Reformulation and taxes for healthier consumption: Empirical evidence in the French Dessert market

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Abstract

Many countries have implemented the taxation of unhealthy food. Facing such a tax, firms can adapt their pricing strategy and modify the characteristics of their products. There are, so far, only a few ex-ante analyses of the impact of taxes on consumption that endogenize the price response of firms to the tax policy. However, none of them takes into account the possibility for firms to modify the characteristics of a product. In this paper, we propose an ex-ante evaluation of the effects of a tax that targets products high in caloric sweeteners on key market outcomes, by integrating not only the strategic price reactions of firms, but also the exogenous changes in a product's nutritional composition. We develop a structural econometric model that integrates the consumer's substitution patterns between products, accounts for competition between firms, and integrates the possibility for firms to modify the characteristics of a product in response to taxation. Using household scanner data from the French dessert market, we show that ignoring how firms might react to a tax policy leads to a significant underestimation of the potential impact of taxation on the consumption of taxed nutrients. In our case, we show that ignoring the combined effect of strategic price reactions and product reformulation leads to the impact of the tax on the intake of the taxed nutrient being underestimated by 44%. From a policy-oriented perspective, we conclude that a taxation scheme should be designed to favor product reformulation by firms.

JEL codes: H32, L13, Q18, I18

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1 Introduction

The number of countries that have implemented a tax on unhealthy foods is growing rapidly.[1] Most taxes target sugary beverages but in some cases they also target sugary products or fatty products.[2] Ex-post evaluations of the impact of taxation show that they can curb consumption (e.g., Colchero et al., 2015; Silver et al., 2017; Mora et al., 2019; Capacci et al., 2019). The decrease of consumption is generally considered to be a consequence of the price increase of taxed products. However, several studies have shown that the price transmission of the tax is heterogeneous. For example, in the case of the soda tax in Berkeley, Silver et al. (2017) found that the pass-through of the tax depends on the type of retailer.[3] Capacci et al. (2019), in the case of the soda tax in France, found that the pass-through rate depends on the type of beverage.[4]

In addition to price changes, tax policy can also induce changes in the characteristics of products, as has been shown in theoretical analysis. Duvaleix-Tréguer et al. (2012) studied how firms react to a tax based on the nutrient content of their products. In their framework, a product is taxed only if its content in the targeted nutrient is above a threshold. They showed that, provided that the threshold is not too low, a firm prefers to reformulate its product to avoid the tax, leading to positive results for health and welfare. They also showed that prices are readjusted after the introduction of the tax, even if a firm escapes the tax by modifying the nutrient content of her product. Réquillart et al. (2016) studied how two competing firms, with each firm producing one good, react to various nutritional policies. With excise tax proportional to the nutrient content of the product, they found that both the nutrient content and the price of the two products sold on the market are affected by the tax. This result holds even if the tax directly affects only one firm. In this case, the firm producing the low-quality good (that is, a good with a high content of a nutrient that has an adverse effect on health) improves the quality of her good in order to pay a lower tax and the firm producing the high-quality good (which does not pay any tax) decreases the quality of her good. Overall, the tax increases welfare. These theoretical changes in the product recipe were observed for the revised soda tax implemented in France.[5] Thus, integrating the possibility for firms to reformulate their products is

[1] From 2010 to 2013 at least five countries have implemented taxes on unhealthy products, and since 2015, more than 10 countries and several cities have enforced a tax on sugary drinks (Cornelsen and Smith, 2018).

[2] A well-known example is the Danish tax on fatty products (Jensen and Smed, 2013).

[3] The pass-through rate was larger than 1 in supermarket chains but lower than 1 (or even negative) in some independent shops.

[4] They found that the tax was fully transmitted in the case of sugary sweetened beverages (SSB) and over-shifted in the case of diet products. In a previous study, Berardi et al. (2016) also found pass-through rates that depend on the type of beverages.

[5] The new soda tax is triggered at 3€ per hectolitre for products containing less than 1g of added-sugar per 100ml of product. It in-

crucial to be able to produce an accurate and relevant assessment of the tax; all the more so from the perspective of assessing the consequences of the policy on health. If firms react to this ‘quality’ incentive by lowering the content in the taxed nutrient, consumers’ nutrient intakes are affected whether consumers modify their consumption of taxed products or not.

The aim of this study is to assess the effect of an (ex-ante) tax policy on key market outcomes, such as the equilibrium prices, market shares, firm profits, and nutrient consumption, by integrating firms’ reactions to both the prices and characteristics of products. While there are now a small number of works that endogenize how firms are likely to modify their prices in response to taxation (Bonnet and Réquillart, 2013; Nesheim et al., 2018; Allais et al., 2015; Dubois et al., 2018), to the best of our knowledge, there is no empirical study that integrates a change in the characteristics of products that might result from taxation.[6] In this paper, we assume an exogenous firms’ response in product quality to the tax. These changes consist of decreasing the content of the taxed nutrient so that a firm can lower the level of the tax she must pay or even in some cases fully escape the tax. The proposed changes are *a priori* beneficial for the firms, in the sense that the decrease in the amount of the per-unit tax is larger than the cost increase, if any, to achieve product reformulation. However, we cannot claim that these changes in the nutritional content of products are the changes that would occur at equilibrium.

Specifically, we develop a structural econometric model that integrates consumers substitution patterns and accounts for competition between firms. The methodology is based on a four-step approach. First, we estimate price and quality preferences of consumers for the differentiated products in the market, using a random coefficient logit model. Second, a supply model is developed assuming price competition between firms. The model provides estimates of the marginal cost and margin of each product. Third, using estimated marginal costs and input price data, we estimate a cost model that is used to assess the cost change due to product reformulation. Finally, we evaluate the impact of sugar taxation. Following Duvaleix-Tréguer et al. (2012), we assume that a product is taxed if its sugar content is above a certain threshold, and the amount of the excise tax is proportional to the

creases gradually according to the added sugar content, reaching for example 23.5€ per hectolitre for products containing 14 to 15g of added sugar per 100ml of product. Several brands anticipated the change in the tax design and reduced the sugar content of their products (see https://www.bfmtv.com/economie/sprite-7up-lipton-ice-tea-pourquoi-ces-sodas-contiennent-soudainement-moins-de-sucre-1490320.html)

[6] More generally there are very few empirical studies evaluating the impact of nutritional policies on the nutrient contents of food products, except if the policy directly targets the nutrient content (e.g., product reformulation policies). An exception is Moorman et al. (2012), who investigated how firms respond to standardized nutrition labels on food products required by the US Nutrition Labeling and Education Act. They showed that firms did modify the characteristics of their products in response to the policy.

product's sugar content. We use the structural demand and supply model to determine and compare the new market equilibrium in two different cases: one in which firms do not reformulate their products; and a second in which firms do reformulate their products. In any case, firms strategically react in price to the taxation scheme, as in Bonnet and Réquillart (2013).

The methodology is applied to evaluate the impact of taxation targeting products that are high in caloric sweeteners in the French dessert market. In this market, we focus the analysis on compotes, yogurts, fromages blancs/petits suisses (FBPS) and other dairy desserts (ODD). We choose the dessert market for different reasons. First, these products are an important contributor to simple carbohydrate intakes, the consumption of which needs to be reduced. In particular, yogurts and FBPS are the second major contributor of children's carbohydrate intakes. Second, there is room for product reformulation as, within each family of products, there is a large heterogeneity in the sugar content of products. Third, these products are made of several ingredients in addition to the sweeteners. This makes the analysis of product reformulation more interesting, in the sense that a reduction in the sugar content from added caloric sweeteners of a product may be accompanied by an increase in the content of some other nutrients, such as fat from milk or fructose from fruits. The net impact on health may be positive or negative, depending on the product recipe changes.

We first analyze the potential impact of product reformulation, and show that reformulation is a potentially important tool to decrease the intake of caloric sweeteners. Thus, we estimate that product reformulation would lead to a decrease in the intake of caloric sweeteners by about 7%. Most of the effect comes from the mechanical impact of the product reformulation whereas changes in demand and prices induced by product reformulation plays a minor role. Then, we analyze the impact of taxation and show that firms' price reactions amplify the potential impact of the tax on the intake of caloric sweeteners. Thus, firms have an interest to over-transmit the price changes to consumers as in Bonnet and Réquillart (2013). In some sense, they partly counterbalance the decrease in the quantities sold by an increase in the per-unit margin, but by doing so, they amplify the decrease in consumption leading to a larger impact of the tax on caloric sweetener intake. We also show that the industry facing the tax has an interest in reformulating the products sold. Reformulation is a way for the industry to limit the negative impact of taxation on their profits. By lowering the caloric sweetener content of their products, firms face lower taxes per unit of product and in some circumstances, and for some products, they fully escape the tax. Finally, we show that taxation and reformulation act in the same direction; that is, to reduce the intake in the taxed nutrient. These results have important consequences. From a research perspective, ignoring how firms might react to a tax policy leads to a significant under-estimation of the potential impact of taxation on the consumption of taxed nutrients. In our case, we show that ignoring the combined effect of strategic price reactions and product reformulation leads to an underestimation of the impact of the tax on the intake in the taxed nutrient of 44%. From a policy-oriented perspective, we conclude that a taxation scheme should be designed in order to favor product reformulation by firms.

The paper is organized as follows. Section 2 introduces the data and provides a descriptive analysis of the French dessert market. Section 3 describes the models and methods. Section 4 provides the results on demand and supply. Section 5 provides the impacts on consumption, market equilibrium, profits of reformulation strategy, and taxation scenario. Finally, Section 6 concludes.

