Ref. Ares(2021)4225925 - 29/06/2021

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 774548.

EC Framework Programme for Research and Innovation

Horizon 2020
H2020-SFS-2017-2-RIA-774548-STOP:
Science & Technology in childhood Obesity Policy

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childhood Obesity Policy

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Start date of project: 1st June 2018 Duration: 48 months

D6.2: Peer-reviewed publication on secondary data analysis of the benefits and challenges of food reformulation initiatives

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Version: Final
Preparation date: 28/06/2021

Dissemination Level

PU	Public	☒
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	

CO	Confidential, only for members of the consortium (including the Commission Services)	

Abbreviation	Definition
DID	Differences and differences
EC	European Commission
EU	European Union
PHE	Public Health England
PPP	Public-Private Partnerships
SDIL	Soft Drinks Industry Levy
SSB	Sugar-sweetened beverages
STOP	Science & Technology in childhood Obesity Policy (H2020 project)
WHO	World Health Organization
WP6	Work Package 6 of the STOP project

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Abstract

Children in the Western world are currently consuming more sugar than is recommended. Its contribution to the total energy intake is largely above the 10% of total energy intake recommended by the WHO. This excessive consumption can have severe consequences on health in childhood and adulthood, in particular on obesity and diabetes. To address these public health issues and given the modest impacts of policies intended to promote preventive behaviors thanks to information campaigns and food product labelling, public health agencies and policy makers have implemented additional policies targeting changes in the quality and variety of foods and beverages sold in market. Two of them have received singular attention from public health authorities: Public-Private Partnerships (PPP) policy and taxation of unhealthful products/nutrients.

Food reformulation and how it can be encouraged are central to these policies. It may be a feasible way to reduce children's sugar intake and to improve the nutritional quality of their diets, even if they continue eating the same products. However, despite the high potential for food reformulation among many product categories capacities for reformulation remains unexploited. One of the objectives of this task is to better exploit the potential for reformulation by showing further pathways to the industry and government in order to reinforce food reformulation as an impactful lever against childhood obesity. We propose a methodological framework for sensory-led reformulation using chocolate chip cookies as a case study. To achieve our goal, a multi-criteria approach, including nutritional composition, physicochemical, textural, sensory and liking dimensions, was performed to identify pertinent reformulation levers. Then we used an experimental design on identified actionable levers to evaluate the influence of reformulation levers on food properties, perceptions, digestion indicators and children behavior.

Our multi-criteria approach allowed us to identify reformulation pathways to reduce the sugar (-19%), fat (-29%) and chocolate chip (-20%) content and to increase the fiber content with oat bran (+6.5%). It also led to promising results for the reduction of the glycemic index by the means of reformulation, while maintaining the sensory perception and the liking by children, which can be some recommendations for industrials and public authorities.

The second objective is to assess whether and to what extent PPPs policy and tax can lead to changes in the nutrient composition of foods available on the market. We achieve our second goal by comparing the relative changes to the nutritional composition of two specific product categories, namely dairy products with added sugar and sugar-sweetened beverages, in the post-implementation period, relative to the pre-implementation period in countries that has implemented such policies, and to those in other Western European countries that have not instituted such policies. These comparisons offer guidance to policy makers in designing effective policies to encourage food companies to improve the nutrient composition of their products. This ultimate goal turns out to be crucial. Depending on the design of the policy, companies can strategically react more or less to the policy and amplify or weaken its impacts

We find that both the PPP policy (characterized by a strong government leadership and pressure; an involvement of a large number of manufacturers; the publication of guidelines or reduction targets; and an effective monitoring and evaluation) and the tax (based on tiered tax rates that vary according to an unhealthy nutrient concentration and with a sufficiently high value) can encourage the formulation of less sugar-sweetened products. However, we found that a PPP policy would not be as effective as a tax in encouraging firms to reduce the sugar content of sugar-sweetened beverages, but its impact can be strengthened by combining it with a credible threat of tax implementation if insufficient progress is made in reducing the targeted nutrient, as it was shown for milk-based drinks in England.

Introduction

In many parts of Europe over 10% of children aged 5-19 are now obese, with overweight affecting up to a third of the children in some countries. Childhood obesity has become one of the most dramatic features of the global obesity epidemic. The rise in childhood obesity with its long-term health risks is of growing concern to public health authorities worldwide. Childhood obesity has profound health effects. Overweight or obese children are more likely to experience bullying, stigmatisation and low self-esteem.(1) They are more likely to develop Type 2 diabetes in childhood,(2) a condition that was once very rarely seen outside adulthood. They are also far more likely to go on to become obese adults,(3) with a higher risk of developing life threatening conditions such as some forms of cancer, Type 2 diabetes, heart disease and liver disease.(4,5)

While the etiology of overweight and obesity is complex, the increasing prevalence has been widely associated with changes in personal, social, economic and built environments that have shaped individual behaviours increasingly conducive to excessive and imbalanced nutrition, sedentary lifestyles, weight gain and ultimately, diseases associated with it.(6) Among these factors, poor diets and nutrition are the leading causes of disease and mortality.(7) Of the top 20 mortality risk factors in Europe, 12 are related to nutrition and diet.(8) While under-nutrition and micronutrient deficiencies still pose an important burden in low-income countries, the largest nutrition-related burden, however, comes from forms of malnutrition characterized by energy-rich and often nutrient-poor or imbalanced diets, characterized by an excessive consumption of foods high in salt and sugar, regardless of income level.(6)

Children in the Western world are currently consuming more sugar than is recommended: in the United Kingdom, they are consuming up to three times more than the daily recommended intake.(9) The total sugar intake ranges from 16% to 26% of total energy intake, and added sugars contribute between 11% to 17% of the total energy intake of children living in Western Europe.(10) The contribution of the latter is largely above the 10% of total energy intake recommended by the WHO.(11) It has been shown that excessive consumption of added sugars is associated with obesity and type 2 diabetes.(12–14)

To address these public health issues, governments and public health agencies have been implementing policies intended to promote preventive behaviours thanks to information and education campaigns and food product labelling. Reviews of these policies show that they have some positive impacts that, however, remain small, at least in the medium term.(15)

Given their modest impacts, additional strategies to prevent overweight and obesity in childhood have been considered.(4) Encouraging companies to reformulate their products is one of these possible strategies (e.g. reducing the level of ‘bad’ nutrients in food products; increasing the nutrient density of foods by increasing their amount of fibre, whole grains, or specific fats such as omega-3). Food reformulation improves diet and health without largely changing consumers eating habits.(16–18), and might have a higher impact on our diet than changing consumers’ behaviour.(17) Furthermore, several studies demonstrated the feasibility to improve childrens’ diet by food reformulation while children continuously consume the target food.(19–21) However, despite the high potential for food reformulation among many product categories and the voluntary food reformulation agreements among industries,(22,23) capacities for reformulation remains unexploited.

Therefore, it is highly important to **better exploit the potential for reformulation by showing further pathways to the industry and government in order to reinforce food reformulation as an impactful lever against childhood obesity**. Indeed, reformulation of products targeted at children may be a feasible way to reduce children's sugar intake and to improve the nutritional quality of their diets, even if they continue eating the same products. By consequence, the first objective of this report is about: *Development of a multi-criteria reformulation strategy targeting on children: A case study on cookies* (Subtask 1). To achieve our goal, a multi-criteria approach, including nutritional composition, physicochemical, textural, sensory and liking dimensions, was performed to identify pertinent reformulation levers. Then we used an experimental design on identified actionable levers to evaluate the influence of key reformulation levers on properties, perceptions, digestion indicators and children behavior. This new approach makes it possible to consider sugar reduction by putting aside the principle of avoiding changes in the sensory characteristics of products and focusing on reducing the sugar content, sweetness intensity and having an impact of satiation.

Given the modest impacts of information-based policies and the promising effects of food reformulation, public health agencies and policy makers urge the food industry to favour a better food environment through changes in the quality and variety of foods.[1](4,24)

An initial response of the food industry has been to launch new products based on nutrition and health claims and innovative foods targeting health-conscious consumers. Market incentives exist for such a strategy and depend on the number of health-conscious consumers (which can be influenced by public information campaigns) and their willingness-to-pay for healthier and innovative foods. However, this type of initiative only represents a non-substantial proportion of products in the market. In France, for instance, approximately 20 percent of food products have a nutritional claim.(25) Regarding the remaining part of the market, the nutritional quality of food is more contrasted.(26) For this reason, public health agencies urge the food industry to commit in individual or collective agreements to reformulate their products.(27–29)

There are two main categories of voluntary agreements. The first category is agreements that are completely voluntary where businesses have a totally free choice on whether to join and there are no sanctions for non-compliance. On the whole, while there are significant improvements in the nutritional quality of some products, the overall impact of this category of agreements on consumers' intakes is still modest, as these agreements encompass relatively few products.(26) The second category is agreements between governments and manufacturers involving the joint setting of reformulation objectives, namely PPPs policy. PPPs policies can be implemented in many different ways, but these agreements usually include well-specified targets, comprehensive monitoring systems and sanctions for non-

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[1] Changes in advertising and marketing were also considered by policy marker. Marketing and advertising policies are analyzed in WP4.

compliance.(30) This category has gained prominence as a potential cost-effective intervention and received therefore singular attention from public health authorities.(31–33)

The Second objective of the report is to **provide empirical evidences on the effectiveness of PPPs policies in force in Western Europe in improving the nutrient composition of products, and second provide guidance to policy makers in designing more effective PPPs policy** (Sub-task 2). Several studies have shown that the degree of PPPs policy success in improving the nutritional quality of food supply rests on four key drivers: (i) a strong government leadership and pressure; (ii) an involvement of a large number of manufacturers, (iii) setting incremental targets at food product category level with a specified deadline to be achieved using maximum and average or sales-weighted average targets; and (iv) an effective monitoring and evaluation.(33,34) In this subtask, we focus our analysis on the evaluation and the comparison of the impact of PPPs policy that fully achieves these four criteria. Specifically, we assess and compare the effects of PPPs policies in force in the Netherlands and England on the nutritional composition of a specific product category, namely dairy product category, from 2010 to 2019. We achieve our goal by comparing the differences in the trends of the nutrient composition of dairy products with added sugar between Western European countries exploiting both cross-sectional (arising from the presence or the absence of policy between countries) and time (arising from the difference in the date of implementation of the policy) variations.

Although a PPPs policy that achieves these four criteria of success has been shown to be effective, the level of its impact on product nutrient composition can be deemed unsatisfactory by policy makers, and thus insufficient to substantially address the public health challenges. For example in the UK, the overall sugar reduction between 2015 and 2019 was 3% where it was expected to be 20%.(35) Highest sugar reduction was found among yogurts and breakfast cereals with 13%, whereas for biscuits it was found instead an increase of the sugar content for 0.6%.(35,36) Another alternative considered by policy makers is to adopt more stringent policies to force change in product nutrient composition, such as food tax.(25,37)

Food tax can be designed to influence the product nutrient composition chosen by firms. For instance, the regulator might define a quality threshold by which products that have a quality higher than the threshold are not taxed, whereas products that have a quality lower than the threshold are taxed. Such a policy turns out to be theoretically efficient, provided that the quality threshold is not too stringent so that a firm prefers to reformulate its product to avoid the tax, leading to positive results for health and welfare.(38) Empirical evaluations on their impact on the nutrient composition of product are still limited.(35,39,40)

The third objective of this report is to **evaluate the effectiveness of tax policies in place in Western Europe in improving the nutrient composition of products, and second provide guidance to policy makers in designing effective tax policy to foster the improvement of nutrient composition** (Subtask 3). Specifically, we evaluate and compare the effects of Sugar-Sweetened Beverages (SSB) taxes currently in force in the United Kingdom and France on the sugar content time trends of newly marketed SSBs from 2010 to 2019. To achieve our goal, we compare the differences in these trends between Western European countries exploiting both cross-sectional (arising from the presence or the absence of the tax between countries) and time (arising from the difference in the date of implementation of the policy) variations, as in Subtask 2. We also compare the effects of tax and PPPs policy.

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Science and Technology in
childhood Obesity Policy

Part 1: Development of a multi-criteria reformulation strategy targeting on children: A case study on cookies

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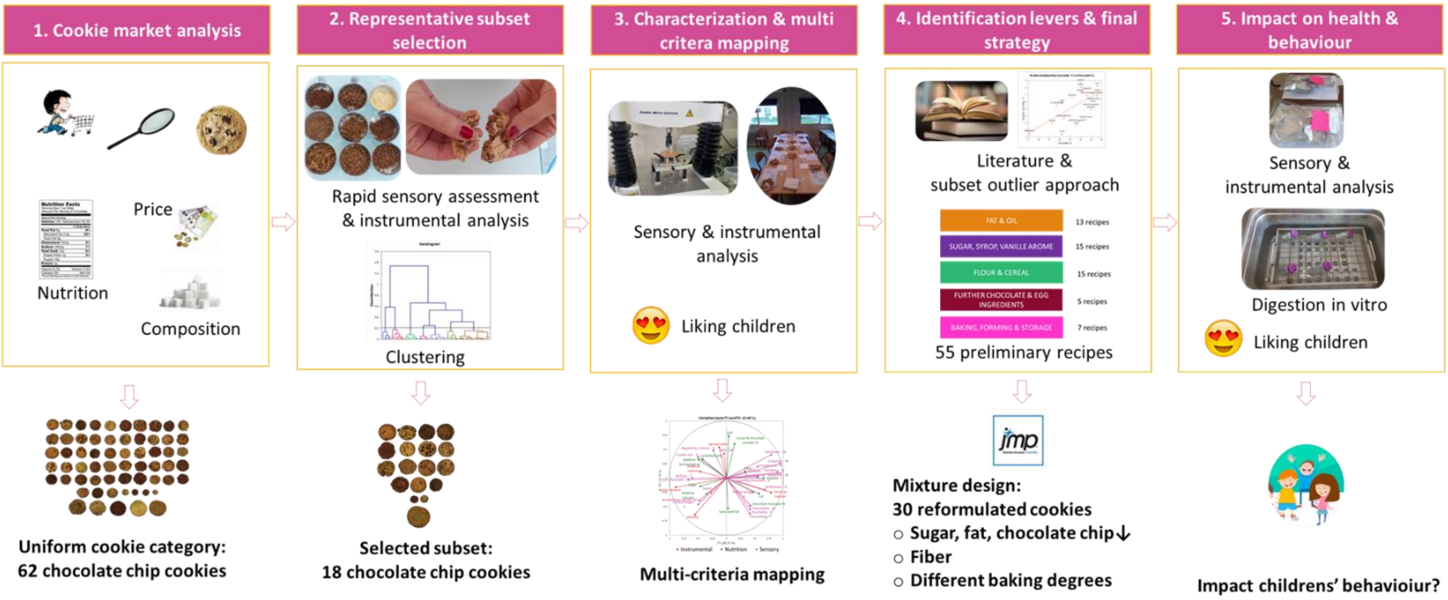
Graphical abstract



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Abstract

The global rise in childhood obesity is a serious public health concern. Food reformulation is one of possible strategy to fight against overweight and obesity. In order to encourage the food industry to make healthier version of food products, this study contributes to identify paths for reformulation at unchanged (or improved) sensory properties, with a focus on cookies.

This work suggested a methodological framework for sensory-led reformulation focused on cookies products. This product was chosen for its large range of recipes, prices and its impactful product category on consumption and diet. A multi-criteria approach, including nutritional composition, physicochemical, textural, sensory and liking dimensions, was performed to identify pertinent reformulation levers. First, the diversity of 62 commercial cookies with chocolate inclusion were investigated. Then, a clustering of the cookies was performed in order to propose a subset selection of cookies, representative of the diversity and based on quantitative and qualitative criteria. The selected subset consists of 18 cookies representative of the cookie market analysis, whose characterization was completed by additional measurements, including liking by children.

The representative subset is thus the base for identifying future reformulation levers, considering nutrition, composition, instrumental and hedonic information as one possible answer to the problem of childhood obesity. An experimental design on identified actionable levers allowed to evaluate the influence of reformulation levers on properties, perceptions, digestion indicators and children behavior. Results showed experimental pathways to reduce the sugar (-19%), fat (-29%) and chocolate chip (-20%) content and increase the fiber content with oat bran (+6.5%).

This work also led to promising results for the reduction of the glycemic index by the means of reformulation, while maintaining the sensory perception and the liking by children, which can be some recommendations for industrials and public authorities.

Keywords: Biscuit reformulation; Sample selection; Market analysis; Childhood obesity; Consumers; Perception

Introduction

The global rise in childhood obesity is a serious public health concern (NCD Risk Factor Collaboration (NCD-RisC), 2017). An important causing factor is the unhealthy diet composed of high caloric, ultra-processed and highly palatable foods (Costa et al., 2018; Forde et al., 2013; Hall et al., 2019). Further it is well known that products targeting at children do have a higher sugar content than compared to those of adults' (Moore et al., 2020; Rito et al., 2019). To prevent overweight and obesity in childhood, food reformulation is one of the possible strategy to improve our diet and health without largely changing consumers eating habits (Gressier et al., 2021; Raikos & Ranawana, 2019; Spiteri & Soler, 2018)

Food reformulation (reducing overconsumed nutrients such as sugar, fat and salt) can enhance nutritional quality and providing healthier and nutritious food (Raikos & Ranawana, 2019). Spiteri and Soler (2018) assume that food reformulation might have a higher impact on our diet than changing consumers' behaviour. Several studies demonstrated the feasibility to improve childrens' diet by food reformulation while children continuously consume the target food (Hashem et al., 2019; Muth et al., 2019; Yeung et al., 2017).

Recent modeled food reformulation studies with a multi-nutrient approach showed that food reformulation lead to a statistically significant reduction in daily energy, fat, sugar and salt intake and to a statistically significant increase in fiber intake among children and adolescents (Combris et al., 2011; Leroy et al., 2016; Masset et al., 2016; Muth et al., 2019). However, classical food reformulation approaches in the past often excluded consumer oriented methodologies such as sensory perception and hedonic evaluation – although consumer preference is a key determinant of food reformulation (Federici et al., 2019; van Kleef et al., 2006). Recent studies proofed the feasibility to reformulate while maintaining the liking among children. For example, for dairy products and grape nectar it was possible to reduce the sugar content up to 27%, respectively 21.6% while maintaining childrens' appreciation (Lima et al., 2019; Velázquez et al., 2021)

However, despite the high potential for food reformulation among many product categories and the voluntary food reformulation agreements among industries (Belc et al., 2019; Breda et al., 2020), the capacity for reformulation remains unexploited. For example in the UK, the overall sugar reduction between 2015 and 2019 was 3% where it was expected to be 20% (Public Health England, 2020). Highest sugar reduction was found among yogurts and breakfast cereals with 13%, whereas for biscuits it was found instead an increase of the sugar content for 0.6% (Moore et al., 2020; Public Health England, 2020). In addition, results among European regions for industry-led food reformulations showed that industries failed in meeting countries' reformulation targets (Campbell et al., 2021).

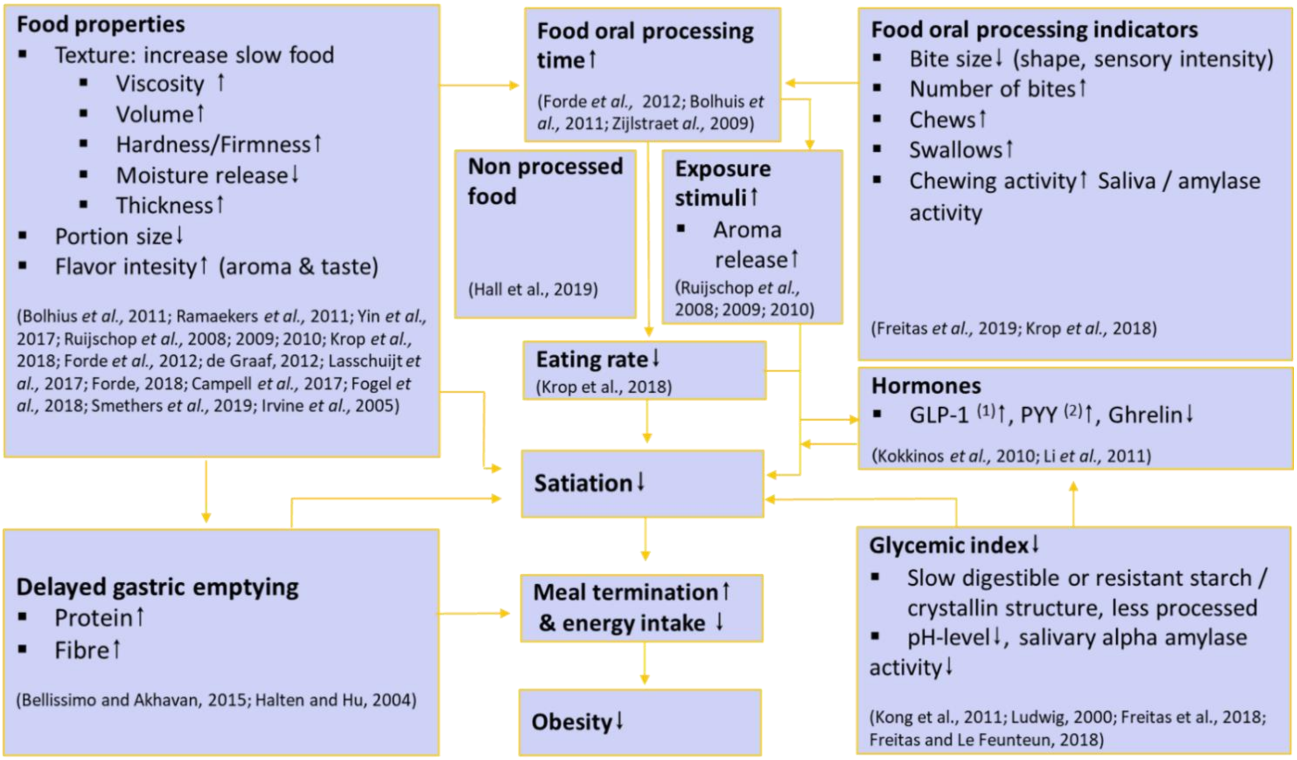


Figure 1 : Summary of foods' properties and possible food reformulation levers with impact on food oral processing and satiation from the literature

Therefore, it is highly important to better exploit the potential for reformulation by showing further pathways to the industry and government in order to reinforce food reformulation as an impactful lever against childhood obesity. Within this frame, it is necessary to promote the development of a range of processed foods having improved nutritional quality while maintaining liking. The food reformulation must therefore be strengthened, in line with public health policies. This can be achieved by studying the composition and properties of products on the market and possible levers. On this basis, it would be possible to set realistic reformulation targets and levers for each food category or family.

First, a study of literature was performed to identify reformulation levers as intervention with impact on health and obesity. Based on the literature, a reduction in energy density from sugar and fat play an important role to reduce childhood obesity (Bogl et al., 2018). Different studies demonstrated a sugar and fat reduction by food reformulation (Combris et al., 2011; Masset et al., 2016; Muth et al., 2019). However, sugar and fat play an important role in consumers' perceptions and liking which makes their reduction very challenging. The stake to maintain similar sensory perception while reducing sugar and fat is thus very high. In this objective, different pathways were described. A sugar reduction while maintaining foods' sweetness might be achieved by using vanilla aroma (Velázquez et al., 2021; G. Wang et al., 2019) and smaller sugar particle size (Richardson et al., 2018). A fat reduction while maintaining foods' texture and mouthfeel might be achieved by using fibers (Conforti et al., 1997; Lee & Inglett, 2006; Milićević et al., 2020; Zoulias et al., 2000).

The literature also shows that it is possible to reduce the total energy intake by enhancing the satiation and satiety, induced by modifying foods' texture and the oral process (Figure 1) (Fogel et al., 2017; Forde et al., 2013; Krop et al., 2018; Quah et al., 2019). In particular, it was shown that texture modification might be successful to decrease the ‘obesogenic’ eating style among children, which is associated with faster eating rates, achieved through larger bites, reduced chewing and shorter oral exposure time (Fogel et al., 2017).

An interesting lever to modify foods’ texture and process oral in order to influence the satiation and satiety, are fibers (Pentikäinen et al., 2014; Priyanka et al., 2019). It was shown that the use of viscous fiber (beta glucan) might lead to an increased bolus viscosity (increase in oral process), a delayed gastric emptying (increase in satiation and satiety) and a limitation of the starch hydrolysis (decrease in glycemic index, increase in satiety and satiation).

Besides the positive effect of food texture on health, texture is an important driver of preference and therefore a relevant lever to make a product more desirable among consumers(Brown & Braxton, 2000; Jeltema et al., 2015). Food reformulation is thus a possible way to enhance both the nutritional properties and the texture of foods (Raikos & Ranawana, 2019).

However, reformulating biscuits for children – such as reducing main energy sources sugar and fat – is challenging due to two reasons: First, sugar and fat are strong drivers of preferences among children. Any modification might have huge consequences on children's liking, pleasure experiences and food choices (Marty et al., 2018; Nguyen et al., 2015; Pareyt et al., 2009). Second, these two macronutrients do have multiple functional properties in the food matrix of bakery products (Ghotra et al., 2002; Miller et al., 2017). A further barrier is the hesitant willingness for voluntary food reformulation on the part of the food industry as cost and time effectiveness are not immediately granted. All these reasons constitute a real challenge is for scientists and food manufacturers.

The objective of this project was **to identify the reformulation levers to increase food healthiness while improving or maintaining its sensory characteristics and liking level**. In the frame of this project, Carole Liechti conducted her PhD research. The objectives of her PhD work consist in:

i. developing a strategy for food reformulation in order to have a healthier product
ii. evaluating the impact of the reformulated cookie(s) on in vitro digestion and children behaviour.

For that, a multi criteria approach, integrating nutrition, sensory, instrumental and hedonic characteristics was proposed, followed by an experimental approach focused on the study of the impact of reformulation on in vitro digestion and childrens’ perception.

Biscuits were chosen as a case study for this project as this category has a high impact on children diet. They contribute significantly to childrens’ high sugar and fat intake. Biscuits have impactful consequences on children’s diet due to its consumption frequency and poor nutritional properties (European Food Safety Authority, 2011 and Alessandrini et al., 2019). In this frame, cookies were the target food in this study. Indeed, cookies are energy dense and play an important role of added sugar intake among children (Afeiche et al., 2018; Denney et al., 2017 and Oqali, 2008). Moreover, cookies belong to the most preferred snacks among children and are known and eaten all over the world (CREDOC enquête CCAF, 2013 and Gupta et al., 2011).

