variables related to manufacturers and product characteristics.

Joint GMM. The parameters of the model are estimated by jointly matching the implications of the demand and supply systems. Let $g(\theta)$ denote the vector of sample moments stacking the demand and supply restrictions:

$$g(\theta) = \begin{pmatrix} \mathbb{E}[Z_{jt}\, \xi_{jt}(\theta)] \\ \mathbb{E}[W_{jt}\, \omega_{jt}(\theta)] \end{pmatrix}. \tag{30}$$

The structural parameter vector θ is then obtained by minimizing a quadratic form in these stacked moments:

$$\hat{\theta} = \arg\min_{\theta}\ g(\theta)'\, \hat{W}\, g(\theta), \tag{31}$$

where $\hat{W}$ is a positive definite weighting matrix.

This joint estimation procedure enforces consistency between the demand system and firms' pricing behavior. By estimating demand parameters and marginal costs simultaneously, the model incorporates the policy-induced cost wedge directly into the supply side while maintaining the structural restrictions implied by oligopolistic price competition.

Integration over formulation states in the GMM estimation. The same integration over formulation states described in the demand likelihood carries through to the structural estimation of the model. Because some products may be sold under different formulations with probabilistic availability, the demand system implies state-contingent market shares and demand derivatives for each configuration $\omega \in \Omega_t$. In practice, the econometrician does not condition on the realized formulation state but instead integrates over the distribution of possible states using the observed probabilities $\pi_{\omega t}$.

Let $S_{jt}(\omega)$ denote the share implied by the demand system under state ω. Expected market shares are therefore given by

$$\bar{S}_{jt}(\theta) = \sum_{\omega \in \Omega_t} \pi_{\omega t} S_{jt}(\omega). \tag{32}$$

These expected shares are used when recovering the unobserved demand shocks $\xi_{jt}(\theta)$ that enter the demand moment conditions. Similarly, the matrix of demand derivatives entering the pricing first-order conditions is computed as the expectation of the state-specific derivative matrices.

As a result, both the demand-side and supply-side moments used in the GMM estimation are evaluated using objects that integrate over the distribution of possible formulation states. This ensures that the structural estimation remains consistent with the stochastic availability of reformulated products observed in the data.

References

Aguilar, A., Gutierrez, E., and Seira, E. (2021). The effectiveness of sin food taxes: Evidence from Mexico. *Journal of Health Economics*, 77:102455.

Allcott, H., Lockwood, B. B., and Taubinsky, D. (2019). Should We Tax Sugar-Sweetened Beverages? An Overview of Theory and Evidence. *Journal of Economic Perspectives*, 33(3):202–227.

Bandy, L. K., Scarborough, P., Harrington, R. A., Rayner, M., and Jebb, S. A. (2020). Reductions in sugar sales from soft drinks in the UK from 2015 to 2018. *BMC medicine*, 18(1):20.

Barahona, N., Otero, C., and Otero, S. (2023). Equilibrium Effects of Food Labeling Policies. *Econometrica*, 91(3):839–868. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.3982/ECTA19603.

Berry, S., Levinsohn, J., and Pakes, A. (1995). Automobile Prices in Market Equilibrium. *Econometrica*, 63(4):841.

Berry, S., Levinsohn, J., and Pakes, A. (2004). Differentiated Products Demand Systems from a Combination of Micro and Macro Data: The New Car Market. *Journal of Political Economy*, 112(1):68–105.

Bonnet, C. and Réquillart, V. (2013). Tax incidence with strategic firms in the soft drink market. *Journal of Public Economics*, 106:77–88.

Capacci, S., Allais, O., Bonnet, C., and Mazzocchi, M. (2019). The impact of the French soda tax on prices and purchases. An ex post evaluation. *PLOS ONE*, 14(10):e0223196.

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

Colchero, M. A., Popkin, B. M., Rivera, J. A., and Ng, S. W. (2016). Beverage purchases from stores in Mexico under the excise tax on sugar sweetened beverages: observational study. *BMJ*, 352:h6704.

Colchero, M. A., Rivera-Dommarco, J., Popkin, B. M., and Ng, S. W. (2017). In Mexico, Evidence Of Sustained Consumer Response Two Years After Implementing A Sugar-Sweetened Beverage Tax. *Health Affairs*, 36(3):564–571.

Conlon, C. T. and Mortimer, J. H. (2013). Demand Estimation under Incomplete Product Availability. *American Economic Journal: Microeconomics*, 5(4):1–30.

Dickson, A., Gehrsitz, M., and Kemp, J. (2025). Does a Spoonful of Sugar Levy Help the Calories Go Down? An Analysis of the UK Soft Drinks Industry Levy. *The Review of Economics and Statistics*, 107(6):1754–1763.

Dubois, P., Griffith, R., and O'Connell, M. (2020). How Well Targeted Are Soda Taxes? *American Economic Review*, 110(11):3661–3704.

Etilé, F., Lecocq, S., and Boizot-Szantai, C. (2021). Market heterogeneity and the distributional incidence of soft-drink taxes: evidence from France. *European Review of Agricultural Economics*, 48(4):915–939.

Griffith, R., O'Connell, M., and Smith, K. (2017). The Importance of Product Reformulation Versus Consumer Choice in Improving Diet Quality. *Economica*, 84(333):34–53. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/ecca.12192.

Griffith, R., O'Connell, M., Smith, K., and Stroud, R. (2019). *The evidence on the effects of soft drink taxes*. IFS.

Griffith, R., O'Connell, M., and Smith, K. (2018). Corrective Taxation and Internalities from Food Consumption. *CESifo Economic Studies*, 64(1):1–14.

Koujianou Goldberg, P. and Hellerstein, R. (2013). A Structural Approach to Identifying the Sources of Local Currency Price Stability. *The Review of Economic Studies*, 80(1):175–210.

Nevo, A. (2001). Measuring Market Power in the Ready-to-Eat Cereal Industry. *Econometrica*, 69(2):307–342. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/1468-0262.00194.

Rogers, N. T., Pell, D., Mytton, O. T., Penney, T. L., Briggs, A., Cummins, S., Jones, C., Rayner, M., Rutter, H., Scarborough, P., Sharp, S., Smith, R., White, M., and Adams, J.

(2023). Changes in soft drinks purchased by British households associated with the UK soft drinks industry levy: a controlled interrupted time series analysis. *BMJ Open*, 13(12):e077059.

Scarborough, P., Adhikari, V., Harrington, R. A., Elhussein, A., Briggs, A., Rayner, M., Adams, J., Cummins, S., Penney, T., and White, M. (2020). Impact of the announcement and implementation of the UK Soft Drinks Industry Levy on sugar content, price, product size and number of available soft drinks in the UK, 2015-19: A controlled interrupted time series analysis. *PLOS Medicine*, 17(2):e1003025.

Seiler, S., Tuchman, A., and Yao, S. (2021). The Impact of Soda Taxes: Pass-Through, Tax Avoidance, and Nutritional Effects. *Journal of Marketing Research*, 58(1):22–49.

Silver, L. D., Ng, S. W., Ryan-Ibarra, S., Taillie, L. S., Induni, M., Miles, D. R., Poti, J. M., and Popkin, B. M. (2017). Changes in prices, sales, consumer spending, and beverage consumption one year after a tax on sugar-sweetened beverages in Berkeley, California, US: A before-and-after study. *PLOS Medicine*, 14(4):e1002283.