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. In this work we consider all purchases of desserts over the period January-May 2009, corresponding to more than 1,600,000 observations. In particular, quantities, prices, brands, and characteristics of goods are registered. The relevant market is the whole dessert market, except ice cream; a rarely purchased product in France during the period of time chosen accounting for less than 1% of the average dessert budget share over the period. Specifically, we define four broad dessert categories as follows: yogurts (plain; sweetened; flavored; with fruits), FBPS (plain; flavored;with fruits),[7] ODD (cream desserts, 'crême brulée' desserts, coffee and chocolate mousses, style custard flans, French rice puddings, Floating Island desserts[8]) and fruit compotes or stewed fruits.[9] We classify yogurts, and FBPS into brand, fat content, sugar content and flavor categories. We get 75 different yogurts and 41 different

[7]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.

[8]A classic French dessert that consists of meringue floating on a sea of vanilla custard

[9]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 three sugar content and flavor categories: plain, sweet, flavored, and with fruits.

Table 1: **Average prices (€/kg) and market shares (%) by brands and product categories.**

	Compotes		Yogurts		Fromages blancs, petits suisses		Other dairy desserts	
	Price	MS	Price	MS	Price	MS	Price	MS
Firm 1								
Brand 1			2.19	1.82	3.09	1.40	3.07	2.65
Brand 2			2.08	0.68	3.04	0.31	3.96	0.30
Brand 3			4.82	0.17				
Brand 4			3.51	0.56				
Brand 5			2.60	2.12	4.02	0.49		
Firm 2								
Brand 6			2.25	1.65	5.37	0.22	3.57	2.92
Firm 3								
Brand 7			1.91	0.80	2.65	0.64	3.79	0.10
Brand 8			2.18	0.83				
Brand 9			2.29	0.42				
Firm 4								
Brand 10	3.31	0.45	1.79	0.58	3.23	0.18	5.59	0.58
Firm 5								
Brand 11	3.27	0.62					4.30	0.32
Firm 6								
Brand 12			1.77	0.74	4.15	0.10	5.52	0.36
Brand 13			3.81	0.22			3.84	0.23
PL firms								
PLs	2.31	3.06	1.74	6.27	2.38	3.96	2.40	8.07
All	2.62	4.04	2.20	15.91	2.90	6.44	3.27	12.46

Product categories

The reported prices of a brand and a category is the weighted average (using market shares as weights) of the prices of this brand in this category over the different retailers. MS stands for Market Shares.

FBPS. We have nine different compotes defined by function of brand and sugar content level.[10] We distinguish 13 primary national brands (NBs), and one private label brand (PL). ODDs are only brand differentiated. Overall, the household product set is composed of 159 differentiated products. Consumers can substitute the considered products with an alternative product, the so-called 'outside option', which includes other desserts (fruits and pastries), as well as cheese that appears to substitute to dairy desserts in many cases. The outside option represents 61% of the entire market on average.[11]

Table 1 reports weighted average prices and market shares for the four broad dessert categories by brands. Compote, yogurts, FBPS, and ODD account for about 4%, 16%, 6%, and 12% of all dessert purchases, respectively.

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

[11] 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.

Table 2: **Content in caloric sweeteners and sweetness index (taste) by brands and product categories (g / 100g of product).**

	Product categories							
	Compotes		Yogurts		Fromages blancs, petits suisses		Other dairy desserts	
	Content	Taste	Content	Taste	Content	Taste	Content	Taste
Brand 1			9.6	9.6	9.2	9.2	20.0	20.0
Brand 2			6.4	10.3	4.9	7.5	11.2	17.7
Brand 3			5.1	9.1				
Brand 4			7.5	11.0				
Brand 5			9.7	11.1	8.4	8.4		
Brand 6			9.1	10.6	10.0	11.6	16.2	16.4
Brand 7			11.5	11.5	5.6	5.6	16.9	16.9
Brand 8			11.2	13.9				
Brand 9			12.2	12.2				
Brand 10	14.1	14.1	9.9	9.9	4.7	4.7	14.9	14.9
Brand 11	14.5	14.5					13.7	13.7
Brand 12			9.8	10.5	4.7	4.7	17.1	17.1
Brand 13			7.1	7.1			12.1	12.1
PLs	14.6	14.6	9.6	10.7	6.9	7.0	16.6	16.6
Average	14.5	14.5	9.5	10.8	7.3	7.5	16.9	17.1
Min	10.7		1.5		0.0		11.2	
First quartile	11.7		4.8		3.3		14.1	
Median	14.4		10.7		4.5		16.2	
Third quartile	17.3		13.2		12.6		18.0	
Max	18.6		17.2		21.6		22.7	

For each brand and product category, we report the weighted average content of sweetener computed over all the different products of a brand

Their respective average price per kg is €2.62, €2.20, €2.90, and €3.27. For each of the four product categories, PL brands are the cheapest and have the highest market shares. This is a market feature that is now common for many product categories and may be due to the fact that consumers no longer perceive large quality differences 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 reducing cholesterol (B3), probiotics (B4, B5), and soy milk (B13) yogurts. The other dairy dessert prices range from €2.40 to €5.59 per kg. The high difference in prices is mainly due to the high heterogeneity of the products (and consequently, the ingredient list) within the category.

Table 2 provides the caloric sweetener content (denoted ‘Content’ in the table) and an index of sweetness (denoted ‘Taste’ in the table) of the different brands and product categories. The caloric sweetener content includes both naturally present sweeteners, such as lactose in milk or fructose in fruits, and added caloric sweeteners, such as sugar or glucose. Except for compotes, there is a large heterogeneity in the mean caloric sweetener content of brands. ODD have the highest content, 16.9% on average, ranging from 11 to 20% depending on the brand. Yogurts and FBPS have the lowest mean contents, 9.5% and 7.3%, respectively. Finally, the average content of compotes is 14.5%. Within a product category, and especially for yogurts and FBPS, we observe an important heterogeneity of caloric sweetener content between products. This content in caloric sweetener will be used to determine (at the product level) the tax rate that is applied to a given product. Because non-caloric sweeteners are also incorporated into some products, we define an index which refers to the sweetness of the product. This index of sweetness of a product is used in the analysis of demand as a proxy for the 'sugar' taste of the product. For products that contain only caloric sweeteners (85% of the products), the index is equal to the caloric sweetener content.[12] For products that contain some (or only) artificial sweeteners, we proxy their sweetness by the sweetness of a similar product that does not contain any artificial sweetener. Artificial sweeteners are used mainly in the yogurt category to enhance the sweetness of products that are low in sugar. On average, the taste index is greater than the content in caloric sweetener for eight brands over the 13 brands of the yogurt category, and the difference, in some cases, is greater than 50%. In most cases, brands with the lowest caloric sweetener content use artificial sweeteners. As a consequence, the heterogeneity in taste is much lower than the heterogeneity in caloric sweetener content. Table 19 (in the Appendix) provides the fat content of the products. Compotes have virtually no fat (0.3% on average), ODD are characterized by a large heterogeneity in fat content and have the highest content (5.6% on average), followed by FBPS (3.9%), and lastly, yogurts (2.4%).

3 Models and methods

Our analysis is based on the following methodology. We first consider a flexible demand model to obtain the price elasticities of demand for every product. The model needs to be as flexible as possible, and we therefore opt for a random coefficient logit model (Berry et al., 1995; McFadden and Train, 2000). We estimate the model using individual data and consider the unobserved heterogeneity of consumers. Second, we model the supply side assuming an oligopolistic competition between manufacturers. The model provides estimates of marginal costs

[12] In theory, it should be the sum of the content in the different caloric sweeteners weighted by their respective sweetness. As we do not have the content in the different sweeteners, we do not weight them by their respective sweetness.

and margins. Third, using estimated marginal costs and input price data, we estimate a cost model that is used to assess the cost change due to product reformulation. Finally, we present the simulation method used to assess the impact of product reformulation and the impact of a tax policy on several market outcomes, such as the new equilibrium prices, market shares, firm profits, and nutrient consumption.

3.1 The demand model: a random coefficient logit model

We use a random coefficient logit model to estimate the demand model and compute the related elasticities between products. The indirect utility function V_{ijt} for consumer i buying product j, for $j = 1,...,J_t$, in period t is given by:

$$V_{ijt} = \beta_{b(j)} + \sum_{c=1}^{C-1} \gamma_{c(j)} - \alpha_i p_{jt} + \delta_S S_j + \delta_L L_j + \delta_{SL} S_j L_j + \theta_N N_j + \theta_F F_j + \varepsilon_{ijt}$$

where $\beta_{b(j)}$ are brand fixed effects that capture (time-invariant) unobserved brand characteristics, $\gamma_{c(j)}$ are category fixed effects that represent (time-invariant) unobserved preferences for the categories, p_{jt} is the price of product j in period t, α_i is the marginal disutility of price for consumer i, S_j is the sugar taste of product j, and δ_S captures consumer taste for sugar, L_j is the lipid (fat) content of product j, and δ_L captures consumer preference for fat taste, δ_{SL} captures consumer preference for fat and sugar taste, N_j is a dummy related to the natural flavor of product j and θ_N captures consumer taste for this characteristic, F_j is a dummy if product j contains fruits in dairy desserts and θ_F captures consumer taste for this characteristic, and ε_{ijt} is an unobserved individual error term.