Overall strategy

To address the objective of reformulation while maintaining pleasure and increase positive behavior from children, a strategy in 5 steps was proposed, as detailed in the figure 2.

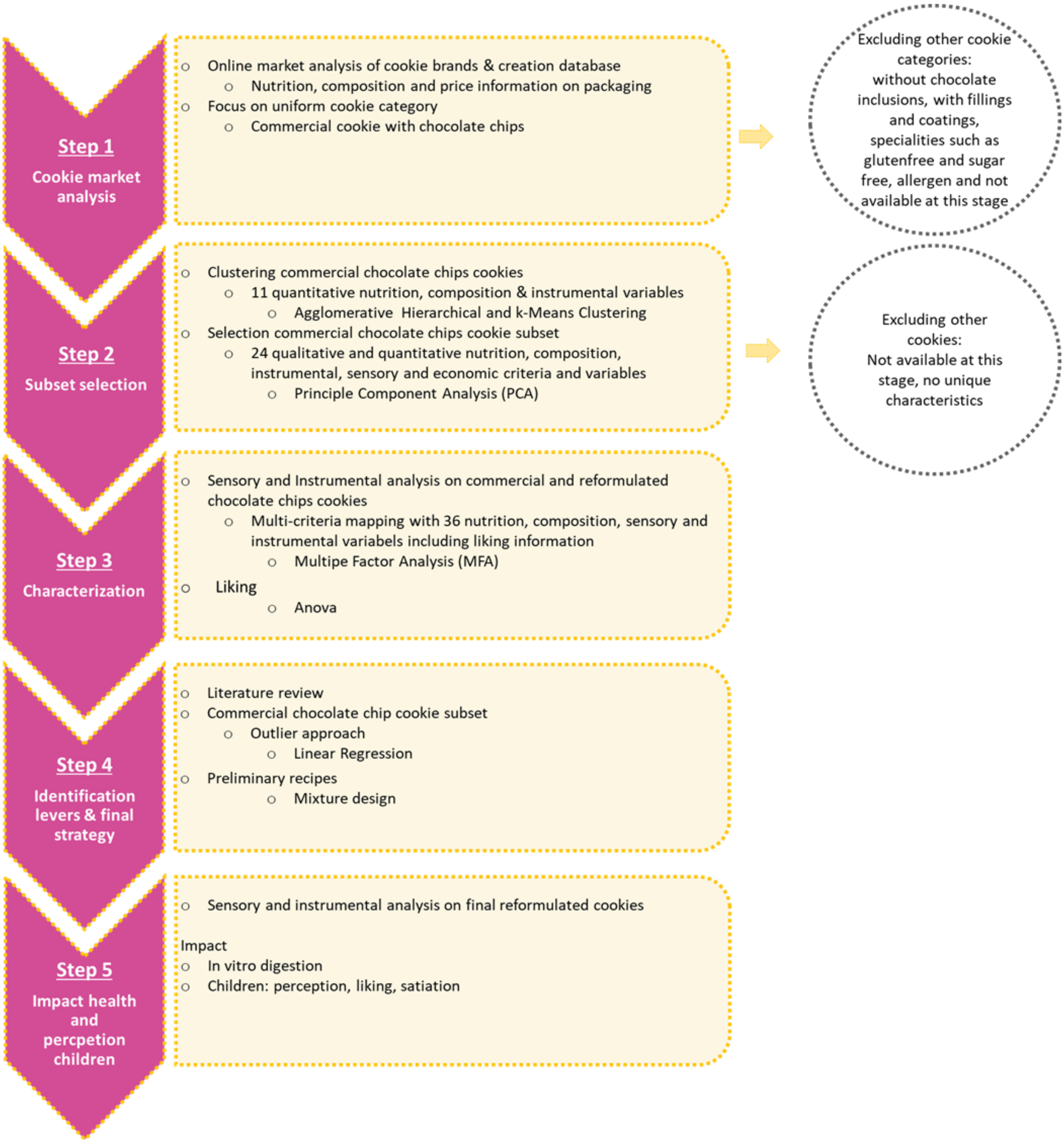


Figure 2 : Description of the 5 steps of the reformulation study, based on a multi-criteria approach

The first step consists inexploring and comparing the diversity of existing products from many different manufacturers (step 1). To be able to derive possible reformulation levers in a later step (4), it is important to have a braod view of the products.However, an in-depth sensory and instrumental characterisation of all the products form the marketplace would be too demanding. It was thus suggested to work on a subset of products that would be representative of the diveristy of the food offer in this category (step 2). Thanks to the subset selection it is possible to investigate the diversity of existing products in order to identify potential levers for reformulation. For that, further in depth sensory and instrumental analysis including liking information are needed to obtain a more complete view of the products (step 3). All these data could used for modeling in order to identify possible reformulation levers while maintaining sensory perception and liking (step 4). Based on this possible reformulation factors, reformulated cookie recipes were created by a mixture design. As a last step, cookies sensory perception and possible inlfuence on health and childrens' perception are evaluated (step 5).

Materials and methods

Cookie commercial products and their characterization (step 1)

To explore the diversity of recipes and nutritional composition, all the cookie brands available online on the French market in 2019 were analyzed. All food products with the specific mention "Cookie" on the packaging were included. Available nutrition, composition and price information from the packaging were gathered and a cookie database was created.

In order to work on a homogeneous product set, we focused on cookie containing chocolate chips for following reasons: i) cookies with chocolate inclusions showed the broadest range and diversity within the French market space, ii) the high sugar and fat content of chocolate inclusions which constitute a real challenge to modify and iii) own conducted focus group discussion demonstrated childrens' preferences for cookies with chocolate inclusions. We excluded all cookies without chocolate inclusions, with fillings and coatings, specialties such as glutenfree, sugar free, allergen-free and cookies which were not available during this collect period of time.

Evaluation of quantitative variables on all commercial cookies

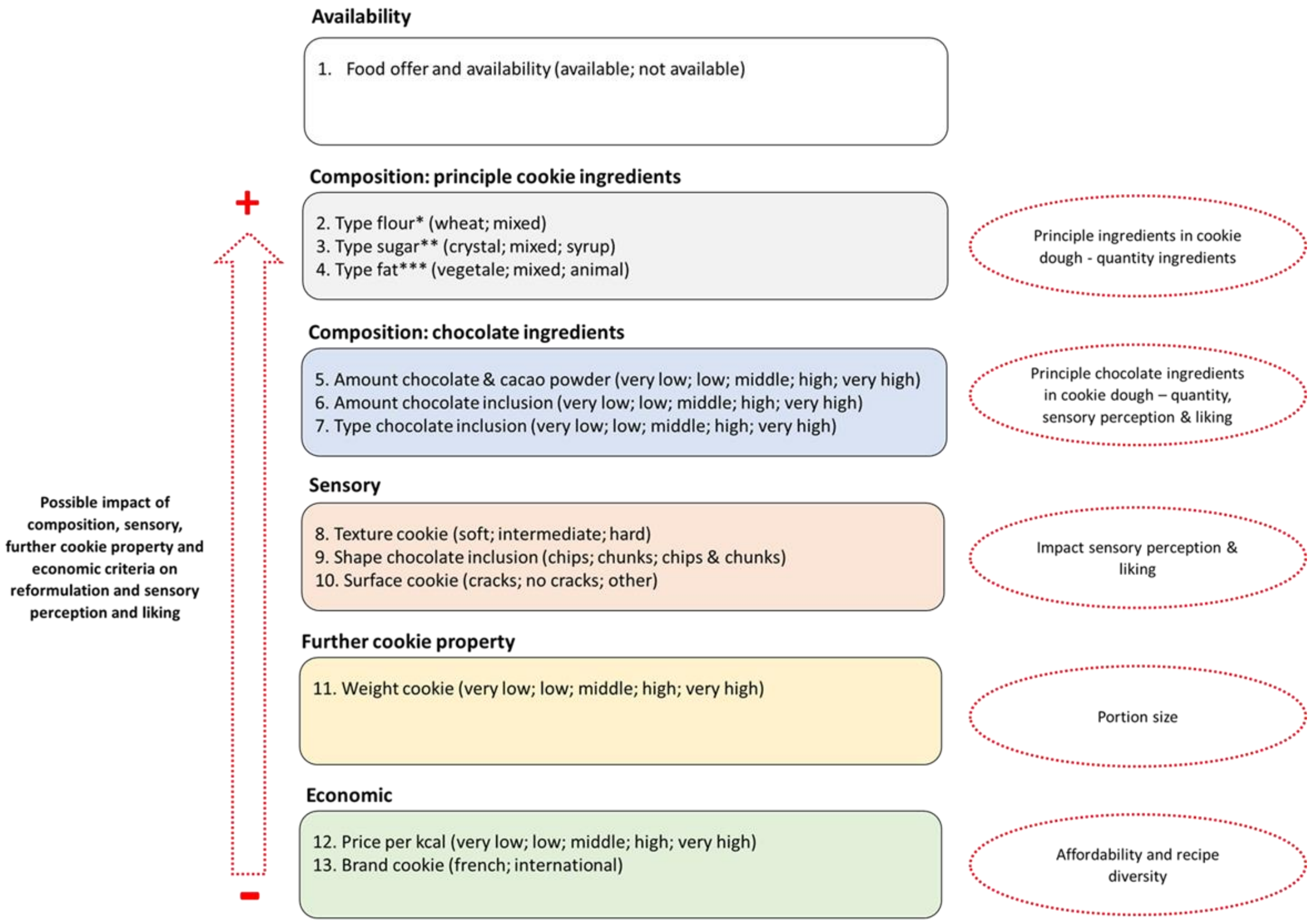
To characterize all commercial cookies of the market, 11 quantitative nutrition, composition and instrumental variables were investigated in the study: fat, saturated fat, carbohydrates, sugar, protein, fiber and salt content per 100g, number of technological additives (important for baking and conservation properties such as baking powder, emulsifier, thickening agents, antioxidants and humectant), number of sensory additives (important for sensory properties such as colorings and artificial sweeteners), number of ingredients and water content. All nutrition and composition information were obtained from the cookie packaging, whereas the water content was measured by instrumental analysis.

Furthermore, based on the nutritional values of the products, the Nutri-score was calculated (Rayner, 2017)

Evaluation of qualitative criteria on all commercial cookies

Some qualitative criteria were added to better assess product diversity. It includes sensory and economic criteria: food offer and availability, type of flour, type of sugar, type of fat, amount of chocolate and cacao powder, amount of chocolate inclusion, type of chocolate inclusion, texture, shape chocolate inclusion, surface of cookie, weight, price, brand. All information for the criteria were gathered during the market analysis, cookie packaging and rapid sensory assessment.

These criteria were then ranked to help to the selection of some representative cookies of the market (Figure 3). Food offer and availability (1) was prioritized, as products must be available in short time and desired quantity for further analysis. All remaining criteria were prioritized according to the possible impact on reformulation, sensory perception and liking.



* Type flour
  - Mixed flour: wheat with buckwheat, oat & quinoa flour

** Type sugar:
  - Crystal sugar: white, cane, invert, vergeoise, dextrose, cassonade, fructose, glucose sugar
  - Syrop: wheat, glucose, glucose-fructose syrop
  - Mixed sugar: crystal sugar and syrop

*** Type fat:
  - Vegetale: palm oil, sunflower oil, shea butter, rapeseed oil, margarine
  - Animal: butter

Figure 3 : 13 qualitative prioritized criteria with their 44 subgroups in brackets

Representative subset selection (step 2)

Clustering cookies

To select representative cookies of the diversity of the market, a clustering analysis was performed based on nutrition, composition and instrumental criteria (section 2.1.1). This will allow to select cookies from each cluster while maintaining the cookie diversity and their representativeness. Two clustering methods were applied. To visualize and select an optimal number of clusters (most balanced cookie numbers per cluster and most divers clusters an Agglomerative Hierarchical Clustering (AHC) was first carried out. After defining the optimum number of clusters, a K-means Clustering was applied.

Selecting cookie subset

In order to maintain the cookie diversity, the selection took place in two steps, between and within clusters. For the first selection step between clusters, we included 13 qualitative criteria (section 2.1.2). We switched from higher ranked to lower ranked criteria (1-13) until a subgroup was unique within a cluster. For the second selection step within clusters, 11 quantitative variables were considered (section 2.1.1). Cookies which were far away from their cluster or spread in one extreme direction were selected.

Cookie characterization: sensory analysis (step 3)

Rapid sensory assessment: Chocolate chip cookies

Rapid sensory assessments (evaluation of perceived texture in hand; visual perception cookie surface and shape of chocolate inclusion) were conducted on all commercial chocolate chip cookies by three panelists. The evaluation took place over six sessions and was conducted in sensory booths in a sequential monadic way, following a balanced order. Samples were coded with random three-digit numbers and presented in blind.

In order to evaluate the hardness perception of all chocolate chip cookies of the market, they were told to break the cookies in two halves by hand and to report their perceived hardness on an unstructured scale from 0-10, where 0 indicated soft and 10 hard. The cookies' surface and the shape of the chocolate inclusions were also evaluated. The visual perceived cookie surface was grouped into the qualitative subgroups “cracks”, “no cracks” and “other” what means neither cracks nor no cracks. The visual perceived shape of the chocolate inclusion was grouped into three qualitative subgroups “chips”, “chunks” and “chips and chunks”.

Sensory Quantitative Descriptive Analysis (QDA) for Commercial cookie subset

Subjects and testing conditions

The sensory evaluation of the subset samples (18 commercial cookies and 30 reformulated cookies) was performed using Quantitative Descriptive Analysis (QDA®; Stone & Sidel, 1993), and with 2 trained panels. For commercial cookies, a panel of 12 volunteers (ten women and two men, between 21 and 64 years old) was recruited at AgroParisTech (Massy, France) in 2020.For reformulated cookies, a panel of 10 volunteers was recruited in 2021. Before engaging in the sensory profile, the panelists signed a consent form to participate in this study and received compensation for their participation.

Chocolate chip cookie samples were presented on a white cartoon plate with randomly selected three-digit numbers

The chocolate chip cookies were presented according to a monadic sequential design. The sample evaluation order was balanced over the panel following a Williams Latin square design to account for potential order and carry-over effects. Panelists were asked to rinse their mouth with mineral water (Evian, Danone, France) between samples.

Procedure

In total, 14 sessions were performed by each panelist. First, four 45-min sessions were dedicated to the generation and selection of attributes, followed by training in the use of these attributes for quantitative description of the products. During the first session, the 12 panelists generated a vocabulary of sensory attributes that covered the visual, odor, taste, after taste, texture in hand and texture in mouth. In total, we collected 303 attributes. We completed a consensus phase in order to reduce the vocabulary down to 20 sensory attributes with their definitions and evaluation protocols. For the second study on reformulated cookies, similar approach was used, with a generation of 220 attributes, and a selection of 23 attributes. Four sessions were then carried out to train the panel on these attributes. Finally, panelists were trained in the use of a 10-cm unstructured linear scale to evaluate the intensity of each attribute, using external references.

For the evaluation session, the subset was evaluated for these 20 attributes by conducting six sessions (six cookies per session).

Cookie characterization: instrumental analysis (step 3)

In addition to sensory characterization, pertinent measurements of physicochemical and structural measurements were performed on commercial and reformulated cookies.

Water content

The water content was determined by oven drying method and adapted from (Upadhyay et al., 2017). First, all chocolate chip cookies were crushed and grinded with a mortar during 15 seconds. After grinding, 3 g of grinded cookies were weighed in a round aluminum dish. It was further put in the oven (EM10, Chopin, France) for 18 hours at 103 °C. The time was set by 18 hours as the weight after drying did not change anymore. The sample was then placed in a desiccator for 1 hour before weighing. All measurements were performed in triplicate among three different cookies and the results averaged.

The mass loss was determined by weighing the sample before and after drying to constant weight:

$$water\ content\ in\ \% = \frac{weight\ (g)\ cookie\ before\ oven - weight\ (g)\ cookie\ after\ oven}{weight\ (g)\ cookie\ before\ oven} * 100$$

Density

The density of the chocolate chip cookie subset was measured with VolScan Profiler (Stable Micro Systems, Surrey, UK) which was used in previous studies for baked products and baking ingredients (Mäkinen et al., 2013). The test conditions were as follows: rotation speed 1 rps and vertical scan increment 2mm. Cookie density was calculated by dividing the cookie weight by the cookie volume. All measurements were triplicated.

Texture

The texture properties of the chocolate chip cookie subset were studied by a three points bending test, carried out with a TA.HDplusC Texture Analyser (StableMicrosystems,Surrey,UK). The machine was controlled by the Exponent connect software. The experiment conditions were as follows: distance between supports 14 mm (7 mm per side); trigger force 0.5 N, probe travel distance 30 mm, pretest speed 1.0 mm/s, test speed 0.2mm/s and post-test speed 1 mm/s. The data were recorded in triplicate.

In order to compare products with each other, the stress (σr) (1) and strain (εr) (2) at rupture, as well as the Young's modulus (Ey) (3) were calculated, thus making it possible to avoid dimensional variations (Baltsavias et al., 1997):

(1)

$$\boldsymbol{\sigma_r = \frac{3 \times F_r \times L}{2 \times l \times h^2}}$$

(kN/m²)

(2)

(%)

$$\varepsilon_r = \frac{6 \times h \times y_r}{L^2}$$

$$(3) \qquad E_y = \frac{L^3}{4 \times l \times h^3} \times \left(\frac{dF}{dy}\right)_{y \to 0} \qquad (N/m^2)$$

With following parameters:

L = the distance or the span length between the 2 fixed uprights of the plane on which the cookie rests (m) , l = width of the cookie (m), h = height of the cookie (m) , F = force (N) , F_r = breaking force (N),

Y = deviation (m)or distance, y_r = distance rupture (m).

Spread ratio

The spread ratio of the 18 chocolate chip cookies was calculated using the formula: diameter of cookie divided by its height. The height was measured in the middle of the cookie (only cookie dough, no chocolate inclusion) and the diameter was measured using a vernier caliper. The results were triplicated.

Cookie characterization: liking among 8 commercial cookies from the commercial cookie subset (step 3)

In addition to instrumental and sensory characterization, we investigated children's liking for the commercial cookies. To indicate the frame for reformulation towards a healthier cookie, while maintaining the sensory properties and liking, a liking study with 151 children from four different cities in France was conducted on 8 selected commercial cookies (the cookies were selected based on 36 nutrition, sensory and instrumental variables). Indeed, this number was a maximum to be evaluated by children in minimizing some possible bias.

Participants

151 children were recruited for this study from the Eurofins SAM database. They all lived in four locations in France (Paris, Aix-en Provence, Nantes, Toulouse), and were recruited about two weeks prior to the experiment using online and phone questionnaires focused on their sociodemographic characteristics and consumption habits. Participants were randomly selected using the quota method so that the composition of the sample was representative of the gender (50% girls / 50% boys), age (50% 7-9 years old / 50% 10-12 years old), and socioeconomic demographics of the city's population.

Questionnaires

The questionnaires were first pre-tested on children. In total 6 online questions about the liking, the perceived hunger level, the motivation to eat and the perception of healthiness were evaluated. The liking, the motivation to eat and the evaluation of the healthiness were measured with a 5 point facial scale (Figure 4.a). To investigate the perceived hunger level, a 5 point hunger level scale (Figure 4.b) was used which was adapted from (Bennett & Blissett, 2014; Faith et al., 2002; Lange et al., 2019).

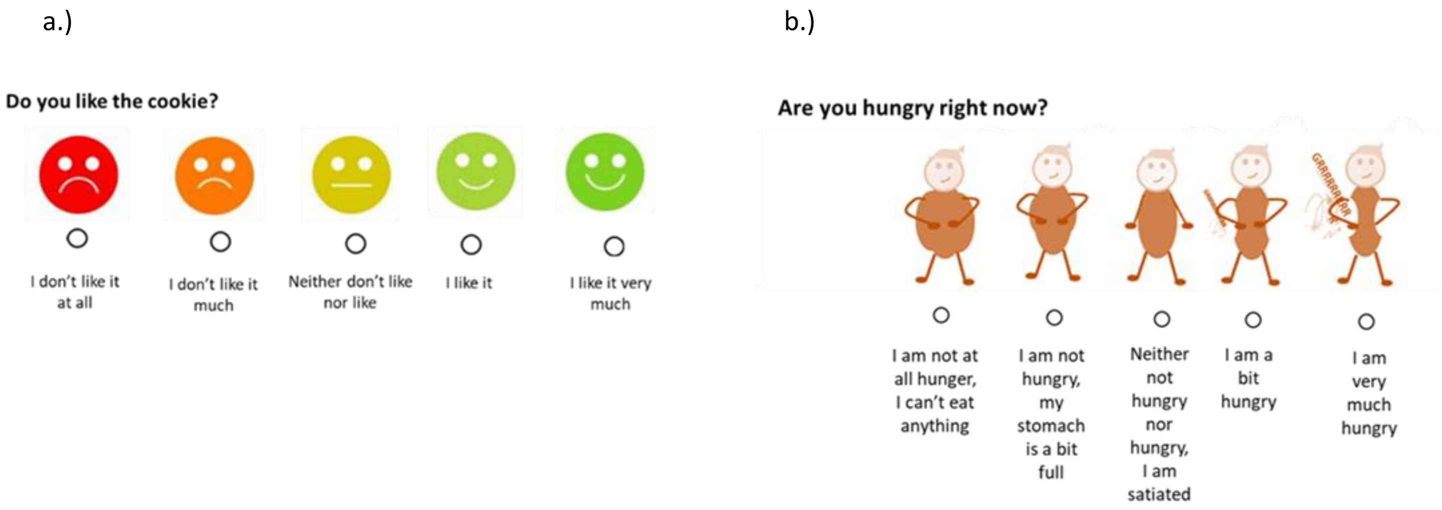


Figure 4 : Questionnaires for children: a.) 5 point facial scale with the anchors 1=I don't like it at all to 5= I like it very much. b.) 5 point hunger level scale from 1=I am not at all hungry, I can't eat anything to 5=I am very much hungry

The study included as well an online questionnaire for parents. The questionnaire included 12 questions about childrens' snacking habits and cookie preferences.

Products

The products were selected based on the multi-criteria mapping with 36 nutrition, sensory and instrumental variables on MFA axes F1-4. Based on the plotted commercial subset, 8 commercial cookies with different nutrition, sensory and instrumental properties were selected (Figure 5). The products were repacked in easy to open mylar bags without indicating products' brand.

Figure 5 : 8 commercial cookies for the hedonic evaluation among 151 children

Study design

All cookies in easy to open mylar bags were first distributed to the parents, in blind conditions. The tasting of the 8 cookies by the children was done by a Home Use Test. The child evaluated the cookies according to a balanced experience plan. He/she was asked to eat only 1 cookie per day. Consumers were asked not to open the bags until to give the product to their child in order to minimize the impact of moisture on the products. In the experiment, the order in which the eight cookies were consumed by children followed a Latin square design and the cookies were coded with 3 digit codes. The data was collected with the Fizz software (Biosystem, Couternon, France)

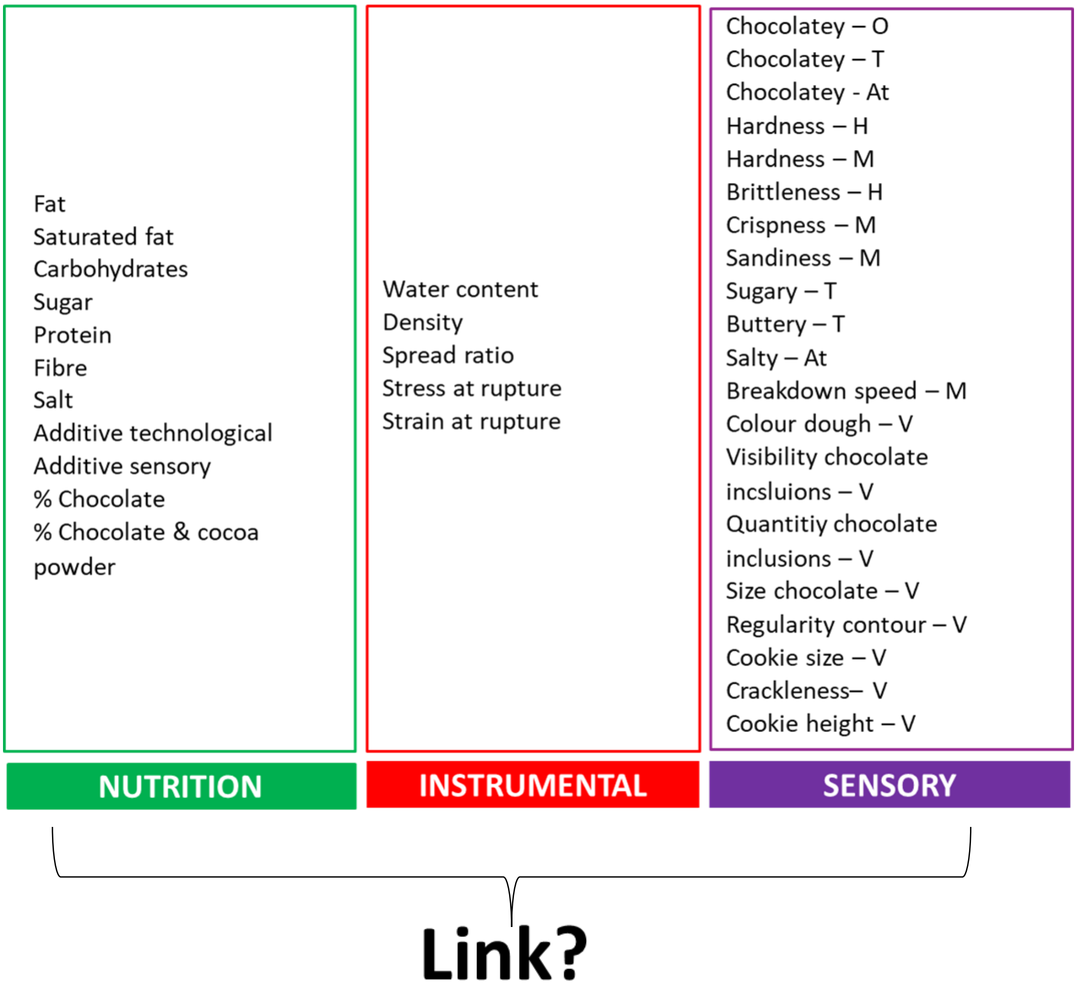
For this liking study, all participants provided written informed consent and the study was approved by a local ethics committee (CER-Paris-Saclay-2020- 025)

As a follow-up to this work, reformulated cookies will be submitted to another round of consumer tests with children in the fall 2021.