In our model, consumers can have a different price disutility; the α_i varies across consumers. We assume that the distribution of α_i follows a normal distribution with mean α and standard deviation σ_α. We can then break down the indirect utility into a mean utility $\delta_{jt} = \beta_{b(j)} + \sum_{c=1}^{C-1} \gamma_{c(j)} - \alpha p_{jt} + \delta_S S_j + \delta_L L_j + \delta_{SL} S_j L_j + \theta_N N_j + \theta_F F_j$ and a deviation from this mean utility $\mu_{ijt} = \sigma_\alpha \nu_i p_{jt}$, where ν_i captures unobserved consumer attributes. The indirect utility is given by $V_{ijt} = \delta_{jt} + \mu_{ijt} + \varepsilon_{ijt}$.

The consumer 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. The utility of the outside good 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 market share of product j at period t in the following way (Nevo, 2001):

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

where P_ν is the cumulative normal distribution function of ν, and $\theta = (\alpha, \sigma, \gamma_1, ..., \gamma_{C-1}, \delta_S, \delta_L, \delta_{SL}, \theta_N, \theta_F)$ is the vector of demand parameters to be estimated.

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

$$\frac{\partial s_{jt}}{\partial p_{kt}} \frac{p_{kt}}{s_{jt}} = \begin{cases} -\frac{p_{jt}}{s_{jt}} \int \alpha_i s_{ijt}(1 - s_{ijt}) \, dP(\nu_i) & \text{if } j = k \\ \frac{p_{kt}}{s_{jt}} \int \alpha_i s_{ijt} s_{ikt} \, dP(\nu_i) & \text{otherwise,} \end{cases} \tag{2}$$

where s_{ijt} stands for the probability that a consumer i chooses product j at time t.

3.2 Supply model

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:

$$\Pi_t^f = \sum_{j \in G_f} [M_t(p_{jt} - c_{jt}) s_{jt}(p)]$$

where G_f is the set of products that are sold by manufacturer f, 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, $s_{jt}(p)$ is the market share of product j at time t, given the vector of product price p. The first order conditions that determine the prices of products are given by:

$$s_{jt}(p) + \sum_{k \in G_f} (p_{kt} - c_{kt}) \frac{\partial s_{kt}}{\partial p_{jt}} = 0 \quad \forall j \in G_f \tag{3}$$

Using the above conditions, prices, and estimates of the demand model, we are able to recover margins of manufacturers $\gamma_{jt} = p_{jt} - c_{jt}$ for each product j at time t and we note $\gamma_t(p|\theta)$ the vector of margins. We derive estimates of the total marginal costs, c_{jt}, which represent the marginal costs of production.

3.3 Cost model

As the recipes change with product reformulation, so do the production costs. To infer the change in cost due to a variation in inputs used, we specify a cost model that allow us to identify the average price paid by firms for the main inputs. Only items belonging to the compote, yogurt, and FBPS categories are reformulated. The recipes of items in the ODD category are assumed to remain constant, due to their various and complex recipes and because of manufacturers' uncertainty about consumers' reaction to the reformulation of gourmet foods (Sebillotte, 2016). We assume that the marginal cost of production c_{jt} for product j at period t follows this linear function :

$$c_{jt} = \rho_0 + \rho_S S_j + \rho_Y Y_j + \rho_F F_j + \rho_C Co_j + \tau_Y PFY_j + \tau_{FY} PFFY_j + \tau_F PFF_j + \omega_{c(j)t} + \omega_t(1 - N_j) + \omega_F r Fr_j + \vartheta jt \quad (4)$$

where ρ_0 represents a constant cost common to all products, S_j is the sugar content of product j and ρ_S represent the price of sugar paid by firms, Y_j is the milk content of plain yogurt in the yogurt j and ρ_Y is the price of milk in plain yogurt [13], F_j is the milk content of plain FBPS in the FBPS j and ρ_F is the price of milk in plain FBPS [14], Co_j is the fruit content of the compote j and ρ_C is the price of fruits in compote, PFY_j is the percentage of fixed other ingredients in yogurt j and τ_Y is the price of related fixed part, $PFFY_j$ is the percentage of fixed other ingredients in yogurt j with fruits and τ_{FY} is the price of related fixed part, PFF_j is the percentage of fixed other ingredients in FBPS j and τ_F is the price of related fixed part, $\omega_{c(j)t}$ are monthly fixed effects for each product category c of product j, N_j is a dummy variable related to the natural flavor of product j, ω_t are the related coefficient that varies across time period t, Fr_j is a dummy if product j contains fruits, $\omega_F r$ is the cost associated to the fruit dummy, and ϑjt is an error term.

When recipes change due to reformulation, the quantity of inputs S_j, Y_j, F_j and Co_j varies and then a new marginal cost is computed thanks to the estimated price of each input $\hat{\rho}_S$, $_Y$, $\hat{\rho}_F$, and $\hat{\rho}_C$, respectively. The new marginal cost is given by $\tilde{c}_{jt} = c_{jt} + \Delta c_{inputs,j}$ where $\Delta c_{inputs,j} = \hat{\rho}_S \Delta S_j + \hat{\rho}_Y \Delta Y_j + \hat{\rho}_F \Delta F_j + \hat{\rho}_C \Delta Co_j$.

[13] Milk cost represents an important part of the cost of plain yogurt

[14] Milk cost represents an important part of the cost of plain FBPS

3.4 Simulation method

We simulate the impact on prices and consumption of excise taxes or product reformulation, given the estimated marginal costs, changes in recipes (if any) and input prices,s as well as the other estimated structural demand parameters. The marginal cost of production is modified by the excise tax, but also by the cost of reformulation; that is, the change in the inputs of item recipes (e.g., a decrease in added sugar, an increase in some other ingredients). The profit-maximization program for firm f is now given by:

$$\max_{\{p_{kt}\}_{k\in G_f}} \sum_{j\in G_f} (p_{jt} - \tilde{c}_{jt}) M_t s_{jt}(p) \tag{5}$$

where $\tilde{c}_{jt} = c_{jt} + \tau_j + \Delta c_{inputs,j}$ is the new marginal cost including the per-unit level of the tax τ_j which depends on the caloric sweetener content of product j and the reformulation costs $\Delta c_{inputs,j}$.[15] The new price equilibrium vector p_t^* is deduced from the following program:

$$\min_{\left\{p^*_{jt}\right\}_{j=1,..,J_t}} \quad \|p_t^* - \gamma_t(p^*/\theta) - \tilde{c}_t\|$$

where $\|.\|$ is the Euclidean norm in $\mathbb{R}^J$, $\gamma_t(p^*/\theta)$ is the vector of manufacturer margins deduced from (5), and the vector $\tilde{c}_t$ is the sum of the vectors of marginal costs obtained from (3), $c_t = (c_{1t},..,c_{jt},..,c_{Jt})$, tax levels, $\tau = (\tau_1,..,\tau_j,..,\tau_J)$, and input variations caused by reformulation, $\Delta c_{inputs} = (\Delta c_{inputs,1},..,\Delta c_{inputs,j},..,\Delta c_{inputs,J})$.

4 Results on demand and supply

We estimated the demand model using household purchase data. For computational reasons, we randomly chose 100,000 observations among the 1,600,000 available to us. We used the simulated maximum likelihood method as in Revelt and Train (1998) and a control function approach for identification issue (see details in the Appendix).

Table 3 shows the estimated coefficients of the demand model. The first column shows the mean marginal utility of product characteristics. The second column shows the estimated standard deviation of price. It is significant at the 1% level, indicating that the marginal utility of price varies with unobservable household characteristics. As expected, the probability of choosing an alternative falls with its price (-1.38). Households prefer compote more than the three other dairy dessert categories, on average. They also prefer yogurt with fruit (0.81). Surprisingly, the

[15]The tax τ_j is 0 for non-taxed products.

Table 3: **Results of the random coefficient logit model.**

	Random Coefficient Logit Model	
	Mean	StD
Price	-1.3798 (0.0001)	0.5198 (0.0000)
Compote	-	
Yogurt	-2.2074 (0.0002)	
FBPS	-1.5548 (0.0001)	
ODD	-0.5896 (0.0001)	
Fruit in Yogurt	0.8053 (0.0001)	
Plain Yogurt and FF/PS	-0.1004 (0.0001)	
Sugar taste	-0.0195 (0.0000)	
Fat taste	0.0478 (0.0000)	
Sugar taste* Fat taste	0.0080 (0.0000)	
Error term	0.5603 (0.0001)	
LL	-246,356	
Number of observations	100,000	
Coefficients $\beta_{b(j)}$ not shown		

Note: FBPS and ODD stand for fromages blancs and petits suisses, and other dairy desserts, respectively.

sweetness of a product decrease the household average utility. However, when integrating the interaction between sugar and fat, for FBPS and ODD, given their high fat content, an increase in sugar content increases utility. The same is not true for compote, the fat content of which is very low. This reflects the observed trend in the market whereby consumers increasingly choose compotes with a low level of sugar. We also found that households prefer fat products (0.05), even more so if they are sweetened.

Table 4: **Aggregated own- and cross-price elasticities by product categories.**

	Compotes	Yogurts	FBPS	ODD	OG
Compotes	-2.6361	0.1292	0.1328	0.1307	0.0993
Yogurts	0.4324	-1.9753	0.4290	0.4207	0.3555
FBPS	0.2303	0.2196	-2.6638	0.2328	0.1590
ODD	0.4928	0.4606	0.5075	-2.4572	0.2940

Note: FBPS, ODD, and OG stand for fromages blancs and petits suisses, other dairy desserts, and outside good, respectively.

Using the structural demand estimates, we compute price elasticities for each differentiated product. Table 4 provides aggregated own- and cross-price elasticities by categories.[16] Own-price elasticities are close to -2.5, except for yogurt products for which the demands are less elastic (about -2.0). Cross-price elasticities by food

[16] Computational details for aggregated elasticities are provided in Bonnet et al. (2018).

Table 5: **Average marginal costs (€/kg) and average margins (%) by brands and product categories.**

	Compotes		Yogurts		Fromages blancs, petits suisses		Other dairy desserts	
	Cost	Margin	Cost	Margin	Cost	Margin	Cost	Margin
Brand 1			1.34	48.2	2.01	36.9	1.91	37.8
Brand 2			1.11	46.9	1.97	37.7	2.65	33.0
Brand 3			3.50	31.7				
Brand 4			2.30	34.7				
Brand 5			1.62	40.8	2.70	32.9		
Brand 6			1.42	42.1	4.05	28.7	2.71	32.9
Brand 7			1.35	46.7	1.73	36.5	2.69	32.9
Brand 8			1.31	40.8				
Brand 9			1.38	39.7				
Brand 10	2.24	32.5	1.15	48.5	2.22	33.1	4.09	28.1
Brand 11	2.29	31.6					3.24	29.1
Brand 12			1.38	49.8	3.25	30.0	4.11	28.2
Brand 13			2.71	30.5			2.68	29.9
PLs	1.41	39.8	0.92	50.1	1.51	38.9	1.74	39.5
All	1.66	37.6	1.26	46.0	1.86	37.2	2.17	36.8

Note: The reported marginal cost (margin) of a brand and a category is the weighted average (using market shares as weights) of the marginal cost (margin) of products for each brand in each category.

category are also almost equal. There is no second-best product category following a price change in a given dessert category. Consumers shift to another product proportionally to its initial market share. We also find that consumers shift to the outside good to a lower extent . For each food category, cross price elasticities with the outside good are lower than those with other product categories. At the brand level (Table 20 in the Appendix), we find that yogurts are less elastic, except for three brands that are characterized by the lowest caloric sweetener contents and, for two of them, high artificial sweetener contents.[17] Consumers react more to a change in prices for these expensive yogurts. For FBPS and ODD, we also find a 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 5). Margins vary from 30% to 50%, and they are higher on average in the yogurt 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

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

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.

Results on the cost model are provided in Table 13. The estimated sugar price is €521 per ton of sugar which is in the range of market prices. Thus, in 2009, the average price of sugar in the EU ranges between 500 and 550 €/t (European Commission, 2019). The estimated cost of milk content of plain yogurt is 504 €/t. Note that production of a yogurt requires 1 to 1.2 litres of milk per kg of final product and that the farm gate price of milk was about 0.34 €/l in 2008 and 0.29 €/l in 2009. Finally, the ratio of matrix cost of FBPS and yogurt is 2.5 (1.261/0.504), which is in line with the quantity of milk needed to produce a kilogram of final product.[18]

5 Results of simulations

We first simulate a specific product reformulation scenario without considering taxation (subsection 5.1), in order to understand how and to what extent it impacts consumers' average nutrient intakes and firms' profit, by disentangling its mechanical effect from the effects of consumers' and firms' reactions. Second, we study the impact of taxation. The assumed tax scheme has one tier depending on the sugar content of products. That is, if the sugar content of a given product is below a threshold, then the product is not taxed. If it is above the threshold, the product is taxed. The chosen rate of taxation is €0.20 per 100 g of sugar.[19] This tax scheme is in line with the results from Duvaleix-Tréguer et al. (2012) who theoretically studied such a scheme and showed that, provided that the threshold is not too low, firms prefer to reformulate their products in order to avoid the tax. They also showed that such a policy might be welfare improving. However, setting a too high threshold is likely to reduce both the number of taxed products and the number of reformulated products. As a consequence, it is likely to reduce the potential health effects associated with a decrease in sugar intake by consumers. To better understand the impact

[18] Plain yogurt requires 1.212 litres of milk per kg of final product whereas fromages blancs and petits suisses require 2.735 and 2.363 litres of milk per kg of final product respectively (https://agriculture.gouv.fr/sites/minagri/files/documents/pdf/Coefficients_Techniques_Lait_cle8e1393.pdf). Therefore, FBPS requires between 1.95 (2.363/1.212) and 2.26 ((2.735/1.212)) times more milk than yogurts.

[19] In practice, this rate leads to a roughly 10 to 20% price increase for taxed products.

of the threshold on market outcomes, we first assess how sugar intakes and firms' profits evolve with tax thresholds (subsection 5.2). We finally discuss in depth a specific case of taxation (subsection 5.3) for highlighting economic mechanisms.

5.1 The impact of product reformulation

The simulated product reformulation scenario consists of decreasing the quantity of added sugar to the minimum level that is technically feasible while in 'sensory' sense, remaining acceptable for consumers. The assessed effects can be considered as the upper bound of the impact of a product reformulation strategy. From a policy perspective, the scenario can be viewed as an hypothetical policy in which the public health authorities would strongly push firms to reduce their product's sugar content, just as the British food industry is experiencing to some extent with their childhood-obesity plan (Public Health England, 2017).[20] The minimum added sugar content was estimated for 18 product recipes using optimization models (see the Appendix for a detailed presentation of the methodology and the models).[21]

We run three cases to decompose the potential impact of product reformulation. In the first case, we assume constant market shares. Consumers continue to buy products as if there were no changes either in the flavor or the price of products. This provides the mechanical impact of product reformulation, assuming no other changes. We find that the intake of caloric sweetener decreases by 6.9 %, whereas fat intake slightly increases (+0.8 %) as, for some products, the decrease in caloric sweetener content is accompanied by an increase in its fat content (see Table 6, second column). As a consequence of the change in the intakes of caloric sweetener and fat, calorie intake also decreases (-3.0 %) but to a lower extent than the caloric sweetener.

In the second case, we assume that prices remain constant but that consumers react to the change in the nutrient composition of the products. Consumers know that products have been reformulated and thus reevaluate the utility they get, given the modified product recipes. As shown in Table 3, both sugar and fat tastes do influence the utility of consumption. Taking this effect into account leads to (very) small changes in consumption. The

[20]Public Health England challenged all sectors of the food industry in 2016 to reduce the amount of sugar in the foods that contribute most to children's intakes by 20% by 2020, by publishing guidelines for total sugar levels per 100g of products for these food categories.

[21]The 18 product recipes correspond to the following products: sweet, flavored or with fruit yogurt (skimmed, semi-skimmed or whole), flavored or with fruit Greek style yogurt, skimmed flavored fromage blanc, fruit semi-skimmed or whole milk fromages blancs, petits suisses with fruit with semi-skimmed or whole milk, compotes and diet compotes.

Table 6: **Reformulation: Change in nutrient intakes**

	Constant market shares	Constant prices	Endogenous prices
Δ OG	-	-0.1 pp	-0.0 pp
Δ caloric sweeteners	-6.9%	-6.7%	-6.8%
Δ lipids	+0.8%	+0.3%	0.1%
Δ calories	-3.0%	-3.1%	-3.2%

Note: pp stands for percentage point, that is the absolute variation of the outside good market share. OG stands for the outside good. The percent change in nutrient intakes is computed over the initial intakes from the four product categories.

comparison with the previous case shows that consumers switch towards products with more sugar and less fat. Thus, the decrease in caloric sweetener intake is a slightly lower, as well the increase in fat intake. This is mostly explained by changes between the categories; in particular, a shift away from yogurts and FBPS, towards compotes. Consumption adjustment benefits the whole industry as its aggregate market share increases, though to a very small extent.

Finally, in the third case, we allow producers to modify prices as both the demand for the different products and production costs have changed. Production costs of compotes slightly decrease (by less than 1 €cent /kg), those of yogurts are unchanged, and those of FBPS slightly increase (by less than 1 €cent /kg). Prices are adjusted but at a very small proportion. As in the previous case, there is a switch towards products with lower fat and higher sugar, mostly due to a shift away from FBPS towards compotes. The market share of compotes increases by 3.3 %, whereas those of yogurts and FBPS decrease by 0.2 % and 1.6%, respectively (not shown). These changes in market share impact firms' profits. Thus, the profit of the compote producers increases by 3.8%, whereas profits of yogurts and FBPS decrease by 0.3% and 1.5%, respectively. The profit of ODD is almost unaffected. Finally, the profit of the whole industry remains unchanged as the gains of compotes producers offset the losses of yogurt and FBPS producers.

From the three simulations, we conclude that the main impact of product reformulation on nutrient intakes is mechanical. Adjustments in demand due to the change in product recipes and firms' price reactions play a minor role in our setting.

5.2 The impact of tax threshold levels on sugar intakes and firms' profits

We now analyze the impact of taxation, assuming that firms reformulate their products. We have assumed that each firm would decrease the content of added sugar to just below the tax threshold to fully escape the tax.[22] When this reduction cannot be technically implemented by the manufacturer, we fix the quantity of added sugar of the product to the minimum level feasible, in order for firms to mitigate the tax. Figure 1 displays how sugar intakes vary with tax threshold levels.[23] Overall, the lower the thresholds, the larger the decrease in sugar intakes. However, the change in sugar intake is not linear with threshold levels. For a given level of compote threshold, increasing the tax threshold for dairy desserts from 6 to 10g of sugar per 100g of product has a relatively small impact on sugar intake (a less than 0.5 percentage point difference per 1g increase in the threshold). In contrast, when the threshold for dairy desserts increases from 10g to 16 g/100g, the impact on sugar intake is large (approximately a 2 percentage point difference per 1g increase in the threshold). We also observe a non-linear response in sugar intake to a change in the compote threshold holding constant the dairy desserts threshold.[24]

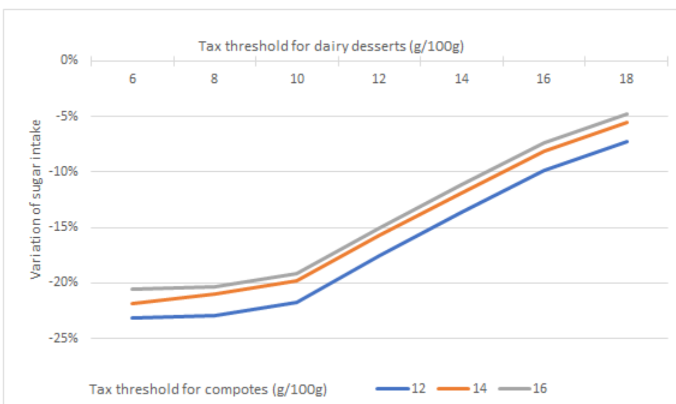

Figure 1: Changes in sugar intake in function of the levels of tax thresholds (with reformulation)

Figure 2 shows how firms' profits vary with tax thresholds levels assuming firms reformulate their products (solid lines) or not (dashed lines). Two main results emerge. First, the negative impact of taxation on firms' profits depends on the tax thresholds. A lower threshold leads to higher losses for the firms. However, the marginal

[22]Note that this scenario of product reformulation is slightly different from the previous one.