Levers of reformulation: used approaches (step 4)

Multicriteria mapping based on commercial cookies

In order to evaluate the relationship between the obtained nutrition, instrumental and sensory variables from the subset characterization (Figure 6), a multi criteria mapping was conducted. In total we included 11 nutrition, composition, 20 sensory and 5 instrumental variables. The multi-criteria mapping is the base to identify then in a next step possible reformulation levers with the outlier approach. Therefore, interesting nutrition and sensory variables were selected for further in-depth analysis.



O=Odour; T=Taste; At=Aftertaste; V=visual; M=texture in mouth; H:Texture in hand

Figure 6 : Nutrition, instrumental and sensory variables to evaluated their relationship

Outlier approach

Among the cookie subset we identified possible reformulation levers with a developed “outlier” approach. For this approach, we conducted a linear regression with a scatter plot with a sensory and a nutrition variable from the multi-criteria mapping (figure 9). The aim of this approach is to identify potential to reduce or increase certain nutrients, while maintaining as much as possible the sensory perception. As well according to Public Health England (2017), the sugar reduction strategy was first based on commercial products. Therefore, the average sugar content among market products was reduced by 20% and a maximal sugar content was set around the 75th percentile.

As an example in figure 7, we conducted a linear regression with a composition (sugar g/100g) and a sensory (sweet taste) variable. The trend of the pair variables showed that the higher the perceived sweet taste, the higher also the sugar content. Nevertheless, some cookies are far away from the linear regression line and therefore called "outliers". On the scatter plot the outlier cookie in a red circle shows potential for sugar reduction, while maintaining the perceived sweet taste by moving it towards the linear regression line to the cookie in the yellow circle. Cookies with missing nutritional values (fiber) or very strong outliers very excluded from the linear regression.

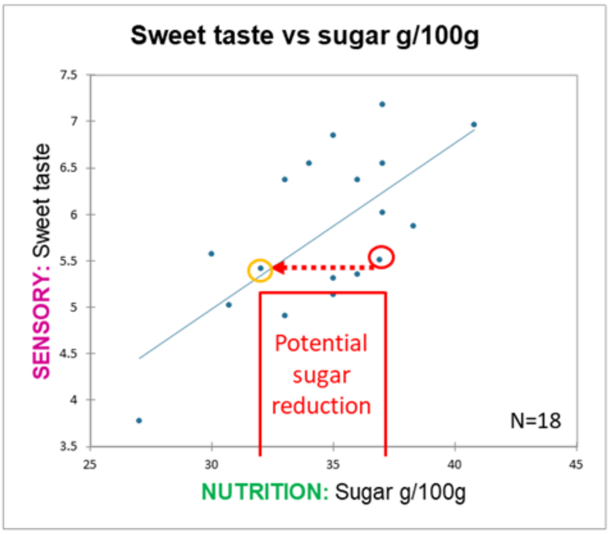


Figure 7 : Scatter plot between the variables sweet taste (sensory) and sugar g/100g (nutrition)

To select most pertinent linear regressions and outliers, the final potential outliers were chosen based on following criteria: high impact on obesity relevant factors (responsible for inducing obesity, implicated as a lever to tackle obesity or possible impact on satiation and satiety); high outlier potential, high effect size, low interactions with other nutrition and composition variables and low scenarios (for example low impact on liking and sensory perception etc.)

Selection of final reformulation levers and applied strategy

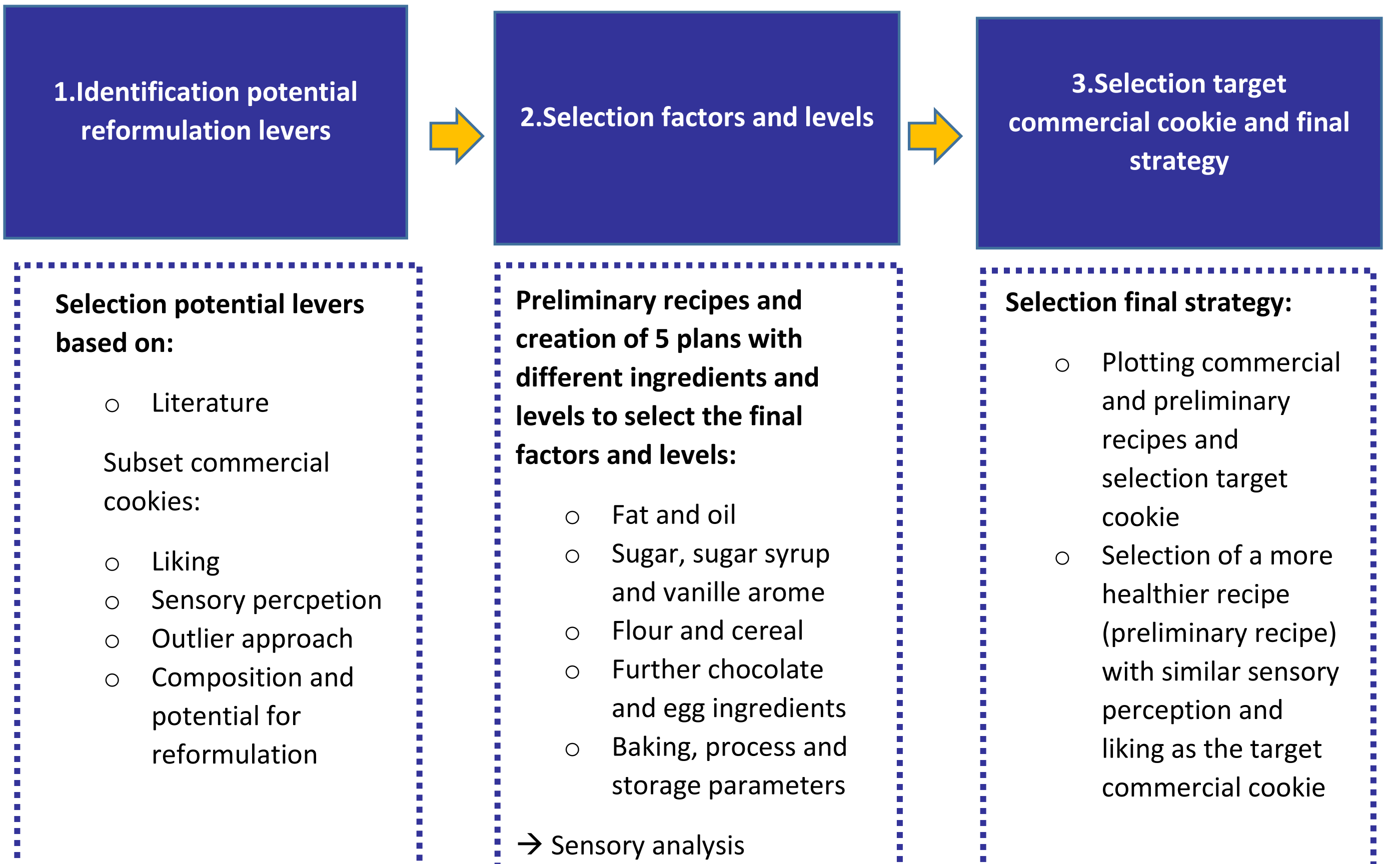
In order to select a healthier recipe but with similar sensory perception and liking, the final reformulation strategy was based on a multidimensional approach (Figure 8) with three steps. First, the identification of the potential reformulation levers was based on the literature and on the commercial cookie subset. The liking was conducted on a reduced number only. In a second step, 5 experimental plans with several recipes were thus created in order to select a final base recipe with factors (ingredients) and their levels tested separately. All ingredients are similar to those among the commercial subset. To evaluate and to compare the sensory perception of the preliminary recipes and the commercial cookies, a sensory analysis on all preliminary recipes was conducted. Further, the sensory analysis will provide results in which frame it will be possible to decrease or increase target nutrients, while maintaining sensory perception. To select the final reformulation strategy as a last step, all commercial cookies from the subset and the preliminary recipes with 7 sensory and 42 composition variables were plotted together. All sensory and composition variables are listed below:

- **7 Sensory variables:**

Sweet taste, chocolate taste, butter taste, hardness, crispness, sandiness, breakdown speed in mouth

- **42 Composition variables based on calculated ingredient lists:**
  - Total ingredients cookie (8):
    - total fat, sugar, flour&ceral, chocolate inclusions, egg, salt, baking powder, vanille arome liquid
  - Type ingredients (25):
    - Flours & cereals: wheat, quinoa, wholemeal, oat bran;
    - Sugar: saccharose, brown, syrup, smaller particle size, sugar powder, fructose;
    - Fat: butter, margarine, palm, rapeseed, shea, sunflower;
    - Chocolate: dark, milk
    - Egg: Egg yolk, egg white
    - Further arome: chocolate, cacao, nougatine, caramel arome and vanille arome powder
  - Further ingredients/additives in small quantities (7): chocolate powder, cacao powder, sugar alcohol, milk powder, whey powder, starch, fibers
  - Ingredients & additives (2): number ingredients & additives

The plotting allowed then to select a target commercial cookie for reformulation. The target cookie was selected based on their potential for reformulation (sugar, fat, chocolate chip and fiber content), the liking score and the sensory perception in comparison with the preliminary recipes. This allowed to define a healthier cookie recipe, while maintaining the sensory perception and the liking.



1.Identification potential reformulation levers

2.Selection factors and levels

3.Selection target commercial cookie and final strategy

Selection potential levers based on:

- Literature

Subset commercial cookies:

- Liking
- Sensory percpetion
- Outlier approach
- Composition and potential for reformulation

Preliminary recipes and creation of 5 plans with different ingredients and levels to select the final factors and levels:

- Fat and oil
- Sugar, sugar syrup and vanille arome
- Flour and cereal
- Further chocolate and egg ingredients
- Baking, process and storage parameters

→ Sensory analysis

Selection final strategy:

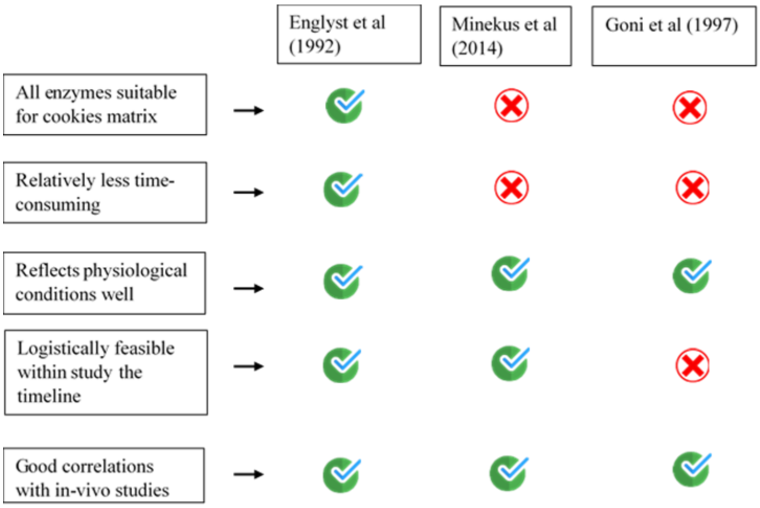
- Plotting commercial and preliminary recipes and selection target cookie
- Selection of a more healthier recipe (preliminary recipe) with similar sensory perception and liking as the target commercial cookie

Figure 8 : Overview of the multidimensional approach to select reformulation levers and the final strategy

In vitro digestion among reformulated cookies (step 5)

Before in vitro cookies characterization, it was necessary to adapt an in vitro digestion method from a previous protocol developed on bread. A critical review of many in-vitro studies was done earlier. Because there are many in vitro protocols available for hydrolysis food, it was important to select a base method that was fit with respect to the composition of cookies. The criteria for selection of the method was that:

1. it had all the enzymes necessary to hydrolyze the various components of the cookies matrix.
2. it is relatively less time-consuming (because the method was going to be used to hydrolyze many cookies)
3. it reflected physiological conditions well (eg. pH of digestive phases)
4. it is logistically feasible within the timeline of the study
5. it had good correlations with in-vivo studies on carbohydrate hydrolysis.



		Englyst et al (1992)	Minekus et al (2014)	Goni et al (1997)
All enzymes suitable for cookies matrix	→	✓	✗	✗
Relatively less time-consuming	→	✓	✗	✗
Reflects physiological conditions well	→	✓	✓	✓
Logistically feasible within study the timeline	→	✓	✓	✗
Good correlations with in-vivo studies	→	✓	✓	✓

Figure 9 : Selection grid for base in vitro digestion protocol

By reviewing the protocols used, three dominant protocols i.e Englyst et al (1992), Minekus et al (2014) and Goni et al (1997) were selected based on their frequent and well accepted use in literature. These protocols were then evaluated according to the selection grid (Figure 9). Some adaptations from the protocols of Minekus et al (2014) and Goni et al (1997) were necessary, such as the addition of invertase enzyme, which is necessary for hydrolysis of sucrose in cookies. The Englyst method was thus selected, since it suited the selection grid well. The in vitro digestion protocol was updated from Englyst et al (1992), Englyst et al (2018) Englyst et al (2000), Freitas & Le Feunteun (2018) and Schuchardt et al (2016) (Figure 10)

Ground cookies was added to enzyme solution (Pepsin-guar gum solution) and incubated at 37˚C for 30 minutes in an orbital shaking waterbath (150±1 shaking/min). Then a mixture of enzyme (pancreatin, amyloglucosidase, invertase). 1mL aliquots were taken at 20, 30, 60, 90, 120 minutes respectively and placed in a tube into a boiling water bath [99±1˚C] for 5 to 8 minutes to stop the enzyme action. After centrifugation the supernatant was analyzed for their glucose content. A blank tube and the reference (1g bread) were also submitted to the same protocol. The glucose was measured using Megazyme D-Glucose Assay Kit (GOPOD Format, Product code K-GLUC), according to the instructions of the manufacturer.

The curve of glucose release versus time of hydrolysis was plotted and the area under the curve was used to calculate the Glycemic index with the white bread as reference.

The incremental area under the curve (AUC) was calculated using the trapezoidal rule (Food and Agriculture Organization, 1998; Freitas & Feunteun, 2018).

The glycemic index was calculated as using equations 1 and 2 (Granfeldt et al., 1992; Giuberti et al., 2016)

$$\text{Hydrolysis Index (HI)} = \frac{AUC\ of\ test\ food\ (i.e\ cookies)}{AUC\ of\ test\ food\ (i.e\ bread)}\ x\ 100 \ \ldots\ldots\ (1)$$

$$\text{Glycemic Index (GI)} = 8.198 + 0.0862\text{HI} \ \ldots\ldots\ (2)$$

Abbreviations:
RAG - Rapidly available glucose **;** SAG: slowly available glucose; AG: Available glucose , TG – total glucose ; D-Dilution ; AMG – Amyloglucosidase

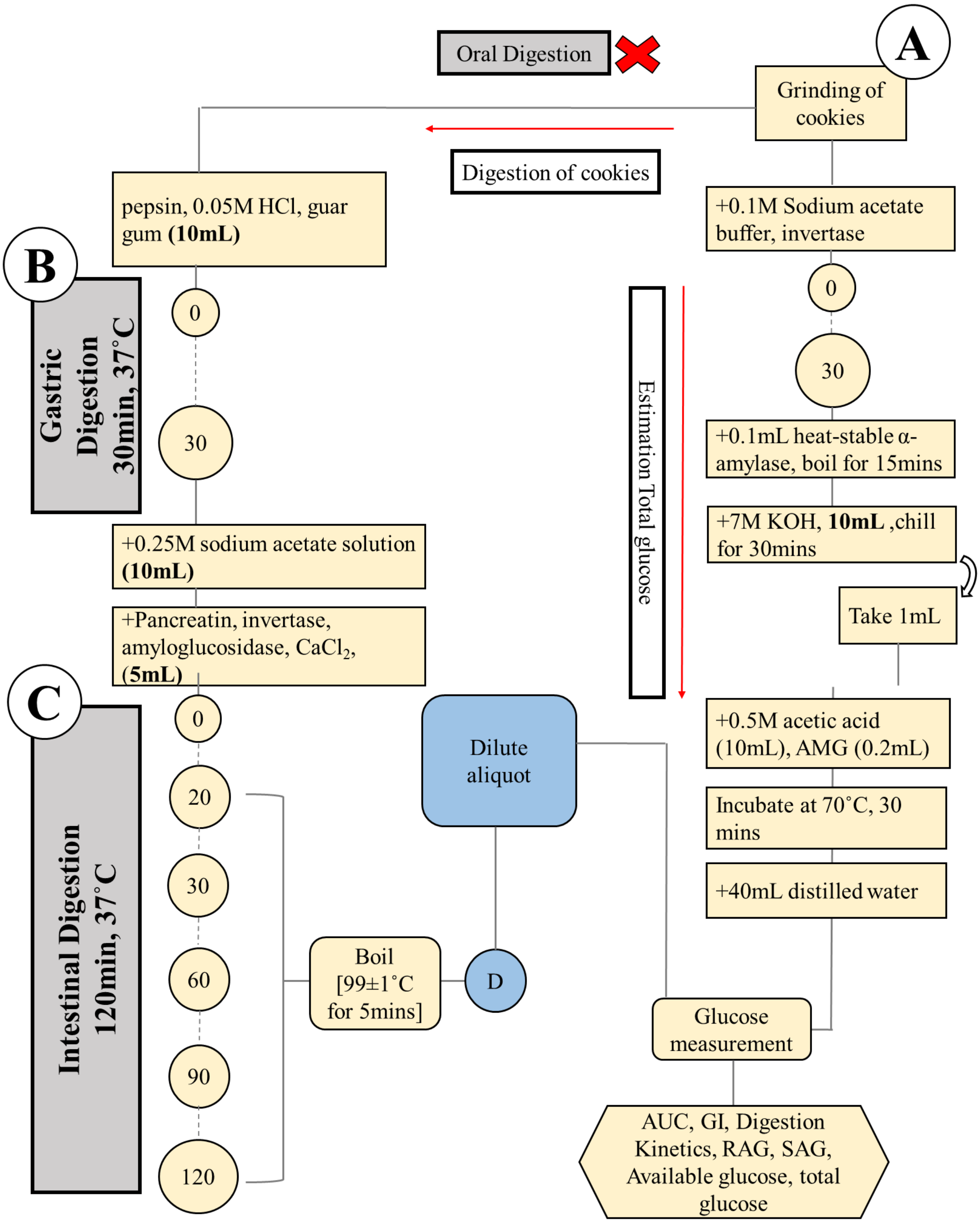


Figure 10 : Flow chart of the In vitro starch digestion protocol adapted from Englyst et al., 1992, 1996, 2000, 2018; Freitas and Le Feunteun 2019 and Schuchardt et al., 2016) and total glucose estimation

Statistical analysis

All statistical analyses were conducted with XLSTAT version 2018.1.1 (Addinsoft, New York, USA) and JMP (v. 13.1.0; SAS Institute Inc., Cary, SC, USA) to generate and analyse the optimal mixture design

For cluster analysis on cookies multicriteria (on nutrition, composition and instrumental characteristics), we ran an Agglomerative Hierarchical Clustering (AHC) based on dissimilarities and truncation (automatic entropy). We applied Euclidean distance and Ward's method (reduced and centered data). Due to the first clustering, we identified the optimal number of clusters, which was seven. Second, a K-means clustering with seven clusters using the Trace (W) criterion (reduced and centered data) was applied.

To visualize the seven clusters from the K-means clustering, the 11 quantitative variables were plotted on a low dimensional map by using Principal Component Analysis (PCA). This allowed to evaluate the multivariate nutrition, composition and instrumental variables. We used Pearson correlation with a significance level alpha = 0.05 and standardized (n) data.

All instrumental and sensory data were treated by Anova or Kruskal Wallis test ($p<0,05$), to evaluate the significant differences between cookies (commercial or reformulated).

For analyses of an inferential nature, $\alpha = 0.05$ was the threshold for statistical significance. To analyze the sensory profiling results, we carried out a three-way ANOVA (Product, replicate, and panelists) with first-order interactions. To visually explore differences in the results, we carried out principal component analysis (PCA) on a correlation matrix; the data were averaged across replicates and panelists.

In addition, the panel performance was evaluated and controlled using ANOVAs with three independent variables (product type, panelist and replicate) and their first-order interactions. A product effect means that panelists discriminated among the different cookies ($p<0.05$). The significance of various interactions revealed whether the panelists consistently scored attributes across replicates (panelist*replicate), whether there was consistency in scoring among panelists (product type*panelist), and whether panelists scored products consistently across replicates (product type*replicate). The performance of individual panelists was also evaluated based on their ability to discriminate among cookies and on repeatability criteria.

To visually explore differences in the results obtained on multiple criteria, we carried out multiple factor analysis (MFA) (centred by group; Pearson type); the data from different criteria were averaged across replicates and/or panellists.

Results and discussion

Cookie market analysis: diversity among international and French cookie brands

In total we identified 178 cookies from 44 different international and French cookie brands from 13 French online supermarkets.

As shown in Table 1, considering the minimum and maximum value, we found a broad diversity for nutritional values among the database with 178 cookies (A) and 62 chocolate chip cookies (B) The calculated Nutri-Score showed that 170 (95.5%) cookies had a Nutri-Score E, while 6 (3.3%) cookies had a Nutri-Score D and 2 (1.2%) cookies had a Nutri-Score B.

Table 1 : Nutritional values for all commercial cookies (A) and chocolate chip cookies (B) from the market analysis

Nutritional values for cookies per 100g	Databases A: 178 cookies B: 62 cookies	Min. value	Max. value	Mean ± SD
Kcal	A	389	572	499.5 ± 25.5
	B	433	518	495.4 ± 15.2
Fat (g)	A	16	32.4	25.4 ± 3.1
	B	17.1	28	24.3 ± 2.0
Saturated fat (g)	A	3.6	20	12 ± 3.3
	B	5.9	18	12.6 ± 2.7
Carbohydrates (g)	A	48	70.8	59.6 ± 3.8
	B	57	70.8	61.6 ± 2.5
Sugar (g)	A	0*	43	32.1 ± 6.0
	B	27	41.8	34.5 ± 3.0
Protein (g)	A	3.5	13	6.2 ± 1.1
	B	4.5	7.6	6 ± 0.8
Fiber (g)	A	0.8	10	3.9 ± 1.5
	B	1.8	5.7	3.6 ± 0.9
Salt (g)	A	0.03	2	0.7 ± 0.4
	B	0.2	1.5	0.8 ±0.3

*Sugar free cookies

For the following study, we choose to focus on the 62 cookies with chocolate inclusions (Table 1,B). They demonstrated slightly a higher mean for the saturated fat (12.6 ± 2.7), carbohydrates (61.6 ± 2.5), sugar (34.5 ± 3.0) and salt (0.8 ±0.3) content. On the other hand, we found a slightly lower mean for the protein (6 ± 0.8) and fiber (3.6 ± 0.9) content compared to the whole cookie database (A).

Among chocolate chipcookies, broad ranges between minimal and maximum values were found for kcal (85), sugar (14.8), carbohydrates (13.8), fat (10.9) and saturated fat (12.1). (Table 1, B). The figure 11 illustrated the diversity among the 62 cookies (Principle Component Analysis) in terms of nutrition, composition and instrumental characteristics.

Besides nutritional values, the commercial cookies had either an intermediate (27), hard (26) or soft (9) perceived texture in hand. Moreover, the mean value of the measured water content among the 62 cookies was below 5% with 3.9% ±1.7%. A significant negative correlation between the measured water content and the perceived texture in hand was observed (R^2=0.579 ; correlation coefficient -0.761;p <0.0001).

To conclude this part, this work confirms the interest to work on biscuits for a reformulation proof of concept, because they are among the core foods which are responsible for a high sugar intake among children (Lever et al., 2018). In this study, we focused on chocolate chips cookies only. Apart from the cookie dough, chocolate chip cookies have an increased level of fat and sugar due to the chocolate inclusion. Therefore, this study suggests that chocolate might play an important role in the reformulation process: firstly, due to its nutritional composition as mentioned before; secondly, the importance of chocolate inclusion in cookies derived by descriptive sensory analysis - most of the sensory descriptors (6) were related to chocolate; lastly, due to childrens' preference for chocolate and the increased consumption of cakes and biscuits with chocolate (Standen-Holmes & Liem, 2013).

Focusing on certain ingredients or specific food products is in line with other studies (Pearson et al., 2020; Sune et al., 2002). It should be noted though that other studies choose to focus on leading brands, high price segments or premium and private label brands for their dataset (Martínez et al., 2002; Schouteten et al., 2018). Considering only market leader brands, might have relieved cookies availability constraint in our study. However, we suggest that especially recipes from different brands, including leader, private labels and niche brands, may provide a higher diversity in cookies which is important for later reformulation.

Among the chocolate chip cookies, we found an important heterogeneity in terms of nutritional, compositional, instrumental and sensory aspects. Moreover, most of the cookies showed the highest Nutri-Score (E), what is associated with poor quality food. This confirms the interest and the possibilities of reformulation for this product category.

Besides the nutrition diversity, we identified three different texture ranges among the chocolate chip cookies: hard, intermediate and soft. Further, the water content among the chocolate chip cookies was below 5%. Similar results regarding cookies' water content were found elsewhere (Chevallier et al., 2000, 2002). Moreover, cookies with a higher water content were perceived as softer, whereas cookies with a lower water content were perceived as more hard.

Cookie subset selection

To maintain this diversity and to select a subset which is representative of all chocolate chip cookies, a subset of 18 cookies was proposed. In Figure 11, the cookies were grouped and represented with different colors based on the seven clusters, obtained by AHC and K-means clustering. The broadest variability was explained by axes F1 and F2 with 47.04%. The observation plot represents the 11 variables explaining the differences between cookies. In Figure 11a, cookies on the right side (axis F1) are characterized by an increased carbohydrate, sugar and water content and a higher number of technological additives. On the left side (axis F1), cookies had an increased protein content. Furthermore, cookies on the top (axis F2) had an increased fat and saturated fat content and a higher number of sensory additives. The selected cookies of each cluster showed a balanced distribution of extreme cookies based on axes F1 and F2.

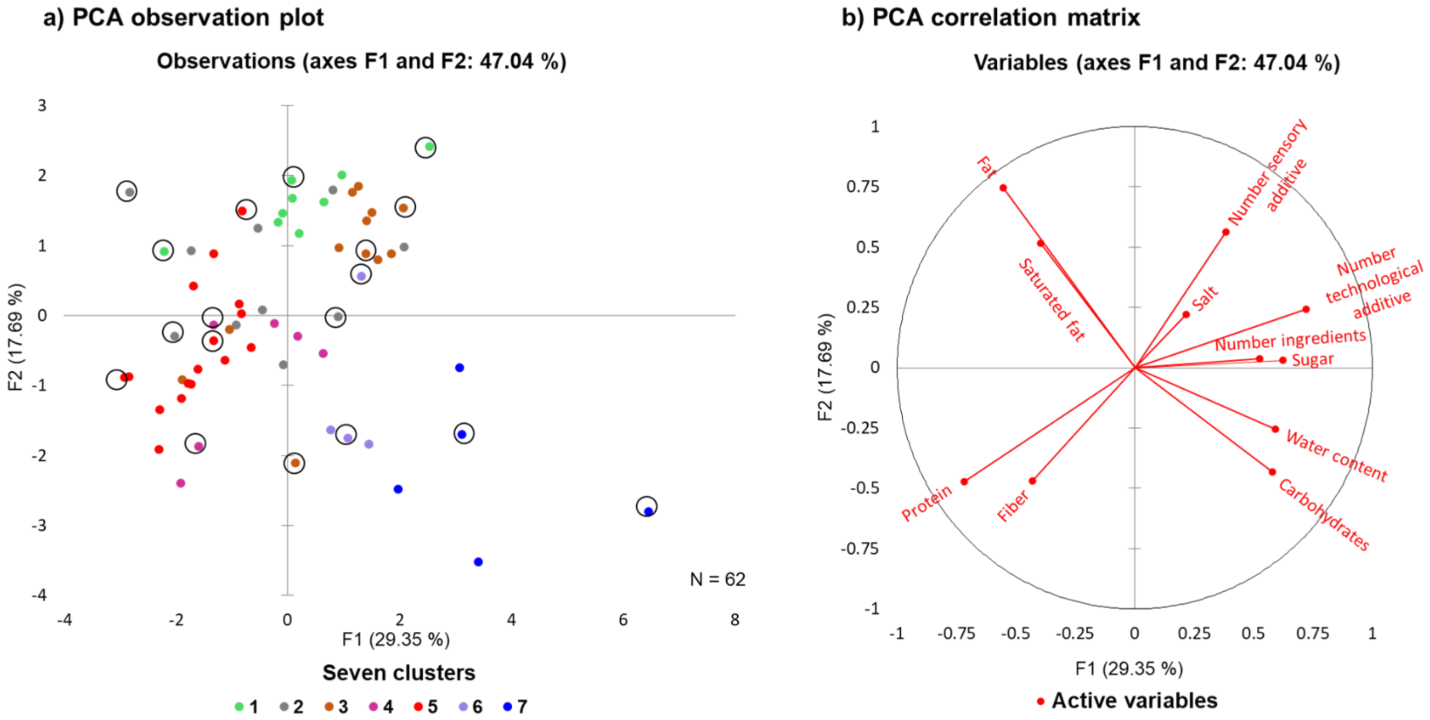


Figure 11 : 11a: 62 chocolate chip cookies with seven clusters in different colors including the selected cookies for the subset in circles. 11b:11 nutrition, composition and instrumental variables plotted on a Principle Component Analysis (axes F1-F2).

This study illustrated how presentative subset of products based on multiple variable and criteria can be selected and derived from a detailed market analysis. Therefore, two clustering methods and a plotting approach were applied to identify potential lever of reformulation.

Cluster-based and uniform design approaches are common methods for selecting a representative subset (Daszykowski et al., 2002). As well other authors used several ranked criteria for the product selection (Mora et al., 2018; Thompson et al., 2004). The PCA is an optimal tool to visualize and plot obtained clustering data to detect class diversity (Baxter, 1995). As well recent studies used the PCA for the evaluation of the relationship between variables and product selection (Esteban-Díez et al., 2004; Vidal et al., 2020)

Identification of reformulation levers

Liking study commercial cookies on 8 cookies

As explained in the M&M part, only 8 cookies were selected for the liking tests among children.

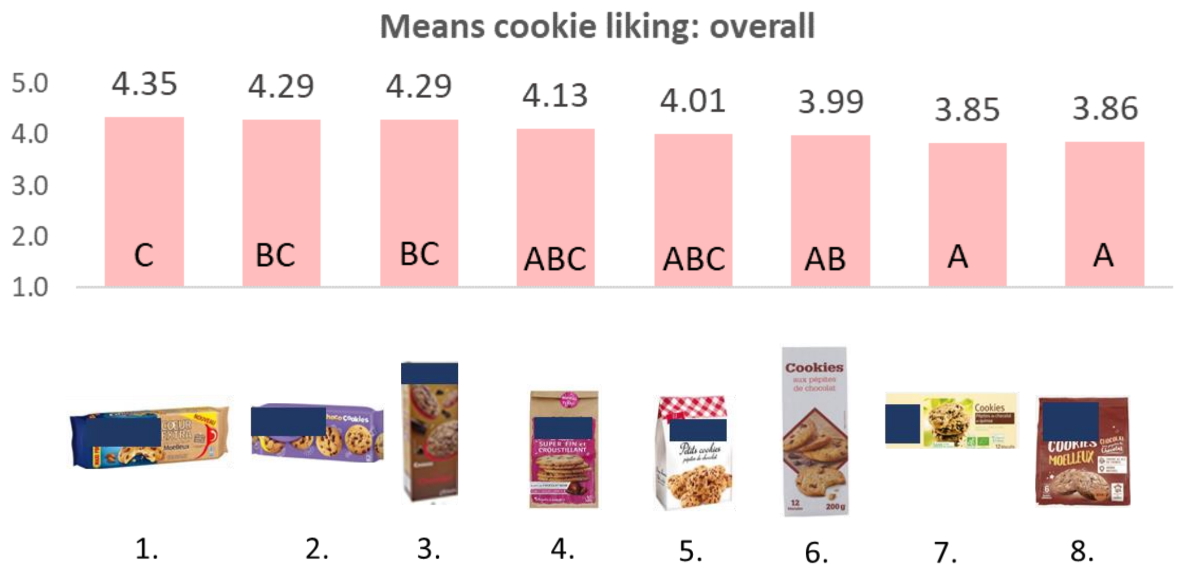


Figure 12 : Overall mean liking score among 151 children and 8 cookies

Overall, the 151 children participants liked the products (Figure 12). Day order did not significantly affect the hedonic scores (or the WTP scores). For each subgraph of Figure 12, the Newman Keuls tests show that liking scores between different products were statistically different (P<0.05).

Furthermore, we found a significant difference for the mean liking score between girls and boys and between younger (7-9 years old) and older children (10-12 years). No differences were found among cities and household income.

Multi-criteria mapping: selection of pertinent pairs of variables and identification of potential reformulation levers with the outlier approach

A multicriteria mapping was performed to represent the diversity between the subset of 18 cookies. The loadings (Figure 13) showed the relationships between 11 active nutrition (green), 20 sensory (violet) and 5 instrumental (red) variables for the subset of 18 commercial cookies. This evaluation will allow to select most pertinent (pathways for kcal reduction) pairs of sensory and nutrition variable for further in-depth analysis in order to identify possible reformulation levers.

We can observe two main cookie patterns. Cookies on the left F1 axes tend to be softer with an increased butter and sweet taste, sugar and water content. Cookies on the right F1 axes however were perceived as harder, with an increased fiber and protein content

Interesting pairs of sensory and nutrition variables are as follows: sweet taste (sensory) and sugar (nutrition); hardness in mouth (sensory) and fiber (nutrition); hardness in mouth (sensory) and fat (nutrition), quantity chocolate inclusions (sensory) and chocolate inclusions % (nutrition).

a. Observation plot

b. Correlation matrix

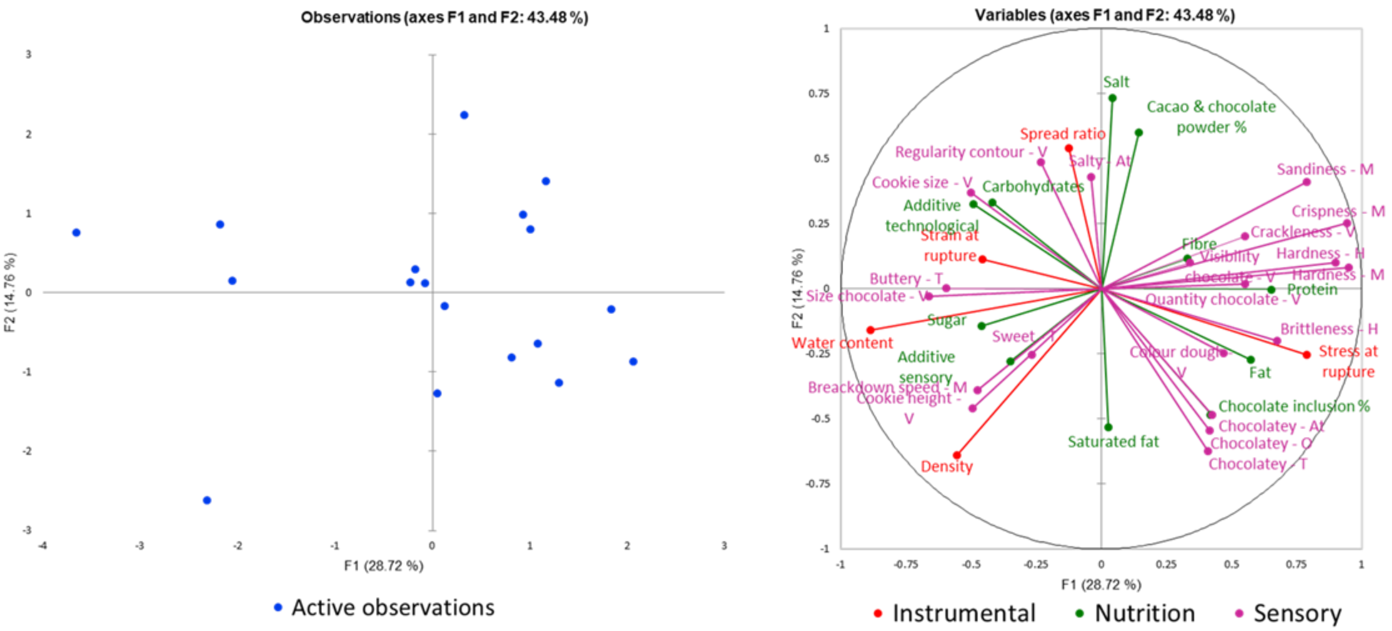
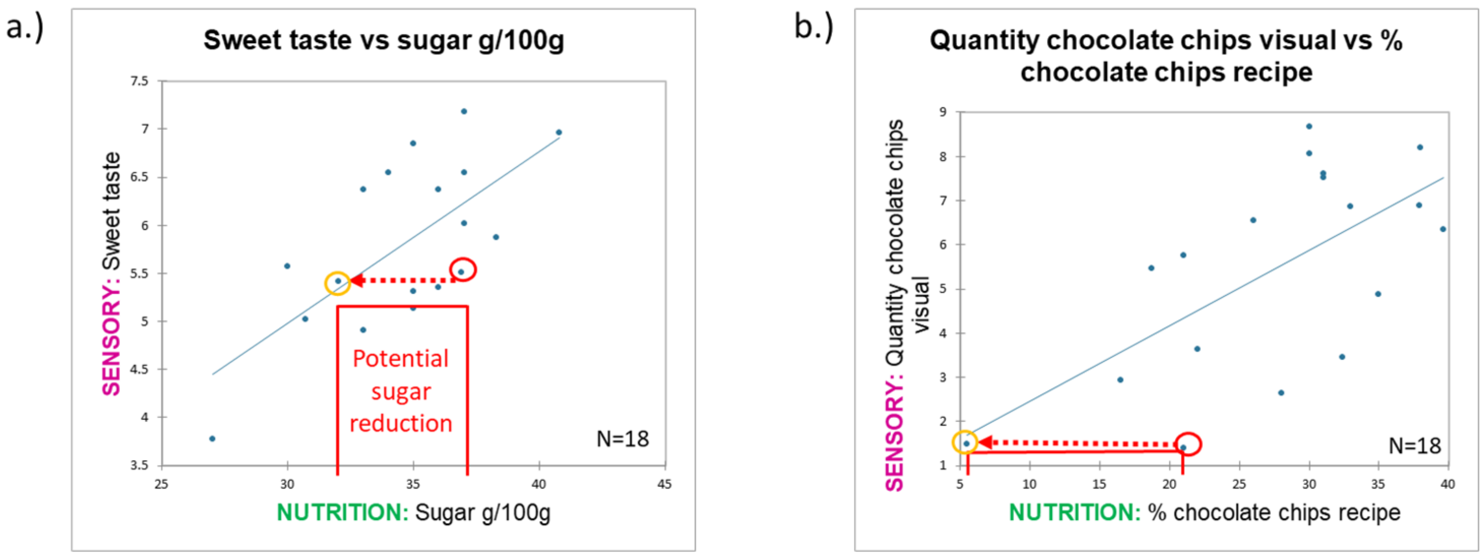


Figure 13 : 18 cookies with 36 instrumental, nutrition and sensory variables plotted on a Multiple-Factor Analysis

The figure 14 demonstrated four scatter plots with the selected sensory and nutrition variables from the multi-criteria mapping. This scatter plots showed potential for a sugar reduction (a), a chocolate chip reduction (b), a fat reduction (c) and a fiber enhancement (d) while maintaining the sensory properties.



0.679 correlation coefficient; 0.002 p-value; R^2=0.461; effect size = 0.855

0.637 correlation coefficient; 0.004 p-value: R2 = 0.406; effect size = 0.683

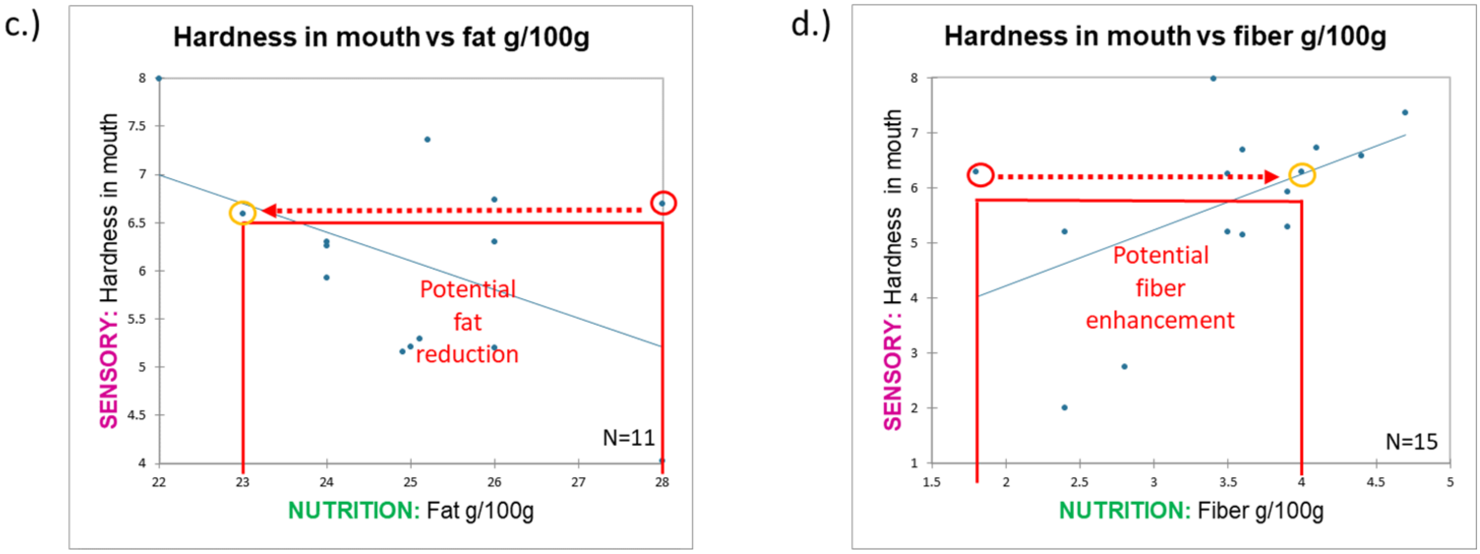


Figure 14 : Identified outliers for a.) sugar reduction, b.) chocolate chip reduction, c.) fat reduction and d.) fiber enhancement

Selection target cookie and final reformulation strategy.

The figure 15 showed the target commercial cookie used as a base of recipe for following reformulation. This cookie was selected as it showed similar sensory perceptions like healthier preliminary recipes and it was close to the cookie most liked among children. Further, this product showed the highest overall sugar (27.4%, 17.8±5%) and an increased fat (18%, 16.2 ±3) content among commercial cookies. In addition, this cookie has a lower fiber content than the average of cookies (2.8g, 3.4±0.8).

Figure 15 : Target commercial cookie for the reformulation

In addition to that, reformulating this target product has as well other benefits and challenge, such as:

- Replacement invert syrup (glucose-fructose) with white crystal and brown sugar
  - Less processed
- Less additives
- Less salt
- Lower number of ingredients
- Replacement palm oil
- Smaller portion size (70g target cookie, reformulated cookie ~30g)

This cookie demonstrated a high potential for reformulation by decreasing the total energy density by sugar and fat reduction, or increase the fiber level. Therefore, there might be as well an interesting pathway to modify cookies' texture towards a higher viscosity induced by soluble fiber. This on the other hand might increase childrens' food oral process with impact on the satiation.

Selected levers and factors and potential for reformulation

Table 2 is demonstrating the summary of selected factors for reformulation issued from the analyses of previous analyses. Following factors were selected to manipulate: sugar%, fat%, oat bran%, chocolate chips% and the baking degree. The maximal potential to reduce the sugar, the fat and the chocolate chip is -19%, -29% and -20%, whereas it is possible to incorporate oat bran +6.5%.

We chose to fix some factors in all recipes: flour%, egg%, baking powder%, vanille arome and salt.

Table 2 : Factors and their levels for the mixture design including the maximal reduction/increase in comparison with the target commercial cookie

Factor manipulation	Maximal reduction or enhancement in comparison with target commercial cookie	Factor fix
Sugar (22.2-26.4%)	-19%	Flour (27.7%)
Fat (12.8-17%)	-29%	Egg (9.5%)

Chocolate chips (13.2-16.5%)	-20%	Baking powder (0.3%)
Oat bran (3.3-6.5%)	+6.5%	Vanilla arome (0.3%)
Baking degree (150-180°)		Salt (0.2%)

As well the baking degree was selected as a further factor for the final experimental plan, as the variation of the baking degree strongly influence cookies' texture (important for sensory perception and liking) and it might as well affect the starch hydrolysis.

Mixture design

Following to the choice of reformulation factor, we decided to set up an optimal mixture design (Table 3), to have a wide range of reformulated experimental cookies and evaluate the role of each ingredient and their interaction on sensory and instrumental properties, in vitro digestion and childrens' perception. Response surface models were performed and included quadratic terms and first-order interactions. The experimental design was such that there was orthogonality among all the terms, which allowed variable effects to be differentiated from one another. Variable levels were chosen following previous study on commercial cookies. In total 30 different cookie recipes were created.

Table 3 : Composition of the different reformulated cookies used in this study by mixture design model. Two cookies were repetitions (R1, 21 and 23 and R2 17 and 28). In total 28 cookies with different levels of sugar, fat, oat bran, chocolate inclusions and baking degree were created.

Nr	Sugar %	Fat %	Oat bran %	Chocolate %	Baking degree %
1	25.26999507	15.86999507	5.436930483	15.42307938	150
2	24.2	14.8	6.5	16.5	165
3	26.4	15.8	3.3	16.5	180
4	25.26999507	15.86999507	5.436930483	15.42307938	165
5	25.3	17	6.5	13.2	180
6	24.2	14.8	6.5	16.5	150
7	26.4	17	4.35	14.25	180
8	25.3	17	6.5	13.2	165
9	25.26999507	15.86999507	5.436930483	15.42307938	180
10	26.4	17	3.3	15.3	165
11	26.4	17	3.3	15.3	150
12	24	17	4.5	16.5	165
13	25.2	17	3.3	16.5	150
14	26.4	15.8	3.3	16.5	165
15	24.06	17	6.5	14.44	150
16	26.4	12.8	6.3	16.5	165
17^{R2}	22.2	16.8	6.5	16.5	180
18	26.4	15.9	6.5	13.2	180
19	26.4	15.9	6.5	13.2	150
20	26.4	14.66	6.5	14.44	165
21^{R1}	26.2	12.8	6.5	16.5	180
22	22.2	17	6.3	16.5	150
23^{R1}	26.2	12.8	6.5	16.5	180
24	26.4	17	5.4	13.2	165
25	22.2	17	6.5	16.3	165
26	26.4	14.6	4.5	16.5	150
27	26.4	12.8	6.5	16.3	150
28^{R2}	22.2	16.8	6.5	16.5	180
29	25.2	17	3.3	16.5	180
30	26.4	17	5.4	13.2	150

To conclude this part, the liking study demonstrated that commercial cookies were overall liked, even if some liking differences exist among children aged 7-12 years old. This shows a broad space for reformulation among the product category “commercial cookies” from the French market. As well this might confirm childrens’ preference for fatty and sweet food (Albataineh et al., 2019; Ambrosini et al., 2015; Moore & Fielding, 2016; van Buul et al., 2014). However, differences for liking among girls and boys and different age classes were observed. This might bring up the question to consider different pathways for reformulation based on specific preferences for girls and boys, respectively different age classes.

It can be pointed out that it was possible to derive possible reformulation levers for sugar, fat and chocolate chip reduction and fiber enhancement based on the subset of commercial cookies while maintaining sensory perception and liking.

Several authors identified the excessive sugar intake as key dietary determinant of obesity among children and adolescents (Ambrosini et al., 2015; Te Morenga et al., 2012). But not only sugar is a key determinant. An energy dense diet from total fat and sugars was also responsible for increased adiposity in childhood and adolescents (Ambrosini et al., 2015). Further, energy overconsumption was associated with the increasing obesity rate (van Buul et al., 2014). Fat is energy dense, contributes to palatability and show weak effect on satiety (Blundell et al., 2010). Thus, in order to tackle childhood obesity, considering total energy from fat and sugar seems to be important. However, fat and sugar reduction in cookie dough may imply the hedonic rating negatively (Biguzzi et al., 2015). To anticipate this, a liking study was integrated in our study.

Besides nutritional quality improvement by the means of formulation, it was shown that texture modification might be successful to decrease the 'obesogenic' eating style among children. Indeed, food oral processing, impacted by texture, could influence satiety and satiation of individuals with faster eating rates and shorter oral exposure time (Fogel et al., 2017). Especially among children is the food texture important, as depending on their age, their perceptions and preferences do change (Lukasewycz & Mennella, 2012; Rose et al., 2004; Szczesniak, 1972; Zeinstra et al., 2010). One lever to increase the oral process is the incorporation of viscous fiber. A previous study showed that biscuits enriched with fiber lead to a higher satiety, fullness and less hunger and desire to eat than biscuits without fiber enrichment (Pentikäinen et al., 2014). Furthermore, another study found a higher consumption time, chewing duration, lower chewing and eating rate due to the increased fiber content (Priyanka et al., 2019.

Fiber is well known to have positive effects on health and weight management. Food which is high in fiber demonstrated a longer oral processing time compared to low fiber food and was therefore associated to induce satiety (Zijlstra et al., 2008). However, reasons for an increased satiety in fiber rich foods are controversial and named as follows: a stronger cephalic phase response (de Graaf, 2012), a lower palatability (Burton-Freeman, 2000) and an increased viscosity due to soluble fiber (Wanders et al., 2011). The fact that fiber has positive effects on satiety and the fact that children do not meet the intake of fiber recommendations in most of European countries, highlight the importance to consider fiber as an important lever for food reformulation (Stephen et al., 2017).

Texture plays further an important role for sensory perception and liking. It is known, that texture is an important determinant for food liking among children (Rose et al., 2004). For example, children do have preferences for soft but as well for more hard textures (Laureati et al., 2019). Available information about cookies composition and its texture allows to reformulate a healthier cookie while maintaining or even improve cookies texture supposed to be more desirable.

Still, food reformulation for children is challenging, as pleasure strongly influence childrens' hedonic evaluation and childrens' preferences for fatty and sugary food. The more important is it to conduct multi-criteria food reformulation approaches to anticipate childrens' perception and liking.

Preliminary results impact on health: in vitro digestion

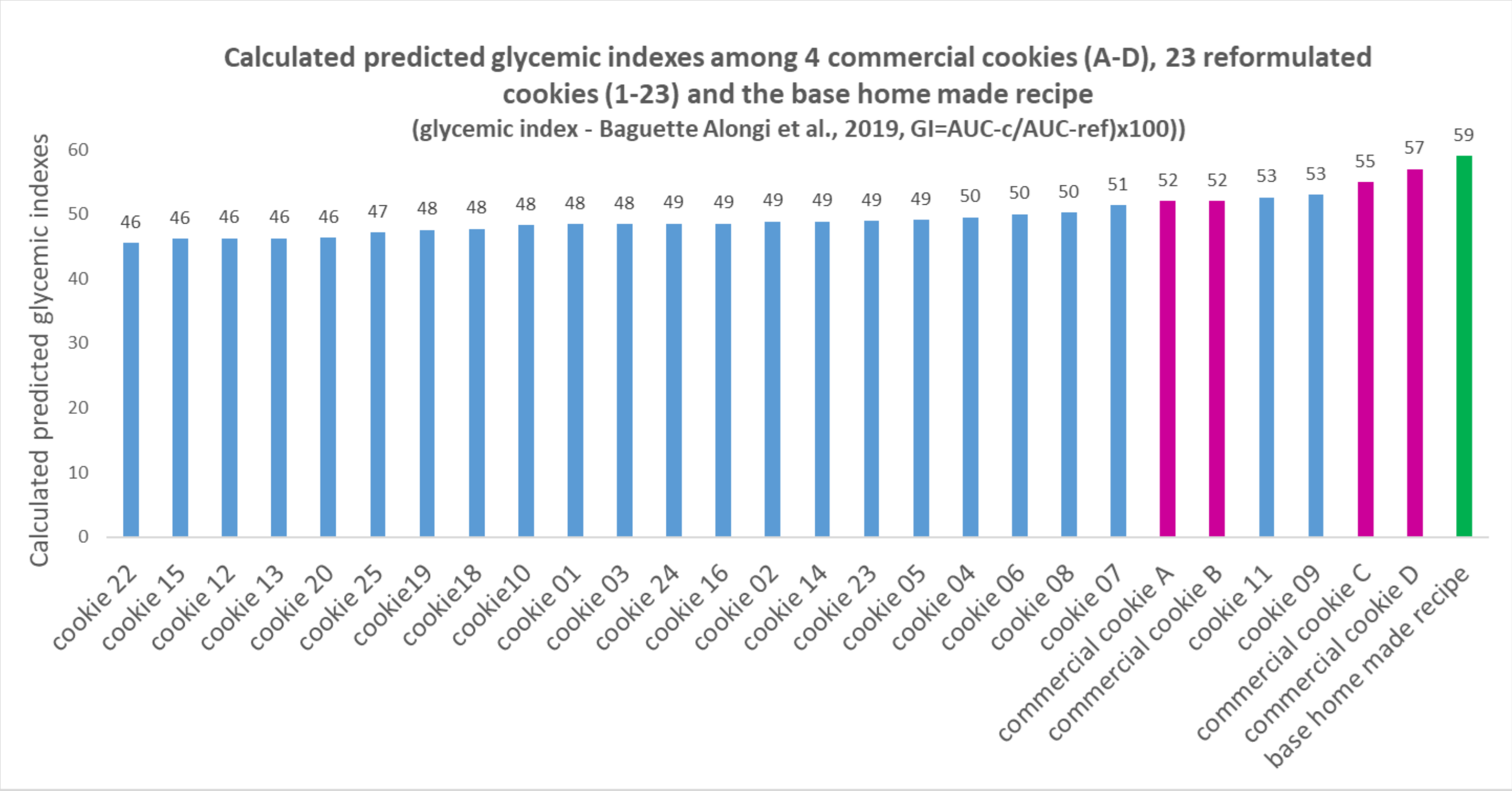


Figure 16 : Estimated glycemic index from in vitro starch hydrolysis of 23 reformulated cookies (1-23) in blue color, commercial cookies (A-D) in pink color and the base home made recipe in green color

The estimated glycemic index from in vitro starch were evaluated on the reformulated cookies. This parameter is essential to evaluate a part of performance of the used reformulation levers.