[23]Product reformulation also leads to slight increases in the fat content of reformulated products, except for compotes which have almost zero fat content. They are not shown as the changes are very small.

[24]For a given threshold for dairy desserts, for example, 10g/100g, the change in sugar intake is much larger when the compote threshold increases from 12 to 14 g/100g than when the compote threshold increases from 14 to 16 g/100g.

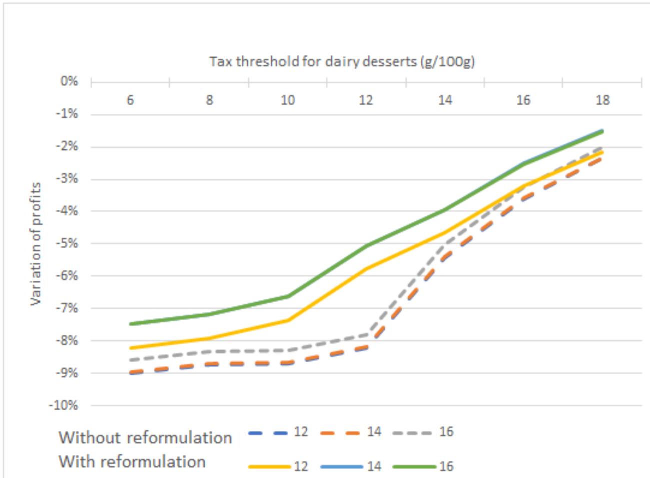

Figure 2: Variation of industry's profits for different levels of tax thresholds (12, 14 and 16g/100g) for compotes in function of the level of the tax thresholds for dairy desserts (without or with reformulation)

impact on profit of a change in the threshold is not constant. For example, at a given threshold for compotes, the marginal impact of modifying the threshold for dairy desserts is small for 'low' values of threshold (in the range 6 to 10 g/100g) and much higher for 'high' values of the threshold (in the range 10 to 18 g/100g). We also observe a similar but opposite result for compote threshold (at a given threshold for dairy desserts). The variations of profits are almost identical for the high values of the compote threshold (from 16 to 14 g/100g) whereas the variation of profits is higher for low values of the compote threshold (from 14 to 12 g/100g). This result comes mainly from the following mechanism: a change in the tax threshold affects the number of products that are taxed but not the level of the tax for taxed products. The higher the threshold, the lower the number of taxed products. Therefore, when the threshold decreases, more and more products are taxed, explaining why firms' profits decrease. The evolution of firms' profits in function of tax threshold level depends on the distribution of sugar content among the products. Second, Figure 2 shows that firms have an interest in reformulating their products. The (negative) impact of taxation is lower when they reformulate their products. This means that the cost of reformulation is lower than the gain from reformulation. The gain mainly comes from a mechanical decrease (or a full escape of the tax when it is technically possible to lower the sugar content to just below the threshold) in the amount of the tax, resulting from the reformulation.

Figure 3 provides the impact of taxation on firms' profits by product category, assuming that firms reformulate

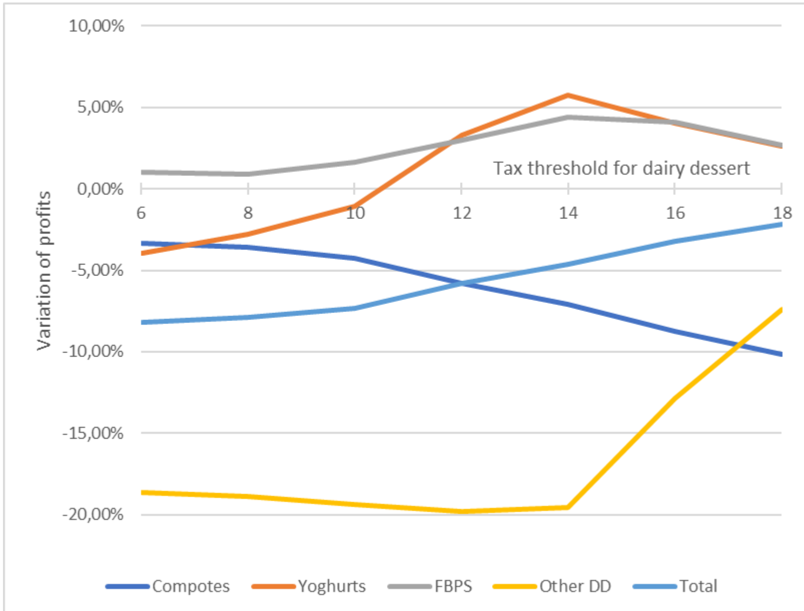

Figure 3: Firms' profits in function of the dairy dessert tax threshold
Note: the compote tax threshold is 12g/100g; firms reformulate their products. FBPS and ODD stand for fromages blancs and petits suisses and other dairy desserts, respectively.

their products, and for a fixed tax threshold for compotes (12g/100g of product). In order to analyze the impact of taxation on profits by the categories of products it is necessary to consider the following: first, a direct effect (that is, the extent of taxation for the category of product); and second, an indirect effect (that is, the extent of taxation on the categories of products which are substitutes). For compotes, the direct impact of taxation does not change with the threshold for dairy desserts, since its level is fixed. The decrease in their profits when the threshold for dairy desserts increases is thus only due to the indirect effect. Thus, when the threshold increases, fewer products from their competitors are taxed, and as a consequence, the profit of compote producers is negatively impacted (that is, compote producers benefit less from substitutions). For ODDs, when the tax threshold increases, losses from taxation first slightly increase and are significantly reduced above 14g/100g. When the threshold is low, the indirect effect is at stake. Nonetheless, for higher values of the thresholds, the direct effect plays a role as some products escape the tax (the content and distribution in caloric sweetener of ODD is provided in Table 2), thus reducing the impact of the tax on their profits. Finally, for both yogurts and FBPS, the profits exhibit inverted U-shape curves when the tax threshold increases. Thus, when the tax threshold increases, they mainly benefit from the direct effect; that is, more and more products escape the tax, but for larger values of the thresholds, the indirect impact plays an important role as some products from the ODD category are no longer taxed. Note that globally, FBPS producers benefit from the tax which is due to the fact that their competitors are taxed whereas only a fraction of their products is taxed. The latter category has a lower content in caloric sweeteners than the other dairy dessert categories (see Table 2).

5.3 Supply and demand mechanisms

We now detail the supply and demand mechanisms at stake. The analysis is conducted with a tax threshold for compote equal to 12g/100g of sugar and 8g/100g of sugar for dairy desserts. We choose these thresholds as they lead to a significant decrease in sugar intake from these four product categories. The amount of the tax is € 0.20 per 100g of sugar. Firms reformulate their products, as assumed in the previous sub-section. Table 7 reports both the share of taxed products and the amount of the tax by brand and product category.[25] Given the assumed tax scheme, only a subset of products is taxed. Almost two thirds of compotes, more than half of yogurts and a third of FBPS are taxed. All ODD are taxed. Brands with a high average sugar content have more products taxed than brands with a low average sugar content. This results in a strong disparity in the shares of taxed products between brands, mostly for yogurt and FBPS categories. Although yogurts are on average sweeter than FBPS, the average amount of the tax (computed over taxed products only) for yogurts (€0.21/kg) is lower than that for FBPS (€ 0.24/kg).[26] A few brands fully escape the tax: two brands of yogurts and one of FBPS. Compotes and ODD, which are the sweetest products (see Table 2), support the highest levels of the tax.

We found that firms choose to pass more than the tax to consumers (see Table 21 in the Appendix). The prices of taxed products increase by about 20% more than the amount of the tax. This result is in line with analyses of taxation in other food product categories, such as sugar sweetened beverages, butter and margarine, and fresh dairy products (Bonnet and Réquillart, 2013; Nesheim et al., 2018; Allais et al., 2015). The prices of non-taxed products are also slightly modified, between -0.1% and +0.3% (not shown). Table 8 provides the average price change for each brand in each category. Within a product category, brands experience rather heterogeneous price increases. For example, in the yogurt category, some brands (brands 2 and 3) do not experience a change in price whereas the

[25]For a brand, the reported share of taxed products is computed as the ratio, in percent, of the market share of taxed products and the total market share of the brand. The reported amount of the tax is a weighted average tax of taxed products, using market shares as weights.

[26]This comes from the fact that only a subset of products are taxed. Among this subset of taxed products, FBPS products are sweeter than yogurts.

Table 7: **Taxation with product reformulation: Share of taxed products (%) and tax level (€/kg) by brand and product category**

	Compotes		Yogurts		FBPS		ODD	
	Share	Tax	Share	Tax	Share	Tax	Share	Tax
Brand 1			50	0.21	47	0.26	100	0.40
Brand 2			0		0		100	0.22
Brand 3			0					
Brand 4			29	0.21				
Brand 5			51	0.24	49	0.22		
Brand 6			35	0.23	52	0.29	100	0.32
Brand 7			85	0.22	14	0.27	100	0.34
Brand 8			70	0.21				
Brand 9			100	0.16				
Brand 10	27	0.27	59	0.24	19	0.21	100	0.30
Brand 11	65	0.28					100	0.27
Brand 12			69	0.22	19	0.19	100	0.34
Brand 13			61	0.19			100	0.24
PLs	68	0.26	57	0.22	36	0.22	100	0.33
All	62	0.27	53	0.21	35	0.24	100	0.31

Note: A proportional tax of €0.20 per 100g of sugar is implemented when sugar content is above 12g for compote and 8g for other product categories. The amount of the tax is computed over taxed products only. FBPS and ODD stand for fromages blancs and petits suisses, and other dairy desserts, respectively.

price of some other brands increases by €0.19 (brand 9) or €0.23 (brand 7). Thus, for a brand, the average change in price depends on both the change in price of the taxed products and the share of taxed products within the brand. Within a product category, brands that experience the lowest price increase are those that have the lowest share of taxed products.

Table 8 also presents the impact of the tax on consumers. All product categories lose market shares, but in very different proportions. FFBS is almost not impacted with a 0.5% decrease in its market share whereas ODD loses one fourth of its initial market share. Compotes and yogurts lose 7.2% and 5.2% of their market shares, respectively. Overall, the tax scheme implemented leads to a change in the market shares of the different products at the expense of products high in sugar and in favor of products low in sugar. Market shares of a few brands increase. This is the case for brand 10 on the compote market, brands 2, 3, and 4 for yogurts, and brands 2, 7, 10 and 12 for FBPS. The brands that support the lowest level of taxes benefit from both intra- and inter-category substitutions. PLs lose more than the average NBs, despite quite similar levels of tax, which is a consequence of a

Table 8: **Taxation with product reformulation: Changes in average price (€/kg) and market share (%) across brands and product categories**

	Compotes		Yogurts		FBPS		ODD	
	Price	MS	Price	MS	Price	MS	Price	MS
Brand 1			0.13	-4.2	0.16	-4.7	0.49	-31.2
Brand 2			0	9.7	0	10.5	0.28	-12.8
Brand 3			0	11.3				
Brand 4			0.07	4.9				
Brand 5			0.15	-4.6	0.14	-0.9		
Brand 6			0.10	-0.1	0.21	-6.2	0.41	-21.2
Brand 7			0.23	-14.2	0.05	5.2	0.42	-22.7
Brand 8			0.17	-8.3				
Brand 9			0.19	-7.7				
Brand 10	0.09	5.9	0.17	-8.5	0.06	5.4	0.39	-14.0
Brand 11	0.22	-7.6					0.34	-15.5
Brand 12			0.18	-10.1	0.05	8.0	0.44	-16.4
Brand 13			0.15	-1.6			0.30	-14.7
PLs	0.21	-9.5	0.15	-7.5	0.10	-1.0	0.40	-26.7
All	0.20	-7.2	0.14	-5.2	0.11	-0.5	0.41	-25.0

Note: A proportional tax of € 0.20 per 100g of sugar is implemented when the sugar content is above 12g for compote and 8g for other product category. 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 fromages blancs and petits suisses, and other dairy desserts, respectively.

Table 9: **Variation of firms profits due to taxation whether firm product reformulation is assumed or not (in %)**

	Product categories								Total	
	Compotes		Yogurts		FBPS		ODD			
Reformul	Without	With	Without	With	Without	With	Without	With	Without	With
Firm 1			-0.3	+0.2	+0.7	-0.2	-22.3	-23.1	-6.2	-6.5
Firm 2			-3.3	+1.6	0.3	-3.6	-14.7	-15.5	-9.8	-8.9
Firm 3			-11.7	-6.4	+7.1	+6.2	-16.4	-17.2	-7.3	-3.8
Firm 4	-7.4	+7.4	-6.7	-5.8	+7.0	+6.6	-7.8	-8.5	-6.0	-2.5
Firm 5	-6.9	-3.8					-9.1	-9.9	-7.3	-5.1
Firm 6			-3.2	-3.2	+7.9	+7.2	-10.0	-10.7	-5.9	-6.3
Firm 7	-11.0	-5.8	-6.6	-5.2	+1.3	+0.6	-20.3	-21.1	-10.8	-10.0
All	-9.7	-3.6	-4.6	-2.8	+1.8	+0.9	-18.1	-18.9	-8.8	-7.9

Note: A proportional tax of € 0.20 per 100g of sugar is implemented when sugar content is above 12g for compote and 8g for other product categories. Columns 'without' indicate the change in profits when firms do not reformulate their products, and columns 'with' when firms do reformulate their products. FBPS and ODD stand for fromages blancs and petits suisses, and other dairy desserts, respectively.

larger relative price effect of taxes, when evaluated in percentage change.[27]

Table 9 provides the impact of taxation on firms' profits when firms can reformulate (column 'with') or not (column 'without').[28] When firms reformulate their products, the profit of the industry decreases by almost 8%. Losses mainly come from the ODD category which experiences a 19% decrease in its profits related to the large drop in market share (-25%). Because firms increase their mark-ups (recall that the pass-through rate is greater than 100%), the loss in profit is lower than the loss in market share. This mechanism also explains why the profit of the FBPS category slightly increases (+0.9%), whereas its market share slightly decreases (-0.5%). Profit losses for compote and yogurt categories remain moderate (-3.6% and -2.8%, respectively). Given that firms are involved in several product categories, all firms register losses, even if the profits coming from the FBPS category increase for five firms among the six producing FBPS.

When firms cannot reformulate their products in response to the tax, the impact of taxation on profits of the industry is larger but remains in the same order of magnitude (-8.8% compared to -7.9% with product reformulation), as shown in Figure 2. However, a scenario without reformulation is better for ODD and FBPS. In the case of ODD, which by assumption cannot reformulate their products, the lower loss in profits is due to the fact that their

[27]NB prices increase by 12%, 12%, 11%, and 12% for compotes, yogurts, FBPS, and ODD, respectively, whereas PL prices increase by 13%, 15%, 12% and 17% respectively. The price transmission of the tax is slightly lower for PLs than NBs, but this is not sufficient to avoid a larger decrease in market shares (see Table 21).

[28]As shown in Table 1, firm 1 owns brands 1 to 5, firm 2 owns brand 6, firm 3 owns brands 7 to 9, firm 4 owns brand 10, firm 5 owns brand 11, and firm 6 owns brands 12 and 13.

(imperfect) substitutes experience a higher level of taxation. As discussed in Section 5.2, product reformulation is a way for firms to decrease the tax rate (see Table 22 in the Appendix). For the other categories, the difference of profit losses between the two cases results from two effects that go in opposite directions: the indirect effect, already discussed for ODD, which depends on how rivals' firms are taxed, and the direct effect which depends on how the tax rate of a firm is affected by reformulation. The net effect relies on the strength of the two forces. In the case of compotes and yogurts, the direct effect is greater than the indirect effect. As a consequence, profit with production reformulation is larger than profits without reformulation. In the case of FBPS, this is the contrary. These results show that considering substitution effects between product categories, and between taxed and non-taxed products, and the potential firms' efforts to escape the tax, are the key issues when evaluating the impact of taxation policies (e.g., see Finkelstein et al. (2013)).

As expected, the taxation policy, assuming reformulation is possible, leads to a decrease (23%) in the intake of caloric sweetener from the four product categories considered (see Table 10). This large decrease is partly due to the reallocation of market shares within product categories and between product categories, as shown above. However, it is also a consequence of a loss of market shares of the four categories, whereby the total market share decreases by 3.7 percentage points. Taking into account the increase in the market share of the outside good, the decrease in caloric sweetener intake is 13.5%. However, the net impact on calories is slightly positive (0.8%), since the calorie content of the considered outside good is much higher than the average calorie content of the four product categories considered. If we disregard substitution to the outside good, calories intake from the four categories decreases by 17.7%.[29]

We also assess to what extent the modelling assumptions affect the estimated impact of the policy on the change in caloric sweetener intakes. Table 11 provides a comparison of the changes in nutrients intake for three alternative modelling assumptions. The first case refers to passive pricing and no reformulation of products. This is a frequent assumption made to evaluate the impact of taxation. The second case refers to strategic pricing without product reformulation. Last, the third case refers to strategic pricing and product reformulation. Given the characteristics of this market and the tax scheme, assuming passive pricing and no reformulation, we estimate that taxation induces a

[29] The reported percent changes in nutrient intakes including or not the change in the outside good market share cannot be directly compared as they are computed over the initial intakes of the considered market; that is, the J products for the four categories and the $J+1$ products when the outside good is included.

Table 10: **Taxation with product reformulation: Changes in caloric, fat, and sugar intakes**

Intake from the four product categories	
Calories	-17.7%
Lipids	-14.2%
Caloric sweetener	-22.9%
Total intake from the desserts including the outside good	
Outside good (market share)	+3.7 pp
Calories	+0.8%
Lipids	+3.5%
Caloric sweetener	-13.5%

Note: pp stands for percentage point. The percent change in nutrient intakes is computed over the initial intakes of the considered market (i.e., over the nutrient intakes from the four product categories in the top of the table and over the whole intake of nutrients from desserts for the second part of the table).

decrease in caloric sweetener intake by about 16%. Considering strategic pricing leads to an estimated decrease by almost 19%. Finally integrating both strategic pricing and product reformulation leads to an estimated decrease in the caloric sweetener content by 23%. In other words, ignoring strategic pricing and product reformulation leads to under-estimate the impact of the tax by more than 44% in the relative term.