According to the figure 16, overall the reformulated cookies, except for cookie numbers 9 and 11, tend to have a lower commercial cookies glycemic index than the commercial cookies. The maximal reduction of the glycemic index among reformulated cookies and the commercial cookies is 9 (commercial cookie D and reformulated cookie 22). Considering the target commercial cookie B, the maximal possible reduction is 6.

Among the reformulated cookies, the maximal reduction of the glycemic index is 5 (cookie 7 and 22). Cookies with lower glycemic index between 46 and 47 showed in general a lower sugar content (22.2%-25.2%) (except for cookie 20 with26.4%). Further, most of them demonstrated a higher fat level with 17% (except for cookie 20 with14.6%) and as well a higher oat bran level over 6% (except for cookie 13 and 12 with 3.3% respectively 4.5%). The chocolate content is among the higher range between 14.4-16.5%. These results suggested interaction between variables that will be assessed by data analysis. All cookies with a lower glycemic index do have a lower baking degrees between 150 and 165°C.

~~The results showed that it was possible to reformulate cookies with a lower glycemic index than the existing commercial cookies. Several studies reported a lower calculated glycemic index when incorporating viscous fiber in food products (Anttila et al., 2004; Roberts, 2003)~~

The results suggested that it was possible to reformulate cookies with a lower calculated predicted glycemic index than the existing commercial cookies when modifying its sugar, fat, chocolate chip and fiber content and the baking degree.

It is well known that rapidly digested and absorbed carbohydrates play an important role when it comes to an increased glycemic index (Wee & Henry, 2020). Therefore, besides a sugar reduction (including chocolate chips) as well other strategies to delay the starch digestion are described in the literature, such as the incorporation of viscous fiber.

The maximal oat bran enhancement was up to 6.5% among the reformulated cookies. An increased fiber content led to a decreased in vitro starch digestibility and a lower glucose response elsewhere (Regand et al., 2011; Schuchardt et al., 2015). Besides the declined in vitro starch digestibility, as well a reduced in vivo starch digestibility was observed. An increase of soluble fiber in cookies led to a lower glycemic index measured among humans (Supparmaniam et al., 2019).

Responsible for the declined starch digestibility and glycemic responses induced by fiber might be the reduction or the delay of postbrandial plasma glucose and insulin during the digestion due to the swelling properties of the soluble fiber. The increased viscosity in the intestine delays the absorption of glucose (Anttila et al., 2004; Roberts, 2003).

However, the maximal glycemic index reduction between the target commercial cookie (B) and the reformulated cookies (22,15,12,13,20) was 6. Reasons for the weak difference might be that we used the same ingredients for all recipes and that the manipulated levels were too weak to achieve larger differences. As well, the flour level (highest starch source) was not manipulated. Taking into account as well different starch sources or different levels of starch might be therefore a pertinent lever in order to lower the glycemic index. For example, reducing starch hydrolysis among starch sources can be further achieved by preserving granular/crystalline and intact cell structure, promoting starch retrogradation, limiting mobility of gelatinized amporphus matrix, using large particle sizes, favouring mashing over milling, strengthening protein network around granules, converting starch in melanoidins and favouring raosting and dry baking over boiling (Lin et al., 2020; Pellegrini et al., 2020).

Furthermore, the viscosity of beta glucan (in oat bran) depends on solubility, concentration and molecular weight (Anttila et al., 2004). This means, the effectiveness of the viscous fiber is dose and quality depending, including processing methods to avoid enzymatic or mechanical breakdown of the beta-glucan molecule (ebd.).

However it can be said that manipulating sugar, fat, chocolate chip content and the baking degree do have a (moderate) influence on the predicted calculated glycemic index. But not necessarily all cookies with a lower sugar content and a higher oat bran content do have a lower glycemic index. Therefore, further investigations are needed to evaluate the impact of the single ingredients including process parameters on starch hydrolysis.

As well rheological measures will be carried out to evaluated the bolus viscosity and the possible impact on oral process, satiation and hunger level.

Overall conclusions

We conclude that an extensive market analysis of the target product is helpful in order to define the potential for reformulation among commercial products and to select a representative subset based on multi-criteria. Further, the approaches to identify reformulation levers such as the multicriteria mapping, the outlier approach and the creation of preliminary recipes based on the subset was a useful tool to derive pertinent reformulation levers while maintaining the sensory perception and liking among children.

This multi-criteria reformulation approach considering nutrition, composition, sensory and instrumental variables demonstrated that it is possible to manipulate several nutrients at the same time and having a positive impact on the calculated glycemic index. Moreover the approach showed the feasibility to reformulate while using the same ingredients as for commercial cookies and maintaining sensory perception and liking. The impact of these healthier reformulation levers on children behavior constitutes a perspective to this work, in order to validate their performance.

This study will allow to give recommendations of reformulation levers while maintaining sensory perception and liking with impact on health and childrens' eating behaviour. Further, it can stimulate the motivation for voluntary reformulation.

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Part 2: To what extent does a voluntary policy aiming at reducing the sugar content of products improve the nutrient composition of products? A case study on dairy products

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Abstract

Objective Assessing the effects of public-private partnership (PPPs) policy implemented in England and the Netherlands on the trends of the nutrient profile of newly marketed dairy products with added sugar.

Method In this observational study we used data on the nutrient composition per 100 g of spoonable dairy products (yogurt and soft cheese) and 100 ml of drinking dairy products (drinking yogurts and flavoured milk), launched in six Western European countries (France, Germany, Italy, the Netherlands, Spain and England) from January, 2010 to December, 2018 (9,342 observations). We mobilised a differences-in-differences empirical strategy comparing the relative change in sugar, fat, saturated fat and calorie content of newly marketed dairy products in the post-implementation period relative to the pre-implementation period among countries that had implemented the policy and those that had not.

Results: Our results indicate that PPPs policies implemented in the Netherlands and England would have encouraged the formulation of less sugar-sweetened dairy products, and no unhealthy nutritional compensation would have taken place for this category. The Dutch voluntary product reformulation policy brought 9%, 10%, 17% and 30% (-0.38, -1.1, -1.2, -2.0, and 3.6 g/100g) significant reductions in the sugar content of dairy products in 2015, 2016, 2017 and 2018, respectively (compared to the average sugar content observed in the category in the Netherlands in 2013). Spoonable dairy products in England experienced lower significant decreases in their sugar content in 2016 and 2017 (-4% and -8%, corresponding to -1.0 and -0.58 g/100g, from the average sugar level observed in spoonable dairy products in England in 2015, respectively). In England, the reduction took place mostly for spoonable yogurts (9% and 13%%, corresponding to -1.2 and -1.7 g/100g, reductions in sugar content in 2016 and 2018, and 2017 respectively, compared to the average sugar content of spoonable yogurts in England in 2015).

We also compared the effects of PPPs policy and a tax threat for drinking dairy products in England. The threat of a sugar tax embedded in the obesity plan is also efficient in favouring lowered sugar innovations in the milk-based drinks sector. We found that the tax threat led almost similar sugar reduction than those estimated for PPPs policy (6% and 8% sugar reductions in 2017 and 2018, from the average sugar level observed in milk-based drinks in 2015). Both drinking yogurts (5% and 8%, in 2017 and 2018, respectively) and flavoured milk (8% in 2017 and 2018) experienced sugar reduction. However, only flavoured milk category experienced reduction in its calorie content (-2% and -4% in 2017 and 2018, respectively).

Conclusions: We showed that obesity plan resulted in lower sugar reductions than the Dutch plan. Our empirical analysis cannot explain why, given the strong similarities between the two plans. Both are characterized by strong government leadership and pressure, involvement of a large number of manufacturers, publication of guidelines or reduction targets, and effective monitoring and evaluation. We also provided empirical evidences showing that PPPs policy with the publication of guidelines or reduction targets associated with a tax threat can drive larger reductions in the sugar content of milk-based drinks than a PPPs policy without a tax threat.

Limitations: Only the effects of the sugar reduction PPPs policies on the innovations in the dairy sector were assessed.

Keywords: PPPs policy impact, nutrient composition of products, differences-in-differences method

Children in the Western world are currently consuming more sugar than is recommended. The total sugar intake ranges from 16% to 26% of total energy intake, and added sugars contribute between 11% to 17% of the total energy intake of children living in Western Europe.(1) In England, they are consuming up to three times more than the daily recommended intake.(2) The contribution of the latter is largely above the 10% of total energy intake recommended by the WHO.(3) This excessive consumption can have severe consequences on health in adulthood and in some cases in childhood. It has been shown that excessive consumption of added sugars is associated with obesity and type 2 diabetes.(4–6)

To address these public health issues, governments and public health agencies have been implementing policies intended to promote preventive behaviours thanks to information campaigns and food product labelling. Reviews of these policies show that they have some positive impacts, however, they remain small, at least in the medium term.(7) Given their modest impacts, public health agencies and policy makers urge the food industry to favour a better food environment through changes in the quality and variety of foods and through changes in advertising and marketing.(8,9)

An initial response of the food industry to the health and nutrition challenge has been to launch new products based on nutrition and health claims and innovative foods targeting health-conscious consumers. Market incentives exist for such a strategy and depend on the number of health-conscious consumers (which can be influenced by public information campaigns) and their willingness-to-pay for healthier and innovative foods. However, this type of initiative only represents a non-substantial proportion of products in the market. In France, for instance, approximately 20 percent of food products have a nutritional claim.(10) Regarding the remaining part of the market, the nutritional quality of food is more contrasted.(11) For this reason, public health agencies urge the food industry to commit in individual or collective agreements to reformulate their products (e.g. reducing the level of 'bad' nutrients in food products; increasing the nutrient density of foods by increasing their amount of fibre, whole grains, or specific fats such as omega-3).(12–14) Public–private partnerships (PPPs) policy, defined as agreements between governments and manufacturers involving the joint setting of reformulation objectives, has gained prominence as a potential cost-effective intervention and received therefore singular attention from public health authorities.(15,16) For example, in England, the partnership between the food industry and the government for salt reduction was based on negotiated reformulation targets signed by 75 organizations in 2010.(17,18)

Our analysis aims to determine whether and to what extent PPPs policy leads to changes in the nutrient composition of foods available on the market. Several studies have shown that the degree of PPPs policy success in improving the nutritional quality of food supply rests on key drivers: (i) a strong government leadership and pressure; (ii) an involvement of a large number of manufacturers, (iii) setting incremental targets at food product category level with a specified deadline to be achieved using maximum and average or sales-weighted average targets; and (iv) effective monitoring and evaluation.(16,19) In this subtask, we focus our analysis on the evaluation and the comparison of the impact of PPPs policy that fully achieves these four criteria.

We propose to achieve our goal by assessing the ex-post effects of PPPs policy implemented in the Netherlands and England in 2014 and 2016, respectively.(20,21) Sugar or calorie reduction guidelines or maximum contents for the top product contributors to an individual's sugar intake—particularly the intake for children in England—have been defined following an extensive programme of engagement and consultation with all sectors of the food industry and with non-government organisations. Specifically, we assess and compare the effectiveness of these two PPPs policies by comparing the relative changes to the nutritional composition of a specific product category, namely dairy products with added sugar, in the post-implementation period, relative to the pre-implementation period in the Netherlands and England, and to those in other Western European countries that have not instituted such a policy. We investigate whether and to what extent PPPs policy has led dairy companies to reduce the sugar content of their products and whether (how and to what extent if they have) they have offset these potential sugar reductions in the product recipe. Is sugar reduction counterbalanced by an increase in fat or saturated fat? What is the net impact on calorie?

Dairy product with added-sugar are targeted by both plans, as ones of the major contributors to children and adolescents' sugar intake. The percentage of yogurts, fromages frais and other dairy desserts contribution to total sugar intakes was 4% for children and adolescents (4 to 18) in England;(22) yogurts contribution was 6% for children aged 7 to 18, and milk and dairy beverages accounted for 10% for girl and 8% for boy in the Netherlands.(23)

Several articles, often based on food-reformulation scenarios and simulation, have studied the potential impacts of such policies on consumer nutrient intake and public health outcomes. Overall, they tend to show that if food companies would implement food-reformulation initiatives, the impact on consumer intakes, chronic disease incidence and mortality could be significant, even in the absence of changes in consumer behaviour.(24,25) Fewer studies have analysed “real” changes implemented by the food industry,(18,26–30) mainly because precise data on food composition at the brand or product level is lacking. Far fewer studies have evaluated their effects on the nutrient profile of products by disentangling the proper effects of the PPPs policy from the effects of other policies embedded with it such as information campaigns.(31,32) This study proposes to also identify the effects of PPPs policy by comparing the differences in the trends of the nutrient composition of dairy products with added sugar between Western European countries exploiting both cross-sectional (arising from the presence or the absence of policy between countries) and time (arising from the difference in the date of implementation of the policy) variations. The comparison of the effects of PPPs policies implemented in England and the Netherlands, also allows us to provide guidance for policy makers to design effective policies and evaluate them. We also compared its effects with those of a policy of threatening to tax milk-based drinks in England.

Achieving our goal requires collecting precise data on new, existing and removed items on the market; in particular, their nutrient contents at brand-level product, at baseline, and after the implementation of a reformulation policy.(19,32) Such branded food databases have been developed in some countries (33) but too few follow changes over time to allow a comprehensive evaluation and comparison of their effects across countries. We overcome this insufficiency by focusing our assessment on new dairy products launched on the market for which a database with an harmonised methodology across countries and over time exists: Mintel GNPD databases.(34) The Mintel GNPD branded food databases is the only database that collects detailed information over time, including nutrition facts, of products innovations (i.e. new product, new variety/range extension, new packaging, new formula and relaunch), called below newly marketed SSBs, introduced in all Western European countries markets (except Iceland and Luxembourg). However, using these databases only allows us to conduct a partial evaluation of food policies. Only the effects on the nutritional composition of newly marketed dairy products could be assessed. Many other reactions--for example, dairy product industry reactions to product withdrawals, and changes in the health profiles of existing products in response to sugar reduction policies--still need to be included to formulate a comprehensive evaluation. Furthermore, effects on consumers nutrient intakes cannot also be assessed in this study. Assessing these effects would imply matching branded food databases to purchase data. However, Mintel GNPD data has the key advantage of collecting nutrient composition data at the brand level in different countries from year to year in a standardised format that allows to assess and compare the effectiveness of PPPs policies, and the identification of key drivers of success to guide policymakers in designing effective policies. Furthermore, although the analysis is partial, the proposed analysis can be a credible assessment of what is occurring in the whole market if the nutrient content distribution of newly marketed products is similar to that observed when all products are considered. In the subtask 3, we show that this assumption seems true for sugar-sweetened beverages.[2]

PPPs policy implementation in Western European countries

The literature has identified that the degree of PPPs policy success in improving the nutritional quality of food supply rests on four key drivers: (i) a strong government leadership and pressure; (ii) an involvement of a large number of manufacturers, (iii) setting incremental targets at food product category level with a specified deadline to be achieved using maximum and average or sales-weighted average targets; and (iv) an effective monitoring and evaluation. In this subtask, we limit our analysis to PPPs policies that fully achieve these four criteria.

In England, guidelines were designed to help food operators achieve a 5% reduction on the 2015 sales weighted average (SWA) figure in grams of total sugar per 100g in the first year of the programme and reach the goal of a 20% reduction on the SWA level of total sugar in the food most commonly eaten by children by 2020. These are based on SWA, which takes into account both

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[2] Unfortunately, the same analysis could not be done for dairy products category due to the lack of data.

the amount of total sugar in a product and the volume of that product sold. This approach should help businesses to focus their reformulation efforts on the top selling products that make the biggest contribution to the sugar levels in each food category. Specifically, the reduction guideline was published in March 2017 and set to achieve a SWA of 11g of total sugar for 100g of product for yogurts and fromages frais, made up of all spoonable sweetened dairy yogurts and fromage frais products and all spoonable yogurts containing low/non-caloric sweeteners. Reduction guideline was published for milk-based drinks only in May, 2018.(35) Natural products are not covered by the plan. A maximum calorie guideline was also set to 175 Kcal for yogurts and fromages frais that are likely to be consumed by an individual at one time. This is to prevent—as far as possible—firms from offsetting sugar reductions by increasing the fat content in products, particularly the saturated fat content, and, when possible, to ensure that sugar reduction is accompanied by calorie reduction. In July 2017 PHE also began engaging with stakeholders relevant to the milk-based drinks categories. Guidelines has been set out for milk-based drinks (e.g., drinking yogurts, flavoured milk) in May, 2018.(35) A key specificity of this category is that it is in threat of becoming eligible for the soft drinks industry levy.[3] For this reason and the later sugar and calorie reduction guidelines publication, we have chosen to analyse the effect of the policy on this category separately. Public Health England is in charge of monitoring and evaluating progress in terms of food product composition, average consumption and sugar intake.

In the Netherlands, the Dutch National Institute for Public Health and the Environment (RIVM) also implemented a PPP policy for dairy products in 2014. Milk-based drinks and spoonable yogurts were targeted by the plan (excluding natural products). Maximum added sugar contents were published in 2015 and established at 11.6 g/100g for yogurts and quarks (very similar to fromages frais), and at 8 g/100g for milk-based drinks.(20) This is equivalent to 15.3 g, 15.4 g and 12.3 g of total sugar content for 100g of yogurts, fromage frais and milk-based drinks, respectively.[4] They have been defined following an extensive programme of engagement and consultation with all sectors of the food industry and with non-government organisations. The maximum added sugar contents had to be met by the end of 2017. The RIVM carries out the monitoring.

To sum up, both plans exclude natural products and are characterized by strong government leadership and pressure, involvement of a large number of manufacturers, publication of guidelines or reduction targets, and effective monitoring and evaluation. Nevertheless, there are three key differences between the two plans. The scope of dairy products targeted by the Dutch plan is broader. The Dutch covers all dairy products, including milk-based drinks, whereas they were integrated in the obesity plan only in May, 2018. Second, the Dutch plan published reduction guidelines in terms added sugar whereas the obesity plan is in term of total sugar. Third, the guidelines of Dutch plan are based on maximum added content level while the obesity plan they are in terms of SWA content level.

The Spanish Ministry of Health and Agency for Consumer Affairs, Food Safety and Nutrition has also launched an ambitious collaborative plan for the improvement of food and beverage composition, involving the whole food operators, aimed at improving the composition of some categories of food and beverage.(38) In particular, an agreement has been reached to reduce the median of added sugars by 2020 of some dairy products by about 10% (such as yogurts with fruits, flavoured yogurts, Greek yogurts with fruits, sweetened natural Greek yogurts, sweetened natural yogurts, drinking yogurts, fermented liquid semi-skimmed milk, semi-skimmed fromage frais with fruits (banana, strawberry), milkshakes, and other products not included in this study; for example, vanilla flans, vanilla custard, egg custard, and rice pudding). However, the plan was launched during 2018, which was the very last period of our study. Table 0 summarizes PPPs policies implemented in England, the Netherlands and Spain. During the period 2010-2018, no other European country set out a voluntary product reformulation policy that the four criteria of success identified in the literature.

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[3] HM Treasury is committed to reviewing the exemption for milk-based drinks from the soft drinks industry levy in 2020, taking into account the progress made through voluntary reformulation (see (36), page 18).

[4] Dairy products naturally contain simple sugars, which are included in the total sugar content displayed in the nutritional facts on the packaging. According to the Ciqual French food composition database,(37) natural yogurts contain on average 3.7 g/100g of sugars; natural fromage frais 3.8 g/100g; and 4.3 g/100g for dairy drinks.

Table 0: Summary of PPPs policies implemented in Western Europe for dairy products

	Period	Who leads	Involvement	Targeted dairy products	Nutrient targeted	Quantitative outcome and reduction level	Monitoring
The Netherlands	2014-2020	Ministry of Health, Welfare and Sport	Chain agreement between Dutch Food Retail Organisation; Federation of the Dutch Food Industry; Royal Dutch Hotel and Catering Association; Dutch Catering Association	All dairy products (except natural products)	Added sugar	Maximum content level 11.6 g/100g for yogurts and quarks; 8 g/100g for milk-based drinks	National Institute for Public Health, each year
England	2016-2020	Public Health England	Extensive discussion and consultation with all sectors of the food industry, non-governmental organisations, other government departments and the devolved nations	Spoonable dairy products (except natural products)	Total sugar	Sales weighted average content level Objective: 20% reduction (5% the first year) compared to 2015	Public Health England
	2018-2021			Milk-based drinks (except natural products)		Tax threat (2016-2018) No quantitative guideline published Sales weighted average content level (06/2018-07/2021); Objective: 20% reduction (10% the first year) compared to 2017	
Spain	2018-2020	Agency for Consumer Affairs, Food Safety and Nutrition	Collaboration of five sectors (manufacturing, distribution, contract catering, modern restaurant, and vending)	Sugar sweetened yoghurt, flavoured yoghurt, fruit yoghurt, drinking yoghurt, white pasteurized cheese (petit), drinking fermented semi-skimmed, milk and flavoured milks	Added sugar	Median content of dairy products; 10% reduction compared to 2016	Agency for Consumer Affairs, Food Safety and Nutrition

Notes: We limit our analysis to PPPs policies that fully achieve (i) a strong government leadership and pressure; (ii) an involvement of a large number of manufacturers, (iii) setting incremental targets at food product category level with a specified deadline to be achieved using maximum and average or sales-weighted average targets; and (iv) an effective monitoring and evaluation.

Data and empirical strategy

Data

The analysis was performed using information about brand level product innovations provided by the private Global New Products Database (GNPD) developed by Mintel,(34) an online database that continuously monitors worldwide product introductions in the consumer packaged goods' markets. It records a product when an innovation is highlighted on the package or communicated by the firm. Five types of product innovations are registered: new products, a new variety/range extension, new packaging, a change in nutritional composition and a relaunch. Below, we refer a product innovation as a newly marketed product, although a new packaging does not involve a new dairy product in terms of flavour, taste, and nutrient composition. The Mintel GNPD documents more than 80 product characteristics to classify food items (e.g., category, subcategory, distribution channel, launch type, and date of introduction in the market) and their packaging (e.g., brand, company, bar code, ingredients list, format, serving size, claims, and nutritional composition). Brand level data are collected on the basis of a standardised protocol involving a network of shoppers, and are categorised into a common classification across countries.

We gathered in our dataset the sugar, fat, saturated fat, and calorie content over time of four dairy product categories in six Western European countries (France, Germany, Italy, the Netherlands, Spain, and England) from 1 January 2010 to 31 December 2018: drinking yogurts, flavoured milk, fromage frais, and spoonable yogurts. We use the ingredients list to determine whether a product recipe contains non-caloric sweeteners. Dairy alternatives produced from plants/cereals (e.g., soy yogurts, coconut milk, almond milk, oat milk, rice milk, and buckwheat milk, etc) were not studied, as they are less targeted for this population. We excluded dairy desserts (such as mousse, custard, rice pudding, chocolate confectionery-based desserts, crème caramel, and panna cotta, etc) and frozen yogurts, which are included in the puddings and ice cream category of the childhood obesity plan, respectively. Categories containing plain, salted (i.e., cheese), concentrated or fat vector dairy products (i.e., butter, cream) were outside of the scope of this study. Finally, all unflavoured or natural products, which are not covered by the plan, were excluded from the dataset (i.e., all products for which the wording "sugar free" or "plain" is indicated on the packaging). However, products that do not contain added sugar but do contain non-caloric sweeteners were included in the set of products studied because the total or partial replacement of sugar by non-caloric sweeteners to preserve the sweet taste may be a formulation strategy of food operators.

Data have been cleaned: missing values were completed when available on the package images provided by Mintel GNPD; serving data were converted to per 100g; outliers were corrected or confirmed by package images; nutritional values have been verified using consistency checks (for example, the sugar content of the product must be less than or equal to the carbohydrate content). In order to include the maximum number of products in the analysis, nutritional values indicated for a per 100ml unit of a product have not been transformed and were considered as the equivalent of a per 100g of product, given their density close to 1.(39) Finally, the dataset contains 12,570 dairy products, of which 9,342 have a specified sugar content, 10,232 a fat content, 9,332 a saturated fat content, and 10,253 an energy value.

Descriptive statistical analysis

Table 1 presents the descriptive statistics on the number of newly marketed dairy products and their average and standard deviation sugar content over the 2010--2018 period in each of the six countries studied. All statistics are displayed per dairy product category. Average fat, saturated fat and calorie contents are displayed in supplemental Table 1. Germany was the most dynamic dairy products market with a much higher number of products collected: 3,796 vs. 2,445 for England and 2,150 for France. The number of products collected in Spain, Italy and the Netherlands was less significant (1,758, 1,483 and 938 new items, respectively). The spoonable yogurts category was, by far, the most represented for all six countries, and accounted for more than 60% of the data collected for each country, except for the Netherlands (46% of newly marketed items). The drinking yogurts category was the second most represented product, ranging from 17% to 27% according to the country considered, except for Germany. Fromage frais, drinking yogurts and flavoured milk categories accounted for a less proportion of newly market product in the six countries.

Table 1: Descriptive statistics

	Category				All
	Drinking yogurts	Flavoured milk	Fromage frais	Spoonable yogurts	
	Number of dairy products				
The Netherlands	252	115	142	429	938
France	420	139	243	1348	2150
Germany	433	430	455	2478	3796
Italy	298	48	47	1090	1483
Spain	393	202	108	1055	1758
England	416	354	162	1513	2445
All countries	2212	1288	1157	7913	12570
	Average sugar content in g/100g (g/100ml for beverages)				
The Netherlands	7.75	10.05	11.62	12.26	10.75
France	11.48	10.76	12.19	12.27	11.99
Germany	11.31	9.78	13.55	13.48	12.76
Italy	11.25	10.47	14.04	13.04	12.57
Spain	10.88	10.76	12.40	11.75	11.48
England	10.04	9.90	11.06	12.85	11.76
All countries	10.63	10.13	12.50	12.77	12.05
	Standard deviation of sugar content				
The Netherlands	3.81	2.37	4.44	3.77	4.18
France	2.13	1.54	3.77	3.11	2.97
Germany	2.31	2.04	3.92	2.80	3.11
Italy	2.83	2.74	1.59	3.00	3.05
Spain	3.73	2.72	3.57	4.09	3.87
England	3.37	2.02	3.29	3.51	3.54
All countries	3.24	2.20	3.89	3.35	3.44

The average sugar content (fat; saturated fat; calorie) of all new dairy products was 12.05 g/100g (3.00 g/100g; 1.88 g/100g; 96.46 Kcal/100g) of dairy product. The spoonable yogurts and fromage frais categories had the highest (and almost the same) sugar, fat, saturated fat, and calorie contents. Drinking yogurts and flavoured milk products have almost the same sugar content (10.63 g/100g and 10.13 g/100g, respectively). However, flavoured milk was fatter and more caloric (1.90 g/100g for fat, 1.22 g/100g for saturated fat, 74.39 Kcal/100g versus 1.37 g/100g, 0.81 g/100g and 70.66 Kcal/100g respectively for drinking yogurts). It is also characterized by a relative lower volatility in the sugar content.

German dairy products had the highest average sugar (12.76 g/100g), fat (3.54 g/100g), saturated fat (2.28 g/100g) content and consequently had a much higher calorie content compared to other countries (104.25 Kcal/100g). Italian dairy products had almost the same average sugar content as in Germany (12.57 g/100g), while products in France and England were the second fattest. Dairy products in Italy, France and England had similar average calorie content. Spanish dairy products had the second lowest average sugar content (11.48 g/100g). Dairy products in the Netherlands had the lowest average sugar content of 10.75 g/100g. This result is driven by the high proportion of drinking yogurt category (27% of total dairy products and 42% of which have non-caloric sweeteners), that was characterised by relatively low sugar content (7.75 g/100ml). Moreover, the average sugar content for the three other categories was also among the lowest for the Netherlands (averages of 10.05 g/100g for flavoured milk, 11.62 g/100g for fromage frais and 12.26 g/100g for spoonable yogurts). Products in Italy, Spain and the Netherlands had the lowest fat (about 2.5 g/100g) and saturated fat (about 1.5 g/100g) content. However, only Spanish and Dutch products had the lowest calorie content (about 88 Kcal/100g). We can also highlight that the volatility in sugar content is the highest in the Netherlands (4.18 vs. 3.44 when the six countries is considered).

When we analyse the nutrient content by both category and country, Italy and Germany were characterised by the highest average sugar content for drinking yogurts (11.25 and 11.31 g/100g), fromage frais (14.04 and 13.55 g/100g) and spoonable yogurts (13.04 and 13.48 g/100g). German items were the fattest (2.45 g/100g for flavoured milk and 4.00 g/100g for fromage frais), except for drinking yogurts (1.38 g/100g) and fromage frais (4.28 g/100g the second fattiest average found after Italy), and the most caloric were flavoured milk (78.75 Kcal/100g) and spoonable yogurts (113.3 Kcal/100g). The most caloric drinking yogurts (fromage frais) were marketed in France (Italy). France had the highest average sugar values for drinking yogurts (11.48 g/100g) and flavoured milk (10.76 g/100g), an intermediate average of sugar content for fromage frais (12.19 g/100g) and among the lowest average for spoonable yogurts (12.27 g/100g). The average sugar content for Spain was at an intermediate level for drinking yogurts (10.88 g/100g) and fromage frais (12.40 g/100g) and was the lowest for spoonable yogurts (11.75 g/100g). Concerning fat and energy averages, Spain presented the same profile as for sugar, except for flavoured milk for which Spain had the highest average sugar content (10.76g/100g) but among the lowest for fat (1.47 g/100g) and energy (71.44 Kcal/100g). Finally, England presented their average sugar contents among the lowest for all categories (9.90 g/100g for flavoured milk, 11.06g/100g for fromage frais), except for drinking yogurts and spoonable yogurts for which the averages were at intermediate levels (10.0 and 12.9 g/100g, respectively). The latter category also had the second highest fat, saturated fat and caloric content (110.77 Kcal/100g), just below Germany.

Figure 1 displays the evolution of the average sugar content of new products launched each year in the dairy products market in the six countries. The evolution for fat, saturated fat and energy contents are displayed in supplemental Figures 1--3. Three countries--the Netherlands, England and Germany--experienced a negative trend during the period studied. But only the Netherlands and England showed considerably lower average sugar contents in 2018 compared to the other countries. In contrast, Spain, Italy and France exhibited an overall stable trend during the period studied. We can also underline that the Netherlands presented a very low average sugar content from 2010 to 2012 (around 10 g/100g) compared to the other countries.

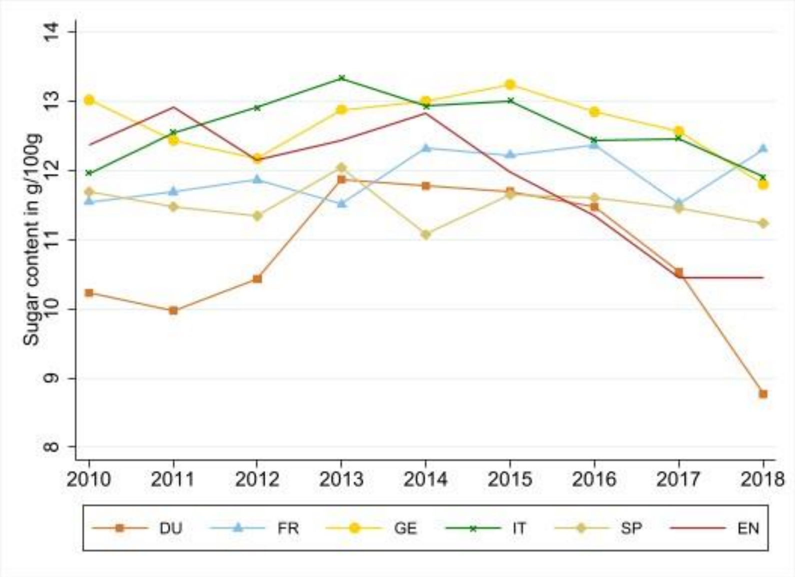


Figure 1: Average sugar-content evolution of newly-marketed dairy products in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

Figure 2 displays the evolution of the average sugar content of drinking yogurt category in each country. The evolution for fat, saturated fat and energy contents of each dairy product category in each country are displayed in supplemental materials. We observed a slight negative trend of the sugar content of drinking yogurts for each country, except for France and Spain (overall stability) and England (a sharp decrease). For the Netherlands, the sugar content of this category was much lower than that in other countries, due to a high proportion of products with non-caloric sweeteners (42% versus 13% in the other countries, over the period).

The evolution of the sugar content of flavoured milk products is displayed in figure 3.[5] We can notice that the sugar content of flavoured milk in England experienced a clear negative trend in 2014 to finally reach a mean sugar content of 8.35 g/100g in 2018. Dutch flavoured milk experienced an overall negative trend after 2012, although a one-time increase was observed in 2016. Germany also experienced a slight decrease in the sugar content between 2014 and 2018. France exhibited a fairly stable level while the evolution in Spain is quite erratic after 2015.

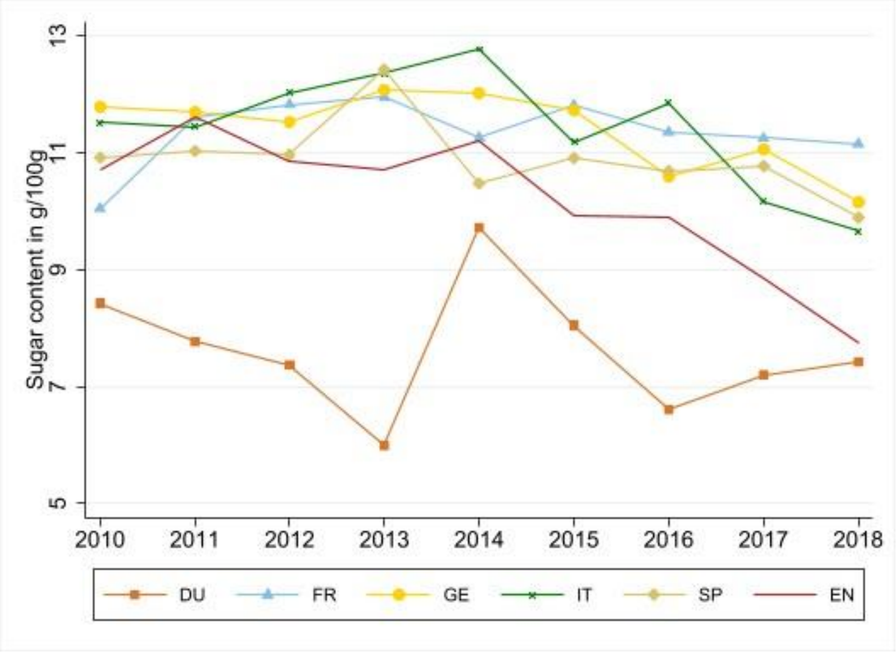
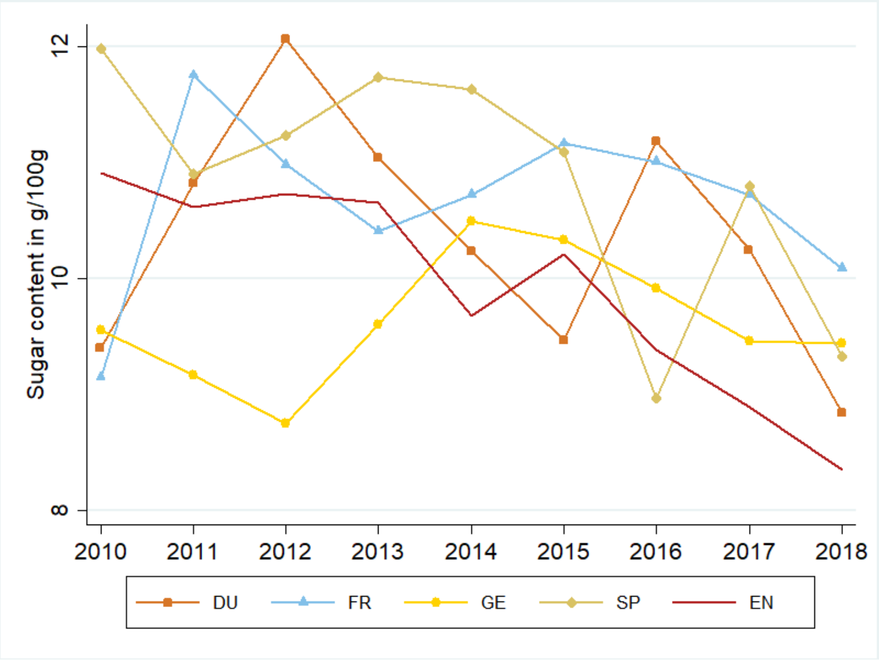


Figure 2: Average sugar-content evolution of newly marketed (1) drinking yogurts in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)



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[5] The sugar content evolution for Italy is not displayed, as too few products were collected over the period.

Figure 3: Average sugar-content evolution of newly marketed flavoured milk in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

The evolution of the sugar content of fromage frais is displayed in figure 4. [6] The category of fromage frais was characterised by strong variations in the average sugar content for all countries. This was probably partly related to the diversity of recipes (see the standard deviation in Table 1) and the low number of products collected by Mintel for this category. No statistical analysis was done for this category due to these two specificities.

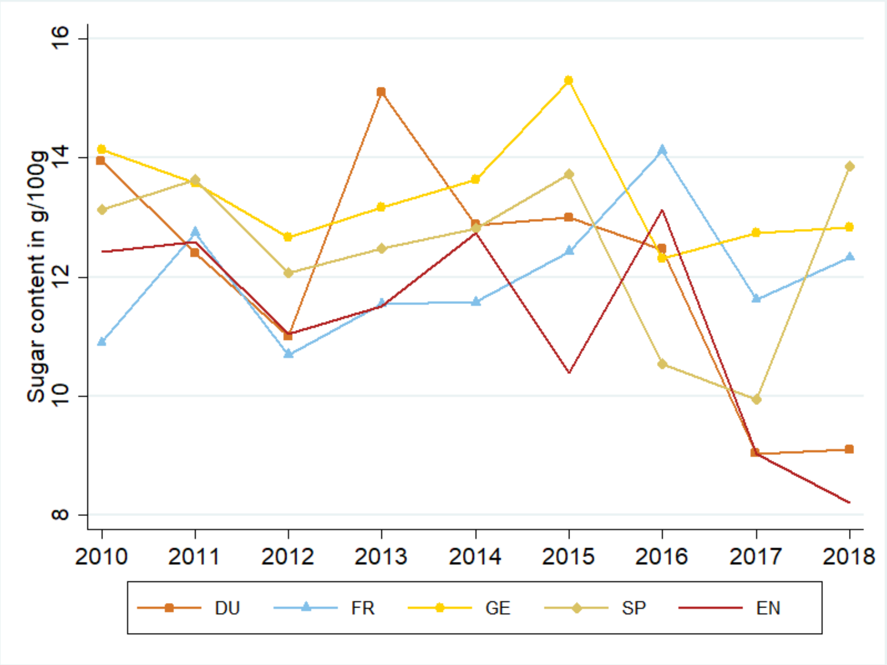

Figure 4: Average sugar-content evolution of newly marketed fromage frais in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

The evolution of the sugar content of spoonable yogurts is displayed in figure 5. Marked negative trends are observed for England and the Netherlands, slight decreases for Germany, whereas an overall stability are displayed for Spain, Italy and France. England had the second highest mean sugar content in 2010 (13.41 g/100g), but a sharp negative trend occurred during 2014--2017 period, to finally exhibited the second lowest average level in 2018 (11.76 g/100g). The average sugar content of Dutch spoonable yogurts, after several increases/-decreases during the 2011-2014 period, started decreasing from 2014 onwards. It was at the lowest level in 2010 (11.8 g/100g), spiking in 2014 (13.73 g/100g) and it then kept falling to reach 9.72 g/100g in 2018, the lowest level among the six countries.

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[6] The sugar content evolution for Italy is not displayed, as too few products were collected over the period.

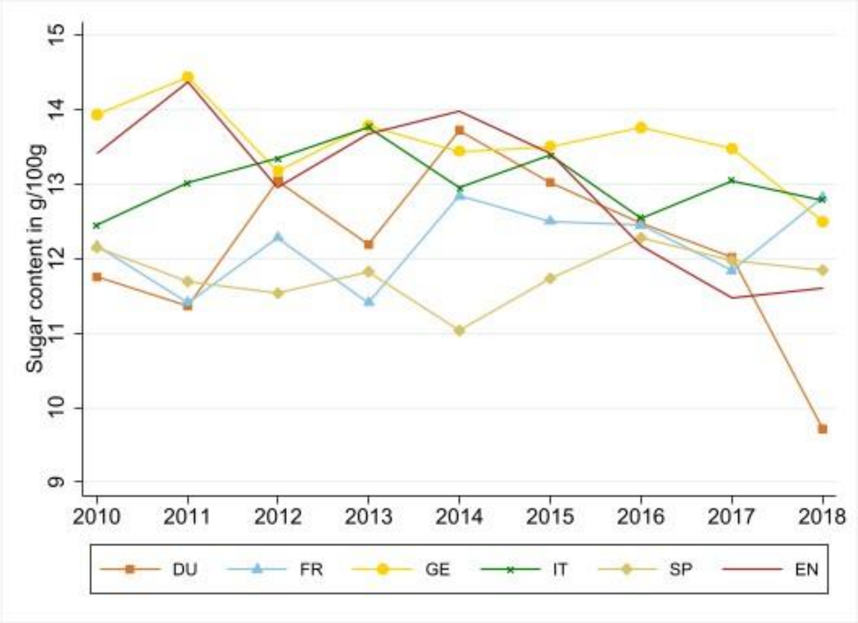

Figure 5: Average sugar-content evolution of newly marketed spoonable yogurts in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

Empirical strategy

As PPP policy was implemented nationally, it was not possible to construct a true experimental design in the Netherlands or England to study its effects on the nutrient composition of dairy products. Our identification strategy was based on a pre-post quasi-experimental approach using countries in which no PPP policy was implemented as counterfactuals, the control countries group. We used a difference-in-differences (DID) strategy to estimate policy's instantaneous and dynamic effects.(40) Specifically, we calculated the DID estimator of the lth dynamic effect, denoted below $DID_{c,t,l}$, that compares the evolution of the nutrient (calorie) content in grams (Kcal) per 100g of dairy products category from period t-l-1 to t in a treated country c that have implemented the policy (either the Netherlands or England) for the first time in year t-l, and in countries that have not from 2010 to year t. It provides the effect of having implemented the policy for the first time l years ago. We estimated policy's instantaneous (l=0) and dynamic effects (l≥1) on the sugar, saturated fat and calorie content of all dairy products and for each dairy product category, targeted by the policy. We also allowed for different linear trends across dairy products categories, by including dairy products category fixed effects. Under common trends assumption, this estimator is robust to heterogeneous and dynamic effects.(40) The supplemental materials of subtask 3 provide additional details on the DID estimators used.

Plausibility of common trends assumption

Our strategy has the advantages and disadvantages of a DID strategy. On the one hand, it allows us to control for country, dairy products category and time-period fixed effects so that all time-invariant differences across countries— such as food and beverage preferences or population health conditions (to the extent that they change slowly over time)— and dairy products categories over time were controlled for. On the other hand, the identification strategy relies also on the assumption that the trends of the mean sugar saturated fat or calorie content would have been the same in both the countries control groups and treated country in the absence of PPP policy. In other words, any selection bias implied by using data from France, Germany, Italy and Spain to build the counterfactual and not captured by the fixed effects is either constant over time, or, if it does evolve over time, the evolution is linear. It is also possible that England or the Netherlands and countries control group experience different evolution of the outcome of interest (sugar, fat, saturated fat or calorie content) over time, but the DID approach can still produce unbiased estimators provided that those differential evolutions are accounted for by the change in country's covariates. Thus, we also integrate in regressions time- and country-varying covariates that may affect the nutrient composition of dairy products. Specifically, we control for a number of time varying country characteristics that can be correlated with firms' product reformulation strategy, such as country's variable indicators of health (childhood obesity rate,(41) share of out-of-pocket medical expenses over total health spending,(42) death rate due to NCDs among populations aged 30--70 years (43) and dietary and high body mass index risks (44)); and the proportion of dairy products with non-caloric sweeteners in each country over time. However, health indicators except the share of out-of-pocket medical expenses were not significant in all regressions investigated. It was difficult to distinguish their effects with our DID estimation strategy given their weak variability over time. In our estimations below, the share of out-of-pocket medical expenses controlled for nutrient content variations caused by changes in a country's health context. For example, if out-of-pocket medical expenses increase (i.e., the health care system becomes less protective), an individual might become more inclined to adopt health promoting habits, furthering the likelihood of their purchasing more healthful food items, which in turn might encourage firms to improve the health profile of their products. The proportion of dairy products with non-caloric sweeteners controlled for company- (aggregated at the country level) and time-varying reformulation strategies regarding the use of non-caloric sweeteners in dairy product recipes.

Unfortunately, this critical assumption is not directly testable, but to assess its plausibility, estimations can be implemented using pre-policy observations.(40,41) The assessment consists in comparing the mean evolution of the sugar saturated fat or calorie content in grams (Kcal) per 100g of products from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{c,t,l}$: The Netherlands or England that have implemented the PPP policy for the first time in year t-l, and countries that have not from 2010 to year t (France, Germany, Italy and Spain). The estimator of this comparison is the lth placebo DID estimator, denoted below $DID^{pl}_{c,t,l}$. If common trends assumption holds, then $E[DID^{pl}_{c,t,l}] = 0$. So finding an estimation of $DID^{pl}_{c,t,l}$ significantly different from 0 would imply that the common trends assumption is violated: The Netherlands or England experienced different trends before implementation of the policy than countries belonging to the countries control group used to reconstruct The Netherlands or England counterfactual trend when The Netherlands or England has implemented the policy. Thus, the lth placebo estimator assesses if common trends assumption holds over l+1 years, the number of years over which the assumption has to hold for the lth dynamic effect, $DID_{c,t,l}$, to be unbiased. Contrary to the standard common trends test in event-study regressions, the test is robust to heterogeneous and dynamic effects. The supplemental materials of subtask 3 provide additional details on placebo estimators used. All the standard errors of the estimators were computed using a block bootstrap at the country level (1000 replications). The Stata 15 module *DID_multiplegt* was used for all analyses.(42,43)

Results

Main results

The estimates of England's PPPs policy instantaneous and dynamic effects on the nutrient composition of spoonable dairy products (columns 3--5) and spoonable yogurts (columns 7--9) were displayed in Table 2. Specifically, we analyse the sugar, fat, saturated fat content in grams per 100g of dairy products and calorie content in Kcal per 100g of dairy product. The effects of the policy on fromage frais category were not estimated given their limited number of observations over the period (15, 18 and 13 in 2016, 2017 and 2018, respectively). The countries control group was made up of France, Germany, Italy, and Spain for all estimations. We integrated country fixed effects, and controlled for the share of out-of-pocket medical expenses over total health spending in all estimations. To assess the plausibility of the estimates, we computed (also reported in Table 2) the placebo estimators, $DID^{pl}_{EN,t,l}$, $l = \{0, 1, 2\}$. $DID^{pl}_{EN,2016,0}$ compares the mean evolution of the sugar, saturated fat (calorie) content in grams (Kcal) per 100g of spoonable dairy products or yogurts from 2014 to 2015 in England that implemented the policy for the first time in 2016 and countries belonging to the countries control group that have not since 2016. The other placebo estimators $DID^{pl}_{EN,2017,1}$ and $DID^{pl}_{EN,2018,2}$ perform the same comparison but between 2013 and 2015, and 2012 and 2015, respectively.

Spoonable dairy products in England experienced a significant decrease in their sugar content in 2016 and 2017 (-0.46 and -1.01 g/100g, respectively). These reductions relate to 4% and 8% reductions from the average sugar level observed in spoonable dairy products in 2015. Furthermore, no significant variation in their fat, saturated fat and calorie content was found between 2016 and 2018. Table 2 also reported the effects of the PPPs policy on spoonable yogurts. Significant sugar reductions were estimated in 2016 (-1.24 g/100g), 2017 (-1.68 g/100g), and 2018 (-1.20 g/100g). The reductions were higher than those found in the whole spoonable dairy product category. These reductions relate to 9% and 13% reductions in sugar content in 2016 and 2018, and 2017 respectively, compared to the average sugar content of spoonable yogurts in England in 2015. As for the spoonable dairy category, we found no significant reduction in the fat (except in 2016), saturated fat and calorie content of spoonable yogurts.

We found that the placebo estimators $DID^{pl}_{EN,2016,0}$ were significant for sugar, fat, saturated fat and calorie contents in spoonable dairy products and yogurts, meaning that England experiencing a differential pre-trend from 2014 to 2015 than those in France, Germany, Italy and Spain. Our estimates of the instantaneous effect are biased. The decreasing trend in sugar content in the dairy category observed in England between 2014 and 2015 (see Figure 1), two years before the implementation of the obesity plan, is not observed in any country in the control group. On the other hand, our estimates of $DID^{pl}_{EN,2017,1}$ and $DID^{pl}_{EN,2018,2}$ (except for sugar) are insignificant. These tests indicate that parallel trends assumption holds over 2012-2015 for fat, saturated fat and calorie content of spoonable dairy products and yogurts. Our estimates of $DID_{EN,2017,1}$ would be unbiased for the sugar content of spoonable dairy products and yogurts.

The estimates of Dutch PPPs policy's instantaneous and dynamic effects on the sugar, fat, saturated fat and calorie content of all dairy products (drinking yogurts, flavoured milk, fromage frais and spoonable yogurt) are displayed in Table 3. As for England, the countries control group was made up of France, Germany, Italy, and Spain for all estimations, and country fixed effects were integrated in all estimations. We also considered the share of out-of-pocket medical expenses over total health spending and the proportion of dairy product (spoonable yogurts) with non-caloric sweeteners in each country over time as control variables. We only kept significant control variables in the regression models. To assess the plausibility of the common trends assumption, we also reported the placebo estimators.

We found that voluntary product reformulation policy implemented in the Netherlands brought about significant decreases in the sugar content of newly marketed dairy products by 2015 onwards, when reduction guidelines were published, at the 1% significance level. We found 9%, 10%, 17% and 30% significant reductions in the sugar content of dairy products in 2015, 2016, 2017 and 2018, respectively (compared to the average sugar content observed in the category in 2013). As for England, the policy did not provoke significant variations on fat, saturated fat and calorie content. We unexpectedly found that Dutch spoonable yogurt category has experienced no significant decrease in its average sugar content. The relatively low average sugar content observed in 2013 (see Figure 2.4), the year preceding policy implementation, i.e. the baseline year for calculating DIDs, explains this result. The low average is due to the relatively high proportion of spoonable yogurts with non-caloric sweeteners in 2013 (14% vs. less than 3% in 2014 and 2015, and 7% in 2016, see supplemental Table 2). We also found no significant reduction in saturated fat and calorie content. Unfortunately, the effects of the policy on drinking yogurt (22, 23, 20, 13 and 37 in 2014, 2015, 2016, 2017 and 2018, respectively), flavoured milk (15, 15, 5, 16 and 21 in 2014, 2015, 2016, 2017 and 2018, respectively) and fromage frais category (9, 11, 23, 13 and 30 in 2014, 2015, 2016, 2017 and 2018, respectively) were not estimated given their limited number of observations over the period. Therefore, it was not possible to identify the dairy product category(ies) that accounted for the estimated downward trend in sugar content in the overall category.