Table 11: **Impact of alternative modelling assumptions on the nutrient intake from the four product categories**

	Passive pricing No reformulation	Strategic pricing no reformulation	Strategic pricing reformulation
Δ caloric sweetener	-15.9%	-18.7%	-22.9%
Δ lipids	-12.3%	-14.9%	-14.2%
Δ calories	-13.5%	-16.0%	-17.7%

6 Discussion

This paper provides a methodology for assessing the impacts of tax policies on food consumption, taking into account manufacturers pricing strategies and possible changes in the characteristics of taxed products. To the best of our knowledge, this is the first empirical paper incorporating the reformulation of products in response to a tax policy. According to our results, ignoring the combined effect of price reactions and product reformulation leads us to greatly under-estimate the impact of taxes on the intake of taxed nutrients. In our case, integrating these two effects in the analysis, there is a change in the estimated decrease in caloric sweetener intake of 44 %.

In our setting, reformulation is exogenous. We assume that in response to the tax, firms set the caloric sweetener content of their products slightly below the tax threshold, in order to fully escape the tax and, when this is not possible, to the minimum level technically feasible. The reformulation scenario is in some sense conservative as it uses as constraints what is observed on the market. For a given type of a product (e.g., 'sweet yogurt') the content of sweetener of 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. Reformulation is exogenous but we show that most firms gain by reformulating their products, as does the industry as a whole. Thus, reformulating a product is a way to partially or fully escape the tax, the level of which depends on the sweetener content of the product. Even if product reformulation lowers the impact of the tax on prices, and as a consequence lowers the impact of the tax on consumption, we show that it increases the overall impact of the tax on the consumption of the taxed nutrient. That is, the intake of the taxed nutrient (which has a deleterious impact on health) decreases more when firms reformulate their products than when they do not. This is because the content of the taxed nutrient has decreased.

However, in our setting, product reformulation is not endogenous and we cannot claim that the case in which all firms reformulate their products is an equilibrium (in terms of characteristics). Modelling how firms endogenously adjust the set of products they offer would involve adding a second stage in the supply model in which firms simultaneously choose product offerings, with the understanding that their actions and their rivals' actions will impact demand and mark-up. Firms would solve the problem by calculating the equilibrium profits they would be likely to achieve under any possible set of product offerings, found in the second stage, and then choose the products that would maximize those profits. We leave these developments to future research.

Some of our results depend on the choice of the outside good; in particular, the overall impact of the scenarios on nutrients intake depends on the choice of the outside option. For example, in this study, the outside option is highly caloric (much more so than the considered dessert products), and consequently, the overall impact of taxation on calorie intake is not negative. Thus, some of the results need to be interpreted with some caution.

In addition, we do not consider that firms can reformulate their products by substituting a caloric sweetener with a non-caloric sweetener so as to keep the sweetness of the product constant. Evaluating this reformulation scenario would involve estimating consumer preferences for non-caloric sweeteners in the demand model. However, only 14 products out of 159 contain non-caloric sweeteners, making it difficult to estimate non-caloric sweetener preference, and suggesting that this reformulation scenario may not yet be credible for the dessert market.

Our results also suggest that designing tax schemes that favor product reformulation is very important for the success of a tax policy. This has already been put into effect in some countries. For example, France has revised its 'soda tax' design. Originally the tax did not depend on the sugar content of the product (and amounted to €0.075 /l). The tax was redesigned in July 2018 as a tiered-tax rate that varies according to the sugar content of a sugar sweetened beverage.[30]

There are other debates about taxes that are not covered in this paper. In particular, we do not discuss possible regressivity of the taxes, and more generally, the redistributive effects of such taxes versus their corrective effects. Recently Allcott et al. (2019) showed that 'an optimal commodity tax depends on two terms: the corrective benefits and the regressivity costs'.

[30] In 2020, the tax is €0.038 per litre for products containing less than 1g of added sugar per 100ml, which progressively increases to above €0.24 per litre for products containing 15g of added sugar per 100ml, and €0.205 per each gram per 100ml added above 15g (Service public, 2018)

References

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

Allcott, H., Lockwood, B., and Taubinsky, D. (2019). Regressive sin taxes, with an application to the optimal soda tax. *The Quarterly Journal of Economics*, 134:1557–1626.

Berardi, N., Sevestre, P., Tepaut, M., and Vigneron, A. (2016). The impact of a soda tax on prices: Evidence from French micro data. *Applied Economics*, 48(41):3976–3994.

Berry, S., Levinsohn, J., and Pakes, A. (1995). Automobile prices in market equilibrium. *Econometrica*, 63:841–890.

Bonnet, C., Bouamra-Mechemache, Z., and Corre, T. (2018). An environmental tax towards more sustainable food: empirical evidence of the consumption of animal products in france. *Ecological economics*, 147:48–61.

Bonnet, C., Corre, T., and Réquillart, V. (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 Réquillart, V. (2013). Tax incidence with strategic firms on 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.

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

Cornelsen, L. and Smith, D. (2018). Viewpoint: Soda taxes ? Four questions economists need to address. *Food Policy*, 74:138–142.

Dubois, P., Griffith, R., and O. Connell, M. (2018). The effects of banning advertising in junk food markets. *The Review of Economic Studies*, 85(1):396–436.

Duvaleix-Tréguer, S., Hammoudi, A., Rouached, L., and Soler, L.-G. (2012). Firms' responses to nutritional policies. *European Review of Agricultural Economics*, 39(5):843–877.

European Commission (2019). Agri g 4 committee for the common organisation of agricultural markets: Sugar price reporting. Technical report. Available online at https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/sugar-price-reporting$_{e}n.pdf, accessed January,$ 2020.

Finkelstein, E. A., Zhen, C., Bilger, M., Nonnemaker, J., Farooqui, A. M., and Todd, J. E. (2013). Implications of a sugar-sweetened beverage tax when substitutions to non-beverage items are considered. *Journal of Health Economics*, 32(1):219 – 239.

Jensen, J. D. and Smed, S. (2013). The Danish tax on saturated fat. Short run effects on consumption, substitution patterns and consumer prices of fats. *Food Policy*, 42(0):18 – 31.

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

Moorman, C., Ferraro, R., and Huber, J. (2012). Unintended nutrition consequences: Firm responses to the nutrition labeling and education act. *Marketing Science*, 31(5):717–737.

Mora, T., Fichera, E., Lopez-Valcarcel, B. G., and Roche, D. (2019). Do consumers respond to sin taxes heterogeneously? New evidence from the tax on sugary drinks using longitudinal scanner data.

Nesheim, L., Griffith, R., and O'Connell, M. (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.

Petrin, A. and Train, K. (2010). A control function approach to endogeneity in consumer choice models. *Journal of Marketing Research (JMR)*, 47(1):3 – 13.

Public Health England (2017). Sugar reduction: Achieving the 20%. Technical report. Available online at https://www.gov.uk/government/publications/sugarreduction-achieving-the-20, accessed March, 2019.

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

Revelt, D. and Train, K. (1998). Mixed logit with repeated choices: households' choices of appliance efficiency level. *Review of Economics & Statistics*, 80(4):647 – 657.

Sebillotte (2016). *Nutrition et bien commun. La construction d un nouveau modèle d action publique*. PhD thesis, Mines Paris Tech - Université de recherche Paris Sciences et Lettres.

Service public (2018). Taxation des boissons. Technical report. Available online at https://www.service-public.fr/professionnels-entreprises/vosdroits/F32101, accessed January, 2020.

Silver, L., Ng, S., Ryan-Ibarra, S., Taillie, L., Induni, M., Miles, D., 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.

7 Appendix

7.1 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 :

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

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. 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

$$\delta_{jt} = \beta_{b(j)} + \sum_{c=1}^{C-1} \gamma_{c(j)} - \alpha p_{jt} + \delta_S S_j + \delta_L L_j + \delta_{SL} S_j \times L_j + \theta_N N_j + \theta_F F_j + \lambda\widehat{\eta}_{jt} + \zeta_{jt}$$

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 12 shows the results of the estimation of the price regression. All instrumental variables are significant and the F-test amounts to 12.08, meaning that the instrumental variables are not weak.

Table 12: **Results on price equation**

	Mean (Ste)
Instrumental variables	
Distance of competing products	
Fruit	4.22 (1.18)***
Nature	7.87 (1.23)***
Sugar content	0.55 (0.10)***
Number of competing products	0.08 (0.02)***
Exogenous variables of the utility function	
Compote	-
Yogurt	-4.87 (1.46)***
FBPS	-1.65 (0.79)***
ODD	-2.02 (0.73)***
Fruit	0.20 (0.13)
Nature	0.62 (0.19)***
Taste: sweetness	0.11 (0.02)***
Taste: fat	0.11 (03)***
Interaction sweetness x fat	0.00 (0.00)
R^2	0.93
IV F-test	12.08 (0.00)
Number of observations	791
Coefficients $\beta_{b(j)}$ not shown	

7.2 Identification of the cost model

Table 13: **Results on cost equation**

	Mean (Ste)
Input variables	
Constant	1.473 (0.355)***
Sugar	0.521 (0.237)***
Milk for Yogurt	0.504 (0.163)***
Milk for FBPS	1.261 (0.329)***
Compote	0.374 (0.355)***
Other ingredients (fixed)	
for yogurt	0.637 (0.978)
for yogurt with fruits	0.843 (1.229)
for FBPS	1.037 (0.394)***
Control variables	
Fruit fixed effect	not shown
Percentage of other ingredients	not shown
Monthly fixed effect by product category	not shown
Monthly fixed effect for no-nature products	not shown
Number of observations	791

7.3 Method of reformulation

Exogenous firms' reactions in product recipe to the tax have been considered for yogurts, FBPS and compotes. ODD recipes are assumed to remain constant, due to their various and complex recipes and because of manufacturers' uncertainty about consumer's reaction to gourmet foods reformulation (Sebillotte, 2016). In order to establish realistic quality response scenarios, the recipe and the minimum amount of added sugar technically feasible for firm and sensory acceptable by consumers had to be determined for each yogurt, FBPS and compote.