The placebo estimators are all not significantly different from zero, except for $DID^{pl}_{DU,2014,0}$ for saturated fat and calorie content of the dairy product category (sugar for spoonable yogurts), and $DID^{pl}_{DU,2015,1}$ for fat content. Therefore, the common trends assumption seems to hold from 2010 to 2013, except for fat. Unfortunately, the robustness of the estimates of the effects $DID_{DU,2017,3}$ $DID_{DU,2018,4}$ cannot be tested due to the absence of data before 2010.

Effects of the PPPs policy on the nutrient composition of newly marketed dairy products without non-caloric sweeteners

We investigate which lever was used to comply with the policy. We analyse to what extent the reductions found in England and the Netherlands resulted from a total or partial replacement of sugar by non-caloric sweeteners or from a firms' genuine effort to reduce the sugar content with no compensatory action to preserve the taste of sweetness. Table 4 reports estimates for all spoonable dairy products and yogurts in England when the dataset was restricted to spoonable dairy products without non-caloric sweeteners. We mobilise the same regression setting used to assess the effects of the PPPs policy for spoonable dairy products and yogurts. The same countries control group (i.e. France, Germany, Italy, and Spain) was used and country fixed effects and the share of out-of-pocket medical expenses over total health spending were integrated in all estimations. Table 4 follows the same structure as Table 2.

The childhood obesity plan has led firms to replace sugar with non-caloric sweeteners in spoonable dairy products. We find a significant sugar reduction only in 2017 and it is lower than the one found when all spoonable dairy products were considered (6% vs. 8% compared to the average sugar content observed in spoonable dairy products without non-caloric sweeteners in 2015). The prevalence of spoonable dairy products with non-caloric sweeteners increased by 10 percentage points (pp) in England over 2015--2018, accounting for 21% and 22% of spoonable dairy products marketed in 2017 and 2018, respectively (see supplemental Table 2). We now found a significant increase in their fat and saturated fat content in 2017 (7% and 16%, respectively), but no significant variation in their calorie content. They also experienced a 24% increase in saturated fat in 2018. The innovative strategy of substituting sugar with non-caloric sweeteners was clearly established for spoonable yogurts. The fall in the sugar content of spoonable yogurts previously found in 2018 (see Table 2) is no longer significant. Moreover, we have estimated lower significant decreases in sugar content (-6% and -8% in 2016 and 2017 compared to the average sugar content observed in spoonable yogurts without non-caloric sweeteners in 2015, respectively). The increase in the prevalence of spoonable yogurts with non-caloric sweeteners was as high as that observed for spoonable dairy products (11pp) over 2015—2018 and accounted for 21% of newly marketed drinking yogurts in 2017 and 2018 (see supplemental Table 2). In contrast to spoonable dairy products without non-caloric sweeteners, no significant variation in fat and saturated fat (except in 2018) content was found, and the sugar reduction estimated in 2017 also resulted in a significant drop in their calorie content (-6%). We found that the placebo estimators $DID_{EN,2016,0}^{pl}$ were significant for sugar, fat, saturated fat and calorie contents in spoonable dairy products and yogurts. On the other hand, our estimates of $DID_{EN,2017,1}^{pl}$ are all insignificant. Parallel trends assumption would hold over 2013-2015.

Table 2: England PPP policy’s instantaneous and dynamic effects on the recipe of spoonable dairy products and spoonable yogurts, and placebo estimators of the common trends assumption

Dairy category	All spoonable dairy products					Spoonable yogurts				
Nutrient content	# obs	Sugar	Fat	Saturated fat	Calorie	# obs	Sugar	Fat	Saturated fat	Calorie
$DID_{EN,2016,0}$	893	-0.465**	0.062	0.086	-0.543	797	-1.237***	-0.208***	-0.075	-6.050
$DID_{EN,2017,1}$	842	-1.008***	-0.078	0.171	-5.401	760	-1.680***	-0.489	-0.058	-12.568
$DID_{EN,2018,2}$	696	-0.584	0.102	0.305	0.142	611	-1.198**	-0.322	0.110	-7.309
Placebo estimator										
$DID^{pl}_{EN,2016,0}$	893	0.911**	0.728***	0.461**	9.749***	797	0.686**	0.679***	0.452**	8.285**
$DID^{pl}_{EN,2017,1}$	842	0.176	0.142	0.148	1.581	760	0.125	0.164	0.142	1.572
$DID^{pl}_{EN,2018,2}$	696	-0.315*	-0.151	-0.057	-1.930	611	-0.431**	-0.210*	-0.089	-3.145*

Notes: $DID_{EN,t,l}$ is the DID estimator comparing the evolution of the nutritional content in grams per 100g of dairy products (in Kcal per 100g of product for calorie content) from period t-l-1 to t in England, that launched PPPs policy in the year t-l=2016 and in countries belonging to the countries control group (France, Germany, Italy and Spain) from 2010 to year t. $DID^{pl}_{EN,t,l}$ stands for the placebo estimator that compares the mean evolution of the corresponding nutrient content in grams per 100g of dairy product (in Kcal per 100g of product for calorie content) from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{EN,t,l}$. $DID^{pl}_{EN,t,l}$ significantly different from 0 would imply that the common trends assumption is violated. # obs is the number of observations in t used to calculate $DID_{EN,t,l}$. All estimations integrated the share of out-of-pocket medical expenses over total health spending and country fixed effects. All standard errors were clustered at country level (1000 replications, not displayed). * $p<0.01$, ** $p<0.05$, *** $p<0.001$.

Table 3: Dutch PPP policy's instantaneous and dynamic effects on the recipe of dairy products and spoonable yogurts, and placebo estimators of the common trends assumption

Dairy category	All dairy products					Spoonable yogurts				
Nutrient content	# obs	Sugar	Fat	Saturated fat	Calorie	# obs	Sugar	Fat	Saturated fat	Calorie
$DID_{DU,2014,0}$	1104	-0.378	-0.843	-0.470	-8.737	750	0.991^{*}	-0.537	-0.078	-1.798
$DID_{DU,2015,1}$	1276	-1.090^{***}	-0.285	-0.167	-9.687	832	0.010	0.632	0.475	2.468
$DID_{DU,2016,2}$	1074	-1.180^{***}	-0.404	-0.246	-12.111	726	-0.318	0.090	0.136	-6.452
$DID_{DU,2017,3}$	1025	-2.004^{***}	-0.527	-0.366	-14.941	635	0.061	-0.200	-0.138	-3.637
$DID_{DU,2018,4}$	901	-3.551^{***}	-1.429	-0.889	-31.922	526	-1.843	-0.712	-0.371	-17.287
Placebo estimator										
$DID^{pl}_{DU,2014,0}$	1104	-0.244	-0.091	-0.168^{**}	-4.604^{**}	750	0.122^{***}	-0.539	-0.081	-2.982
$DID^{pl}_{DU,2015,1}$	1276	-0.257	-0.221^{**}	0.105	2.063	832	-0.784	-0.515^{**}	-0.170	-2.093
$DID^{pl}_{DU,2016,2}$	1074	0.006	0.020	-0.045	0.199	726	0.143	0.694^{*}	0.054	3.718
Controls										
Out-of-pocket medical expenses		N	Y	Y	Y		Y	Y	Y	Y
Proportion of SSBs with non-caloric sweeteners		Y	Y	Y	Y		Y	Y	N	Y

Notes: $DID_{DU,t,l}$ is the DID estimator comparing the evolution of the nutritional content in grams per 100g of dairy products (in Kcal per 100g of product for calorie content) from period t-l-1 to t in the Netherlands, that launched PPPs policy in the year t-l=2014 and in countries belonging to the countries control group (France, Germany, Italy and Spain) from 2010 to year t. $DID^{pl}_{DU,t,l}$ stands for the placebo estimator that compares the mean evolution of the corresponding nutrient content in grams per 100g of dairy product (in Kcal per 100g of product for calorie content) from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{DU,t,l}$. $DID^{pl}_{DU,t,l}$ significantly different from 0 would imply that the common trends assumption is violated. # obs is the number of observations in t used to calculate $DID_{DU,t,l}$. The inclusion of the share of out-of-pocket medical expenses or the proportion of dairy products with non-caloric sweeteners as country- and time-varying control is indicated by Y; N indicates that is not included in the model. All estimations integrated country fixed effects. All standard errors were clustered at country level (1000 replications, not displayed). * p<0.01, ** p<0.05, *** p<0.001.

Table 5 reports the result for the Netherlands, when the dataset was restricted to dairy products without non-caloric sweeteners. It follows the same structure as Table 3. The Dutch policy has encouraged firms to decrease the sugar content in dairy products as early as 2014. We found significant reductions in the sugar content of dairy products without non-caloric sweeteners almost as high as those found when considering the overall category. They were equal to -4%, -9%, -11%, -15% and -29% in 2014, 2015, 2016, 2017 and 2018, respectively (compared to the average sugar content observed in dairy products without non-caloric sweeteners in 2013). In contrast to the results found using the whole dataset, significant reductions, at least at 10% significance level, of the energy content were found between 2014 and 2018. The significant decreases, at 1% significance level, found in 2014 and 2018 stem not only from the decrease in sugar content but also in fat and saturated fat content. It relates to 9% and 25% reductions in calorie content in 2014 and 2018, respectively, compared to the average calorie content of dairy products without non-caloric sweeteners in 2013. In contrast to Table 3, we found significant reductions in the sugar content of spoonable yogurts. Companies' effort was particularly strong in 2018, the very last year before firms had to comply with the maximum added sugar content level established. Specifically, significant falls in the sugar content equal to 5%, 9%, 4% and 20% were found in 2015, 2016, 2017 and 2018, respectively (compared to the average sugar content observed in spoonable yogurts without non-caloric sweeteners in 2013). However, these sugar reduction efforts were associated with a significant increase, at 1% significance level, in fat and saturated fat in 2015 (14% and 16%, respectively) and resulted in a significant increase, at 1% significance level, in calorie content (7%). A 9% rise in calorie content was also estimated in 2017. These increases were not confirmed in 2018.

Placebo estimators indicate that our estimated effects are unbiased, except for the estimate of the instantaneous effect for the saturated fat content of spoonable yogurts. Moreover, the common trends assumption is rejected for fat. The common trends assumption seems to hold from 2010 to 2013 for the other nutrients. Unfortunately, the robustness of the estimates of the effects $DID_{DU,2017,3}$ $DID_{DU,2018,4}$ cannot be tested due to the absence of data before 2010.

Table 4: England PPP policy’s instantaneous and dynamic effects on the recipe of spoonable dairy products and spoonable yogurts witout non-caloric sweeteners

Dairy category	All spoonable dairy products					Spoonable yogurts				
Nutrient content	# obs	Sugar	Fat	Saturated fat	Calorie	# obs	Sugar	Fat	Saturated fat	Calorie
$DID_{EN,2016,0}$	809	-0.419	0.174	0.135	0.652	721	-0.886^{***}	0.078	0.083	-2.734
$DID_{EN,2017,1}$	761	-0.791^{***}	0.281^{***}	0.389^{***}	-2.855	689	-1.134^{***}	0.073	0.295	-7.520^{**}
$DID_{EN,2018,2}$	643	-0.098	0.600	0.589^{**}	5.175	564	-0.429	0.352	0.515^{*}	-0.229
Placebo estimator										
$DID^{pl}_{EN,2016,0}$	809	0.958^{***}	0.761^{***}	0.497^{***}	10.451^{***}	721	0.876^{***}	0.803^{***}	0.545^{***}	10.102^{***}
$DID^{pl}_{EN,2017,1}$	761	0.205	0.024	0.098	0.775	689	0.187	0.062	0.095	0.892
$DID^{pl}_{EN,2018,1}$	643	-0.405^{**}	-0.201	-0.083	-2.343^{*}	564	-0.461^{*}	-0.239	-0.106	-3.330^{**}

Notes: $DID_{EN,t,l}$ is the DID estimator comparing the evolution of the nutritional content in grams per 100g of dairy products (in Kcal per 100g of product for calorie content) from period t-l-1 to t in England, that launched PPPs policy in the year t-l=2016 and in countries belonging to the countries control group (France, Germany, Italy and Spain) from 2010 to year t. $DID^{pl}_{EN,t,l}$ stands for the placebo estimator that compares the mean evolution of the corresponding nutrient content in grams per 100g of dairy product (in Kcal per 100g of product for calorie content) from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{EN,t,l}$. $DID^{pl}_{EN,t,l}$ significantly different from 0 would imply that the common trends assumption is violated. # obs is the number of observations in t used to calculate $DID_{EN,t,l}$. All estimations integrated the share of out-of-pocket medical expenses over total health spending and country fixed effects. All standard errors were clustered at country level (1000 replications, not displayed). * p<0.01, ** p<0.05, *** p<0.001.

Table 5: Dutch PPP policy’s instantaneous and dynamic effects on the recipe of dairy products and spoonable yogurts witout non-caloric sweeteners

Dairy category	All dairy products					Spoonable yogurts				
Nutrient content	# obs	Sugar	Fat	Saturated fat	Calorie	# obs	Sugar	Fat	Saturated fat	Calorie
$DID_{DU,2014,0}$	991	-0.472***	-0.965***	-0.558***	-8.934***	671	0.381	-0.790***	-0.292*	-1.796
$DID_{DU,2015,1}$	1178	-1.194***	-0.299	-0.220	-6.505*	766	-0.634***	0.539**	0.357***	7.338**
$DID_{DU,2016,2}$	972	-1.415***	-0.426	-0.338	-7.255*	668	-1.168***	0.342	0.231	2.676
$DID_{DU,2017,3}$	940	-1.972***	-0.493	-0.438	-9.157*	592	-0.483***	0.633	0.292	9.860**
$DID_{DU,2018,4}$	820	-3.800***	-1.545***	-1.085*	-25.282***	498	-2.676***	0.439	0.243	-0.155
Placebo estimator										
$DID^{pl}_{DU,2014,0}$	991	-0.127	-0.061	-0.158	-2.156	671	0.146	-1.025***	-0.235**	-1.429
$DID^{pl}_{DU,2015,1}$	1178	0.216	-0.159	0.188	4.353	766	-0.312	-0.683***	-0.023	-1.936
$DID^{pl}_{DU,2016,2}$	972	-0.061	0.023	-0.040	-1.264	668	-0.012	0.633***	0.189	0.897
Controls										
Out-of-pocket medical expenses		N	Y	Y	N		N	N	N	N

Notes: $DID_{DU,t,l}$ is the DID estimator comparing the evolution of the nutritional content in grams per 100g of dairy products (in Kcal per 100g of product for calorie content) from period t-l-1 to t in the Netherlands, that launched PPPs policy in the year t-l=2014 and in countries belonging to the countries control group (France, Germany, Italy and Spain) from 2010 to year t. $DID^{pl}_{DU,t,l}$ stands for the placebo estimator that compares the mean evolution of the corresponding nutrient content in grams per 100g of dairy product (in Kcal per 100g of product for calorie content) from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{DU,t,l}$. $DID^{pl}_{DU,t,l}$ significantly different from 0 would imply that the common trends assumption is violated. # obs is the number of observations in t used to calculate $DID_{DU,t,l}$. The inclusion of the share of out-of-pocket medical expenses is indicated by Y; N indicates that is not included in the model. All estimations integrated country fixed effects. All standard errors were clustered at country level (1000 replications, not displayed). * p<0.01, ** p<0.05, *** p<0.001.

Effects of a tax threat on the nutrient composition of newly marketed milk-based drinks in England

No sugar reduction guideline was published for milk-based drinks in the childhood obesity plan in March, 2017. Furthermore, they fall for the time being outside the scope of the Soft Drinks Industry Levy (SDIL), as they are a source of calcium and other nutrients. However, the Health Committee of the SDIL recommended early in 2017 that the *Government consider extending the scope of the levy to include milk-based drinks where sugar has been added* (see (36), page 18). Furthermore, HM Treasury indicated that *it will consider the sugar reduction progress achieved in sugary milk drinks as part of its 2020 review of the milk drinks exemption from SDIL*. HM Treasury also stated that *Sugary milk drinks may be included in the SDIL if insufficient progress on reduction has been made* (see (24) page 8). In early 2018, milk-based drinks therefore have a specific status in England's nutritional health policy: they were not explicitly targeted by the childhood obesity plan or the SDIL, but threatened to become eligible for the soft drinks industry levy if there is no improvement in their nutrient profile by 2020.

PHE has finally published in May, 2018 voluntary sugar reduction guidelines for milk-based drinks with added sugar.(35) All milk-based drinks that contain more than 75% milk such as flavoured milk (e.g. strawberry, chocolate or banana); coffee drinks that contain more than 75% milk; smoothies that are at least 75% dairy and mixed with fruit/vegetables or cereal are in the scope of the Plan.[7] The ambition for sugar reduction (including a sugar allowance for lactose and a proportion of the sugars in milk substitute drinks) is 20% SWA reduction by mid-2021, with an interim 10% sugar SWA reduction by mid-2019 (based on data from the preceding year, August 2018 – September 2019). However, the effects of these guidelines could not be evaluated since they were published during 2018, which was the very last period of our study. Below, we investigate whether a threat of tax implementation, even without the publication of reduction guidelines or targets, embedded in a voluntary product reformulation plan can be effective in driving lowered sugar innovations.

We report the estimated effects of the tax threat on the recipe of milk-based drinks in Table 6. It also displays the effects on milk-based drinks without non-caloric sweeteners. The countries control group was made up of France, Germany, Italy, and Spain for all estimations. We also consider the share of out-of-pocket medical expenses over total health spending and the proportion of dairy products with non-caloric sweeteners as control variables. No statistically significant decrease in the average sugar, saturated fat and calorie content of milk-based drinks and milk-based drinks without non-caloric sweeteners was found in 2016. However, we estimate significant decreases in their sugar content when we consider all milk-based drinks (-0.60 g/100ml and -0.80 g/100ml in 2017 and 2018, respectively) and milk-based drinks without non-caloric sweeteners (-0.68 g/100ml and -1.26 g/100ml in 2017 and 2018, respectively). These reductions relate to 6% and 8% sugar reductions from the average sugar level observed in milk-based drinks (6% and 11% from the average sugar level observed in milk-based drinks without non-caloric sweeteners) in 2015. Furthermore, we get a significant reduction in their calorie content equal to 4% compared to the average sugar content observed in milk-based drinks in 2015, at 1% significance level, in 2018 (3% compared to the average sugar content observed in milk-based without non-caloric sweeteners in 2015). We also found that the common trends assumption is not rejected for all estimations conducted.

We also estimated the effects of the tax threat on the recipe of each milk-based drinks category, namely drinking yogurts and flavoured milk. Results are reported in Tables 7 and 8, respectively. As for the whole category, we provide the effects for drinking yogurts and flavoured milk without non-caloric sweeteners. The drinking yogurts category experienced significant decreases in its sugar content, and the decreases were higher when we only consider beverages without non-caloric sweeteners. We found 5% and 8% sugar reductions for drinking yogurts in 2017 and 2018, compared to the average sugar content observed in drinking yogurts in 2015, respectively. We found stronger decreases in the sugar content of drinking yogurts without non-caloric sweeteners (-8% and -12% in 2017 and 2018,

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[7] Drinks made with milk substitutes drinks such as soya, almond, hemp, oat, hazelnut or rice are also in the scope. These would include flavoured sugar sweetened flavoured varieties (eg strawberry, chocolate or banana).

compared to the average sugar content observed in drinking yogurts without non-caloric sweeteners in 2015, respectively). However, these drops were associated to strong increases in the fat, saturated fat and calorie content of drinking yogurts. We found 29% and 27% (19% and 40%; 7% and 3%) fat (saturated fat; calorie) rises for drinking yogurts in 2017 and 2018, compared to the average saturated fat (calorie) content observed in drinking yogurts in 2015, respectively. We found higher increases in fat and saturated fat content of drinking yogurts without non-caloric sweeteners (30% and 47%; 35% and 47% in 2017 and 2018 compared to the average fat/saturated fat content observed in drinking yogurts without non-caloric sweeteners in 2015, respectively) and calorie (8% and 4% in 2017 and 2018, compared to the average calorie content observed in drinking yogurts without non-caloric sweeteners in 2015, respectively) content of drinking yogurts without non-caloric sweeteners. All estimates for drinking yogurts seem to be unbiased. Our estimates of $DID^{pl}_{EN,2017,1}$ and $DID^{pl}_{EN,2018,2}$ are all insignificant. Parallel trends assumption would hold for drinking yogurts over 2012-2015. Our placebo estimators $DID^{pl}_{EN,2017,1}$ and $DID^{pl}_{EN,2018,2}$ are also not significantly different from 0 for drinking yogurts without non-caloric sweeteners, except for l=1 for calorie and l=2 for sugar, meaning that England and countries in the control group did not experience significantly different trends between 2012 and 2015.

We also found no significant decrease in the sugar content of flavoured milk in 2016. From 2017 onward, significant decreases in the sugar content emerged. The sugar reduction in flavoured milk was almost as high as that estimated in drinking yogurts in 2017 and 2018 (-8%). We found stronger decreases in the sugar content of flavoured milk without non-caloric sweeteners (-9% and -14% in 2017 and 2018, compared to the average sugar content observed in flavoured milk without non-caloric sweeteners in 2015, respectively). However, the unbiasedness of these estimates can be globally questioned: The placebo estimators are all significantly different from 0, except $DID^{pl}_{EN,2017,1}$ for flavoured milk without non-caloric sweeteners. As for drinking yogurts category, flavoured milk category experienced significant increases in its saturated fat content (17%, 13% and 6% rises in 2016, 2017, and 2018, compared to the average saturated fat content observed in flavoured milk in 2015, respectively). But in contrast to drinking yogurts, (i) no significant increases in the fat content and significant reductions in calorie content were found for either flavoured milk or flavoured milk without non-caloric sweeteners in 2017 and 2018: -2% and -4% (-4% and -9%) in calorie in 2017 and 2018 compared to the average calorie content observed in flavoured milk (flavoured milk without non-caloric sweeteners) in 2015, respectively. No significant variation in the saturated fat content of flavoured milk without non-caloric sweeteners was found in 2017 and 2018. The placebo estimators $DID^{pl}_{EN,2017,1}$ and $DID^{pl}_{EN,2018,2}$ for fat and calorie are all insignificant at 5% significance level for flavoured milk and flavoured milk without non-caloric sweeteners categories.

Table 6: England tax threat policy instantaneous and dynamic effects on the recipe of all milk-based drinks and all milk-based drinks without non-caloric sweeteners

Dairy category	All milk-based drinks					All milk-based drinks without sweeteners				
Nutrient content	# obs	Sugar	Fat	Saturated fat	Calorie	# obs	Sugar	Fat	Saturated fat	Calorie
$DID_{EN,2016,0}$	306	0.170	0.066	-0.026	-1.070	275	-0.022	-0.007	0.029	0.900
$DID_{EN,2017,1}$	378	-0.595^{***}	0.169^{*}	0.072	0.825	331	-0.678^{***}	0.111	0.088	-0.166
$DID_{EN,2018,2}$	262	-0.797^{***}	0.166	0.060	-3.241^{***}	227	-1.260^{***}	0.080	0.108	-2.718^{***}
Placebo estimator										
$DID^{pl}_{EN,2016,0}$	306	0.335	0.103	0.042	-1.161	275	-0.321^{*}	-0.028	0.099	-1.075
$DID^{pl}_{EN,2017,1}$	378	0.203	-0.008	-0.067	-1.371	331	0.090	-0.012	-0.016	0.921
$DID^{pl}_{EN,2018,2}$	262	0.205	0.085	0.044	-0.130	227	0.008	0.140	0.079	1.723
Controls										
Out-of-pocket medical expenses		Y		N	N		N	N	Y	N
Share of non-caloric sweeteners		N	Y	Y	Y					

Notes: $DID_{EN,t,l}$ is the DID estimator comparing the evolution of the nutritional content in grams per 100 ml of milk-based drinks (in Kcal per 100 ml of drink for calorie content) from period t-l-1 to t in England, that announced a tax threat for all milk-based drinks in the year t-l=2016 and in countries belonging to the countries control group (France, Germany, Italy and Spain) from 2010 to year t. $DID^{pl}_{EN,t,l}$ stands for the placebo estimator that compares the mean evolution of the corresponding nutrient content in grams per 100 ml of milk-based drinks (in Kcal per 100 ml of drink for calorie content) from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{EN,t,l}$. $DID^{pl}_{EN,t,l}$ significantly different from 0 would imply that the common trends assumption is violated. # obs is the number of observations in t used to calculate $DID_{EN,t,l}$. The inclusion of the share of out-of-pocket medical expenses over total health spending or the proportion of dairy products with non-caloric sweeteners is indicated by Y; N indicates that is not included in the model. All standard errors were clustered at country level (1000 replications, not displayed). * $p<0.01$, ** $p<0.05$, *** $p<0.001$.

Conclusion

The objective of this sub-task was to assess the effects of PPPs policy implemented in England and the Netherlands on the trends of the nutrient profile of newly marketed dairy products with added sugar. Our results indicate that PPPs policies implemented in the Netherlands and England have encouraged the formulation of less sugar-sweetened dairy products, and no unhealthy nutritional compensation would have taken place for this category. The Dutch voluntary product reformulation policy brought about 9%, 10%, 17% and 30% significant reductions in the sugar content of dairy products in 2015, 2016, 2017 and 2018, respectively (compared to the average sugar content observed in the category in the Netherlands in 2013). Spoonable dairy products in England experienced lower significant decreases in their sugar content in 2016 and 2017 (-4% and -8%, from the average sugar level observed in spoonable dairy products in England in 2015, respectively). In England, the reduction took place mostly for spoonable yogurts (9% and 13% reductions in sugar content in 2016 and 2018, and 2017 respectively, compared to the average sugar content of spoonable yogurts in England in 2015).