Step 1: Recipe assessment

Because product nutritional information necessary to assess recipe is not reported in the Kantar database, we determined the recipe of each product using the list of ingredients and nutrition fact label collected by Oqali database.[31] Products collected by Kantar were then matched to those of Oqali. We used compotes and fruit purees, and milk products Oqali datasets, 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.

The amount of added sweeteners (sugar, glucose syrup, ...) is missing information. It has been estimated for each product, using the list of ingredients and nutrition facts label which provide the total amount of sweeteners. We have also estimated the amount of sugar substitutes in case of food reformulation (plain dairy product or fruit purees, depending on the type of products). In some cases, 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 assess 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 3). This is the case for only a few products.

Step 2: Computation of the minimum amount of added sugar

[31] Oqali is the French Food Observatory. Its implementation has been entrusted to a research institute, INRAE (French National Research Institute for Agriculture, Food and Environment) and to a food safety agency, ANSES (French Agency for Food, Environmental and Occupational Health and Safety). It 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). To this end, data on food products characteristics are collected, and a database has been specifically designed to monitor changes in food products over time.

The minimum amount of added sugar used to determine reformulation scenario 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; and
- compotes, diet compotes.

To this end, 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. To simplify, we considered that sugar is the only sweetener used in the case of food reformulation;
- a matrix ingredient, which is a substitute to the sweetening ingredients in the case of food reformulation. The matrix ingredient is plain yogurt, fromages blancs or petits suisses for dairy products and fruit puree for compotes.[32] In the case of reformulation, the matrix ingredients substitute an equal amount of sweetening ingredients; and
- a fixed ingredient for which quantity remains constant. This corresponds to the aroma used in flavored yogurts or fruits for fruit yogurts, for example.

In order to determine the minimum amount of sugar to be used in a given product, we applied an optimization model. We minimized the proportion of sweetening ingredients y_s subject to the technical constraints of formulation, such as product sweetness, texture or other constraints related to manufacturing. Constraints are defined in Table 14. The limit values of constraint were derived from our matched Oqali Kantar dataset, by neglecting the extreme observations corresponding to very specific recipes. Table 15 reports those extrema and the values set to

[32]For soy products, we considered plain soy yogurt as the matrix ingredient. The change in the nutritional composition of soy products, before and after reformulation, takes into account the specific composition of the soy matrix. Nevertheless, when assessing production cost variations, we assume the cost of this soy matrix to be the same as that of dairy yogurt.

calibrate the optimization models for the 18 recipes. Ingredient characteristics used in the constraints are shown in table 16. 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 17.

Step 3: Aggregation into the 159 groups of products

For computational reasons, we had to limit the number of products considered in the demand model. Individual marketed products were thus aggregated into 159 groups of products based on their type (yogurts, fromages blancs, petits suisses, compotes, dairy desserts), brand, aroma (plain, sweetened, flavored, fruits), and nutritional composition (fat and sugar contents). For example, whole milk yogurts with fruits of a particular brand that correspond to one group of products in this study, include several individual marketed products such as strawberry yogurts, pineapple yogurts,and so on, that can be sold as part of a pack of four yogurts, or eight yogurts, etc. Mean nutritional composition was computed for the 159 groups of products, taking into account the market shares of the marketed products. The average amounts of sweetening, matrix ingredients and minimum amount of sugar were also completed for the products for which firms quality reactions are considered. Tables 18 and 19 provide the mean contents in caloric sweeteners and fat, before and after reformulation, by brands and product categories.

Table 14: **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	Sweetening ingredients, in too high proportion, can dilute milk proteins and thus hinder the gelation process	$\frac{y_m * Prot_m}{(y_m + y_s)} \geq G^{+}$ where $Prot_m$ is the protein content of matrix ingredient
Regulatory	A dairy product may be supplemented with flavoring ingredients, provided that this addition does not exceed 30% of the weight of the finished product	$y_s + y_f \leq 30\%$

N.B.: fermentation and gelation constraints could have been released in the case of fruit dairy products because part of the sugar can be added after fermentation and gelation, via the fruits mix.

Subscript (s), (m) or (f) stands for the sweetening ingredients (s), the matrix ingredient (m), or the fixed ingredient (f).

Table 15: **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 acid 0.1%	17.4%	23.1%	14.5	21.5	-	-

Table 16: **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 17: **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 18: **Content in caloric sweeteners before and after reformulation by brands and product categories (g/100g of product)**

	Product categories						
	Compotes		Yaourts		Fromages blancs, petits suisses		Desserts frais
	Before	After	Before	After	Before	After	
Brand 1			9.55	7.96	9.23	8.11	19.99
Brand 2			6.43	6.43	4.89	4.89	11.20
Brand 3			5.14	5.14			
Brand 4			7.45	5.93			
Brand 5			9.71	9.24	8.35	7.33	
Brand 6			9.05	7.27	9.96	8.11	16.22
Brand 7			11.47	9.79	5.64	5.51	16.90
Brand 8			11.16	8.42			
Brand 9			12.20	7.70			
Brand 10	14.12	11.32	9.90	8.85	4.72	4.27	14.85
Brand 11	14.48	12.81					13.65
Brand 12			9.77	9.31	4.67	4.43	17.05
Brand 13			7.13	6.44			12.10
PLs	14.58	12.24	9.63	8.19	6.91	6.10	16.63
All	14.51	12.21	9.53	8.11	7.26	6.46	16.85

Table 19: **Fat Content before and after reformulation by brands and product categories (g/100g of product)**

	Product categories						
	Compotes		Yaourts		Fromages blancs, petits suisses		Desserts frais
	Before	After	Before	After	Before	After	
Brand 1			3.90	3.98	5.58	5.64	5.72
Brand 2			0.10	0.10	0.10	0.10	0.90
Brand 3			0.69	0.69			
Brand 4			0.87	0.89			
Brand 5			2.60	2.62	3.16	3.19	
Brand 6			2.19	2.24	3.80	4.01	7.05
Brand 7			4.68	4.73	2.42	2.42	2.20
Brand 8			1.89	1.98			
Brand 9			1.40	1.46			
Brand 10	0.42	0.42	2.62	2.66	3.04	3.05	12.94
Brand 11	0.51	0.51					2.83
Brand 12			1.62	1.63	3.53	3.53	6.86
Brand 13			2.98	2.99			2.10
PLs	0.27	0.27	2.39	2.45	4.06	4.11	4.82
All	0.32	0.32	2.41	2.46	3.90	3.95	5.61

7.4 Additional tables

Table 20: **Average own-price elasticities by brands and product categories.**

	Compotes	Yogurts	Fromages blancs, petits suisses	Other dairy desserts
Brand 1		-2.47	-3.09	-3.00
Brand 2		-2.42	-3.03	-3.43
Brand 3		-3.59		
Brand 4		-3.28		
Brand 5		-2.81	-3.45	
Brand 6		-2.57	-3.68	-3.26
Brand 7		-2.40	-2.84	-3.40
Brand 8		-2.52		
Brand 9		-2.58		
Brand 10	-3.17	-2.25	-3.12	-3.67
Brand 11	-3.20			-3.48
Brand 12		-2.37	-3.42	-3.63
Brand 13		-3.36		-3.40
PLs	-2.59	-2.09	-2.64	-2.68
All	-2.76	-2.40	-2.89	-2.95

Note: The reported own-price elasticity of a brand and a category is the weighted average (using market shares as weights) of the own-price elasticity of products of this brand in this category.

Table 21: **Taxation with product reformulation: Average pass-through rates across brands and product categories.**

	Compotes	Yaourts	FBPS	ODD
Brand 1		1.22	1.24	1.23
Brand 2				1.26
Brand 3				
Brand 4		1.23		
Brand 5		1.22	1.26	
Brand 6		1.19	1.28	1.25
Brand 7		1.19	1.22	1.24
Brand 8		1.20		
Brand 9		1.21		
Brand 10	1.23	1.20	1.24	1.30
Brand 11	1.22			1.25
Brand 12		1.18	1.24	1.29
Brand 13		1.26		1.24
PLs	1.18	1.18	1.21	1.19
All	1.19	1.19	1.23	1.22

A proportional tax of € 0.20 per 100g of sugar is implemented when sugar content is above 12g for compote and 8g for other product category.

Table 22: **Decrease in the average tax rate by product category and by firm due to product reformulation (in € cents /kg)**

Product Category	Δ tax	Firm	Δ tax
Compotes	4.9	Firm 1	1.3
Yogurts	2.8	Firm 2	2.3
FBPS	1.7	Firm 3	3.7
ODD	0 .0	Firm 4	4.6
		Firm 5	2.2
		Firm 6	0.6
		Firm 7	1.7

A proportional tax of € 0.20 per 100g of sugar is implemented when sugar content is above 12g for compote and 8g for other product categories.