Companies in the Netherlands and England used a different strategy to achieve these reductions. Dutch companies have made a genuine effort to reduce the sugar content in dairy products, particularly in spoonable yogurts category (-5%, -9%, -4% and -20% in 2015, 2016, 2017 and 2018), with no compensation to preserve the sweet taste since 2014. In contrast, the childhood obesity plan has led firms to replace sugar with non-caloric sweeteners in spoonable dairy products. We find significant reductions in the sugar content of Dutch dairy products without non-caloric sweeteners almost as high as those estimated when considering with and without non-caloric sweeteners, while the former reductions are 2 percentage point lower in England.

We also compared the effects of PPPs policy and a threat of a sugar tax implementation for drinking dairy products with added sugar in England. The threat, even without the publication of reduction guidelines or targets, embedded in the obesity plan is also successful in driving lowered sugar innovations in the milk-based drinks sector. We found that the tax threat resulted in sugar reductions in milk-based drinks that were almost similar to those estimated for PPPs policy for spoonable dairy category (6% and 8% sugar reductions in 2017 and 2018, from the average sugar level observed in milk-based drinks in 2015). Both drinking yogurts (5% and 8%, in 2017 and 2018, respectively) and flavoured milk (8% in 2017 and 2018) experienced sugar reduction. However, only flavoured milk category has experienced reduction in its calorie content (-2% and -4% in 2017 and 2018, respectively). In contrast to spoonable dairy products, sugar reductions were higher when considering milk-based drinks, drinking yogurts and flavoured milk without non-caloric sweeteners. England dairy companies have made a genuine effort to reduce the sugar content in milk-based drinks.

Comparison with other studies

Our results are consistent with those obtained in the evaluation of the impact of obesity plan on dairy products.(29) PHE in their assessment of the plan found a 9% reduction in the average sugar content of yogurts and fromage frais (6% reduction in sales-weighted average total sugar content) between 2015 and 2018.(29) We found no significant variation in the calorie content of spoonable dairy products, whereas PHE found a 6.5% reduction in calorie content of yogurts and fromage frais. To the best of our knowledge, there is still no such publicly available evaluation for the Dutch plan. The magnitude of our estimated effects of the obesity plan is lower than that found for England's PPPs policy on salt reduction. The UK voluntary salt reduction plan has reduced the average amount of salt in bread by 20% from 2001 to 2011; soups and ketchup and brown sauces by around a third, branded breakfast cereals by 57%.(44) However, the estimation of the effects of the plan were conducted after the plan had been in place for a longer time. In contrast, we found that the voluntary plan for sugar seems more effective than the PPPs policy for salt in the Netherlands. The salt content in certain types of bread was on average 19% lower and certain types of sauce, soup, canned vegetables and legumes, and crisps had a 12 to 26% lower salt content, in 2016 compared to 2011 in the Netherlands.(28)

Despite these similarities in results, the PHE's evaluation differs from ours in three important aspects. First, PHE considered all yogurts and fromage frais, excluding plain yogurts and fromage frais as in our analysis, not just new dairy products in the market. Our analysis is a credible assessment of what is occurring in the whole market only if the nutrient content distribution of newly marketed products is similar to that observed when all products are considered. In the subtask 3, we show that this assumption is true for sugar-sweetened beverages. Second, the results were sales-weighted average for PHE's analysis. So, we were not able to estimate the impact of our estimated changes on sugar consumption. Third, the identification methods were different (comparison between average outcomes in 2019 and the baseline year 2015). Our approach is a quasi-experimental approach. We also compared the effects of the PPPs policy with those of a threat of tax implementation for milk-based drinks. We also provided the effects for each dairy product category.

Policy implications

Our results suggest that the obesity plan would have resulted in lower sugar reductions than the Dutch plan for newly marketed dairy products. The Dutch voluntary product reformulation policy would have brought about 1.2, 2.0, and 3.6 g/100g reductions in the sugar content of dairy products in 2016, 2017 and 2018, respectively. The England PPP policy would have achieved 0.3, 1.6 and 1.4 g/100g reductions in the sugar content of dairy products in 2016, 2017 and 2018, respectively, if we combine the results for spoonable dairy products and milk-based drinks. However, the Dutch plan started earlier than the England's plan, and so our evaluation of the Dutch plan is performed after the plan had been in place for a longer time (2014-2018) than that of the obesity plan (2016-2018). Since reformulation or product development takes time for companies, the potentially higher effectiveness of the Dutch plan may be primarily due to this difference. Furthermore, the scope of products targeted by the Dutch plan was broader (reduction guidelines for milk-based drinks were published in the obesity plan only in 2018).

Our empirical analysis cannot explain why the Dutch plan would have been more effective in encouraging sugar reduction, given the strong similarities between the two plans. Both are characterized by strong government leadership and pressure, involvement of a large number of manufacturers, publication of guidelines or reduction targets, and effective monitoring and evaluation. Nevertheless, the Dutch plan published reduction guidelines in terms of maximum added sugar contents while the obesity plan they are in terms of SWA of total sugar. However, we cannot conclude that publishing a reduction guideline in terms of maximum content provides a greater incentive for companies to improve the nutritional quality of products than publishing a reduction guideline in terms of SWA content. But, we acknowledge that the latter can be considered more coercive for companies.

We also analysis whether a threat of a tax implementation if insufficient progress on reduction is made can strengthen PPPs policy impact. We showed that a sugar tax threat embedded in a voluntary product reformulation plan is as effective as PPPs policy in driving lowered sugar innovations. However, no sugar reduction guidelines or targets were published when the sugar tax threat was set in early 2017. It seems that their publications in May, 2018 combined with the existing tax threat has enhanced sugar reductions: PHE evaluated that there were large sugar reductions for pre-packed fermented (yogurt) drinks (down 26.0%), pre-packed flavoured milk substitute drinks (down 21.7%), pre-packed milk-based drinks (down 21.0%) between 2017 and 2019. This relate to 22.1% and 13.4% reductions in sales-weighted average total sugar content for pre-packed milk-based drinks and pre-packed fermented, respectively.(30) These reductions were higher than those estimated by PHE for yogurts and fromage frais for which no tax threat was established: there was a 12.9% reduction in total sugar per 100g in products sold between 2015 and 2019.(30) These results suggest that PPPs policy effects can be enhanced with a credible tax threat.

Limitations

Only a partial evaluation of food policies was possible with Mintel GNPD data. Although we think that the proposed method can be applied to comprehensively assess the effects of a policy on the nutrient composition of products, only the effects on the nutrient profile of newly marketed dairy products could be assessed. Many other reactions--for example, dairy product industry reactions to product withdrawals, and changes in the health profiles of existing products in response to sugar reduction policies--still need to be included to formulate a comprehensive evaluation. Assessing such factors would involve collecting nutrient composition data at the product or brand level in different countries from year to year in a standardised format. This would allow us to follow the complete food supply evolution resulting from product removals, roll out of new products and reformulation of already existing products. It is also crucial to analyse how firms adjust their prices in response to PPPs policies, which in turn strongly conditions consumer reaction. Effects on consumers were also not assessed in this study, nor did we evaluate how changes in the dairy supply might have improved a population's diet. Assessing these effects would imply matching branded food databases to purchase data or, ideally, consumption data. Given the acknowledged central role of the food supply in the causation of chronic diseases, nutrient composition data collection for branded foods in different countries, from year to year, matched to individuals' purchases or consumption data, based on a similar data collection and food classification, to allow powerful comparisons and objective monitoring of product changes and individuals' nutrient intakes over time should be a priority for academics, stakeholders and private users active in the area of food, nutrition and health in next years.

Table 7: England tax threat policy instantaneous and dynamic effects on the recipe of drinking yogurts and drinking yogurts without non-caloric sweeteners

Dairy category	Drinking yogurt					Drinking yogurt without sweeteners				
Nutrient content	# obs	Sugar	Fat	Saturated fat	Calorie	# obs	Sugar	Fat	Saturated fat	Calorie
$DID_{EN,2016,0}$	174	0.404	-0.022	-0.016	0.269	123	-0.280	0.292***	0.063	4.714***
$DID_{EN,2017,1}$	229	-0.492***	0.376***	0.129**	5.053***	146	-0.585*	0.399***	0.290***	5.719***
$DID_{EN,2018,2}$	172	-0.817***	0.357**	0.276***	1.879***	103	-1.077***	0.622***	0.394***	3.319***
Placebo estimator										
$DID^{pl}_{EN,2016,0}$	174	1.263***	0.185	0.208	3.285	123	0.168	0.361**	0.403***	4.330**
$DID^{pl}_{EN,2017,1}$	229	0.038	-0.236	-0.142	-3.216	146	-0.061	0.106	-0.014	1.402***
$DID^{pl}_{EN,2018,2}$	172	0.010	-0.158	-0.055	-3.111	103	-0.509**	0.133	0.074	0.856
Controls										
Out-of-pocket medical expenses		Y	Y	Y	Y		Y	Y	Y	Y
Share of non-caloric sweeteners		N	Y	Y	Y					
Countries control group		FR, GE, IT, SP	FR, GE, IT	FR, GE, IT	FR, GE, IT		FR, GE, SP	FR. GE. IT	GE, IT, SP	FR, GE, IT

Notes: $DID_{EN,t,l}$ is the DID estimator comparing the evolution of the nutritional content in grams per 100 ml of drinking yogurt (in Kcal per 100 ml of drink for calorie content) from period t-l-1 to t in England, that announced a tax threat for all milk-based drink in the year t-l=2016 and in countries belonging to the countries control group (defined in the last row of table) from 2010 to year t. $DID^{pl}_{EN,t,l}$ stands for the placebo estimator that compares the mean evolution of the corresponding nutrient content in grams per 100 ml of drinking yogurt (in Kcal per 100 ml of drink for calorie content) from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{EN,t,l}$. $DID^{pl}_{EN,t,l}$ significantly different from 0 would imply that the common trends assumption is violated. # obs is the number of observations in t used to calculate $DID_{EN,t,l}$. The inclusion of the share of out-of-pocket medical expenses over total health spending or the proportion of dairy products with non-caloric sweeteners is indicated by Y; N indicates that is not included in the model. All standard errors were clustered at country level (1000 replications, not displayed). * $p<0.01$, ** $p<0.05$, *** $p<0.001$.

Table 8: England tax threat policy instantaneous and dynamic effects on the recipe of flavoured milk and flavoured milk without non-caloric sweeteners

Dairy category	Flavoured milk					Flavoured milk without sweeteners				
Nutrient content	# obs	Sugar	Fat	Saturated fat	Calorie	# obs	Sugar	Fat	Saturated fat	Calorie
$DID_{EN,2016,0}$	132	-0.044	0.160	0.228^{*}	1.924	118	-0.015	0.026	0.136^{**}	0.477
$DID_{EN,2017,1}$	149	-0.694^{***}	0.155	0.174^{**}	-1.546^{***}	141	-0.927^{***}	0.041	0.096	-3.197^{***}
$DID_{EN,2018,2}$	90	-0.692^{**}	-0.064	0.079^{***}	-3.315^{**}	79	-1.426^{***}	-0.247	-0.087	-6.880^{***}
Placebo estimator										
$DID^{pl}_{EN,2016,0}$	132	-0.674^{**}	-0.352	-0.126	-6.300^{***}	118	-0.774^{**}	-0.393^{**}	-0.156	-6.446^{**}
$DID^{pl}_{EN,2017,1}$	149	0.664^{*}	0.228	0.279^{**}	5.862	141	0.486	0.200	0.253^{**}	5.225
$DID^{pl}_{EN,2018,2}$	90	0.601^{***}	0.267	0.310	5.593	79	0.470^{**}	0.280	0.304	5.468

Notes: $DID_{EN,t,l}$ is the DID estimator comparing the evolution of the nutritional content in grams per 100 ml of flavoured milk (in Kcal per 100 ml of drink for calorie content) from period t-l-1 to t in England, that announced a tax threat for all milk-based drink in the year t-l=2016 and in countries belonging to the countries control group (France, Germany and Spain) from 2010 to year t. $DID^{pl}_{EN,t,l}$ stands for the placebo estimator that compares the mean evolution of the corresponding nutrient content in grams per 100 ml of flavoured milk (in Kcal per 100 ml of drink for calorie content) from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{EN,t,l}$. $DID^{pl}_{EN,t,l}$ significantly different from 0 would imply that the common trends assumption is violated. # obs is the number of observations in t used to calculate $DID_{EN,t,l}$. All estimations integrated the share of out-of-pocket medical expenses over total health spending. All standard errors were clustered at country level (1000 replications, not displayed). * $p<0.01$, ** $p<0.05$, *** $p<0.001$.

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Part 3: To what extent does a sugar tax improve the nutrient composition of products? A case study on sugar sweetened beverages

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Febuary, 2021

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Abstract

Objective: Assessing the effects of Sugar Sweetened Beverages tax policy implemented in France and the United Kingdom on the sugar-content time trends of newly marketed Sugar Sweetened Beverages.

Method: In this observational study we used data on the sugar content per 100ml of sugar sweetened beverages (fruit-flavoured still drinks, carbonated soft drinks, flavoured waters, and iced teas), launched in six Western European countries (France, Germany, Italy, the Netherlands, Spain and the United Kingdom) from January, 2010 to December, 2019 (10 695 observations). We mobilised a differences-in-differences empirical strategy comparing the relative change in sugar content of newly marketed soft drinks in the post-implementation period relative to the pre-implementation period among countries that had implemented the policy and those that had not.

Results: The British soft drink industry levy was successful in reducing the sugar content of newly marketed Sugar Sweetened Beverages from its announcement (-17% and -13% in 2016 and 2017, respectively) to its implementation (-31% and -21% in 2018 and 2019, respectively) relative to the year before announcement. Carbonated soft drinks were the most impacted SSB category (-9%, -10%, -16% and -20% in 2016, 2017, 2018, and 2019 from the average sugar level observed in this category in 2015, respectively). We showed that the drops resulted from a British firms' genuine effort to reduce the sugar content with no compensation to preserve the sweet taste since 2016. We also found no significant effect of the 2012 French SSB excise tax. In contrast, the 2018 French tax, a tax in tiers according to the sugar concentration of drinks akin to the British levy, brought about a reduction in the sugar content of SSB tax in 2018 but not in 2019. The effect was lower than that estimated for the United Kingdom tax (ranging from -6% to -11% in 2018). The most impacted category in France was fruit-flavoured still drinks (-14% and -15% in 2018 and 2019, respectively). We also compared the effects of SSB tax and voluntary agreements between public authorities and manufacturers involving the joint setting of reformulation objectives, implemented in the Netherlands. We found that the latter policy was not as effective as the United Kingdom tax policy in reducing the sugar content of newly marketed SSBs (8% and 13% sugar reduction in 2015 and 2016, but no significant decrease was found in subsequent years).

Conclusions: By comparing the British and the French tax effects, we can first conclude that a tax design in tiers according to the sugar concentration of drinks encourages more healthier innovations than an excise tax design. Second, the comparison of their effects over 2018-2019 suggests that the level of tax, and in particular the level of the first tier above which a tax is levied is likely to be a key factor in encouraging reductions in the sugar content of SSBs.

Limitations: The dataset used only allows us to conduct a partial evaluation of SSB tax. Only the effects of the sugar reduction policies on the innovations in the SSB sector were assessed.

Keywords: Tax impact, product sugar content, differences-in-differences method

In the previous subtask, we have shown that a PPPs policy characterized by a strong government leadership and pressure; an involvement of a large number of manufacturers; the publication of guidelines or reduction targets; and an effective monitoring and evaluation is effective. However, the level of its impact on product nutrient composition can be deemed unsatisfactory by policy makers, and thus insufficient to substantially address the public health challenges. For example in the UK, the overall sugar reduction between 2015 and 2019 was 3% where it was expected to be 20%.(1) Another alternative considered by policy makers is to adopt more stringent policies to force change in product nutrient composition, such as food tax.(3,4)

Tax has been widely implemented around the world (5) and also evaluated. Comprehensively assessing their effects is challenging. Total nutrient intakes and health outcomes must be quantified, as a result of the food industry's strategic reactions in terms of prices and health profiles of products, and consumer reactions in terms of consumption choices (including products not targeted by the policies).(6,7) Food taxes introduced in jurisdictions around the world appear to have been effective in reducing the purchases of the products targetted by the tax and dietary intakes,(8–11) as a consequence of the increase in prices of taxed beverages, although the degree to which these taxes are passed-through onto product consumer prices can vary depending on the type of retailer (12), product (13,14) and package size.(13) However evaluations on their impact on the nutrient composition of food are still limited.(15,1,16)

The main objective of this subtask is to assess the extent to which the effects of the tax can influence firms to improve the nutient composition of their products and to determine which tax design and/or levers are most effective in achieving this goal. Their identification is crucial. Depending on them, companies can strategically react more or less to the tax and so amplify or weaken its impacts.

We propose to achieve our goal by assessing the ex-post effects of sugar-sweetened beverage tax. Sugar-sweetened beverages (SSB), as one of the main contributors to sugar intake among children and adolescents, are often taxed.(5) The percentage of SSBs' contribution to total sugar intakes was 7% (11%) for children aged 1 to 10 (11 to 17) in France;(17) 21% (33%) for children aged 4 to 10 (11 to 18) years in the United Kingdom;(18) 17% for children aged 13 to 17 in Spain;(19) 21% (25%) for boys (girls) aged 7 to 18 in the Netherlands;(20) 5% (8%) for boys (girls) aged 10 to 18 in Italy.(21) Furthermore, their consumption is associated with an increased risk of weight gain,(22–24) obesity(25) and incidence of type 2 diabetes.(26–28) These two arguments explain why SSB tax has been largely recommended to reduce sugar consumption as an effective intervention to curtail the modifiable risk factors for non-communicable diseases. (29,30)

The objective of this study was to evaluate and compare the effects of SSB taxes currently in force in Western European countries on the sugar content time trends of newly marketed SSBs from 2010 to 2019. We also compared its effects with those of another policy that has also received singular attention from public health authorities to encourage improvement in product nutrient composition: PPPs policy. In that respect, we have compared the differences in these trends between Western European countries exploiting both cross-sectional (arising from the presence or the absence of the tax between countries) and time (arising from the difference in the date of implementation of the policy) variations. Comparing the effects of tax implemented in the United Kingdom and France also allowed us to provide guidance to policymakers in designing effective policies and evaluating them.

Achieving our goal requires collecting precise data on SSBs on the market (including new, existing, and removed ones) and their sugar content over time at brand level.(16,31) Such branded food databases have been developed in some countries (32) but too few follow changes over time to allow a comprehensive evaluation and comparison of their effects across countries. We overcome this insufficiency by focusing our assessment on new SSBs launched in the market for which a database with an harmonised methodology across countries and over time exists: Mintel GNPD databases.(33) The Mintel GNPD branded food databases is the only database that collects detailed information over time, including nutrition facts, of products innovations (i.e. new product, new variety/range extension, new packaging, new formula and relaunch), called below newly marketed SSBs, introduced in all Western European countries markets (except Iceland and Luxembourg). However, using these databases only allows us to conduct a partial evaluation of SSB tax. Only the effects on the nutrient composition of newly marketed SSBs could be assessed. Many other reactions--for example, drink industry reactions to product withdrawals, and changes in the sugar content of existing SSBs in response to sugar reduction policies--still need to be included to formulate a comprehensive evaluation. Furthermore, effects on consumers nutrient intakes cannot also be assessed in this study. Assessing these effects would imply matching branded food databases to purchase data. However, Mintel GNPD data has the key advantage of collecting nutrient composition data at the brand level in different countries from year to year in a standardised format that allows to assess and compare the effectiveness of SSBs tax, and the identification of key drivers of success to guide policymakers in designing effective tax. Furthermore, although the analysis is partial, the proposed analysis can be a credible assessment of what is occurring in the whole market if the nutrient content distribution of newly marketed products is similar to that observed when all products are considered. In Figures 1 and 2 for the United Kingdom and Figure 3 for France, we show that this assumption seems true for SSBs.

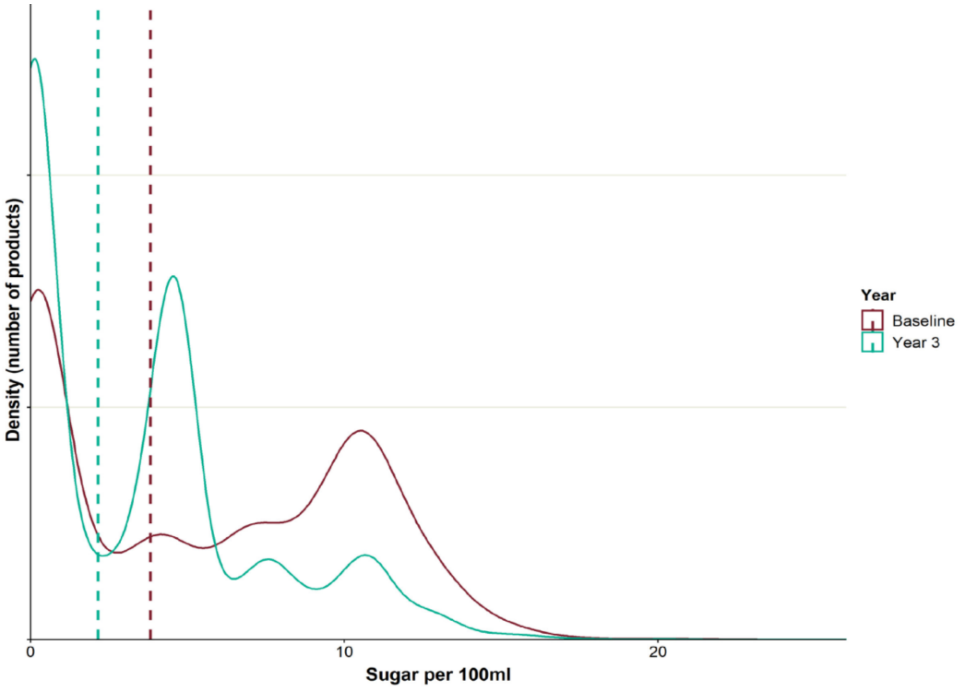
SSB tax implementation in Western European countries

Taxes on soft drinks were adopted in France and the United Kingdom but at different time periods and with different designs.

The French tax is a tax on manufacturers and importers of soft drinks. It covers all sweetened drinks, including those with artificial sweeteners and drinks sold as powders. Milk based drinks and drinks containing >1.2% alcohol (0.5% for so-called non-alcoholic beers) are exempt from the tax. A first design of the tax was implemented in 2012. It was an excise tax with a flat tax of € 7.53 cents per litre. This tax was redesigned in July 2018 as a tiered tax rate that varies according to the sugar concentration of SSBs, to further incentivise reformulations of their sugar levels. Since this date, the tax has been € 3.11 cents per litre for products containing less than 1g of added sugar per 100ml and progressively increases to almost € 24 cents per litre for products containing 15g of added sugar per 100ml, and € 0.20 per each gram per 100ml added above 15g.(34).

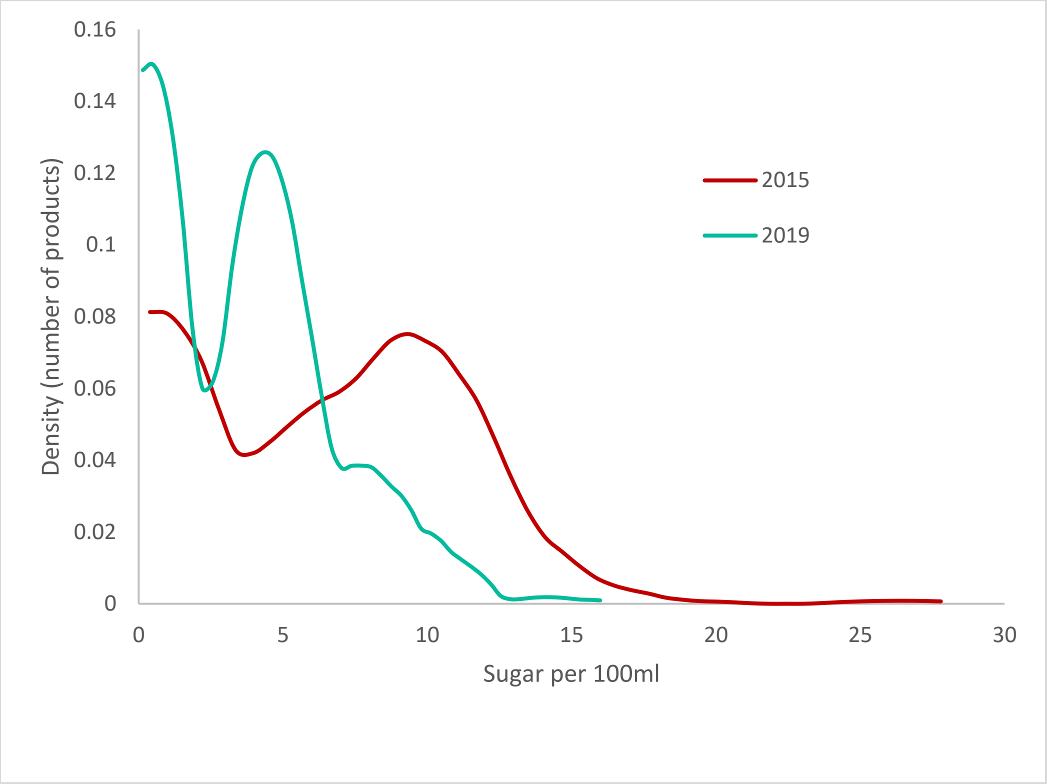
In 2016, the United Kingdom Treasury announced the introduction of a sugar tax on any packaged soft drinks with added sugar, officially named the "Soft Drinks Industry Levy" (SDIL).(36,37) The tax came into effect on 6 April 2018. This two-years delay between announcement and implementation allowed time for businesses to respond by reformulating drinks, reducing product sizes, or removing and/or introducing products from and/or to the marketplace. Milk based drinks (at least 75% milk), pure fruit juices, drinks sold as powders and drinks containing >1.2% alcohol by volume are exempt from the tax. The SDIL is a tax on manufacturers and importers of soft drinks in tiers according to the sugar concentration of drinks. The tax has two tiers: a lower rate of £ 0.18 per litre for beverages containing more than 5g sugar per 100ml; and a higher rate of £ 0.24 for those above 8g sugar per 100ml. Drinks with less than 5 g sugar per 100 mL are not levied (no levy tier). These rates were announced in March 2016 but not confirmed until February 2017 in a prebudget statement. Figure 4 provides a graphical comparison of the tax levels with respect to the sugar content for the United Kingdom and the two French tax designs.

Figure 1: Number of drinks subject to the Soft Drinks Industry Levy purchased by total sugar per 100ml for baseline (2015) and year 3 (2019) for retailers and manufacturer branded products (source: PHE, 2020, fig 29)



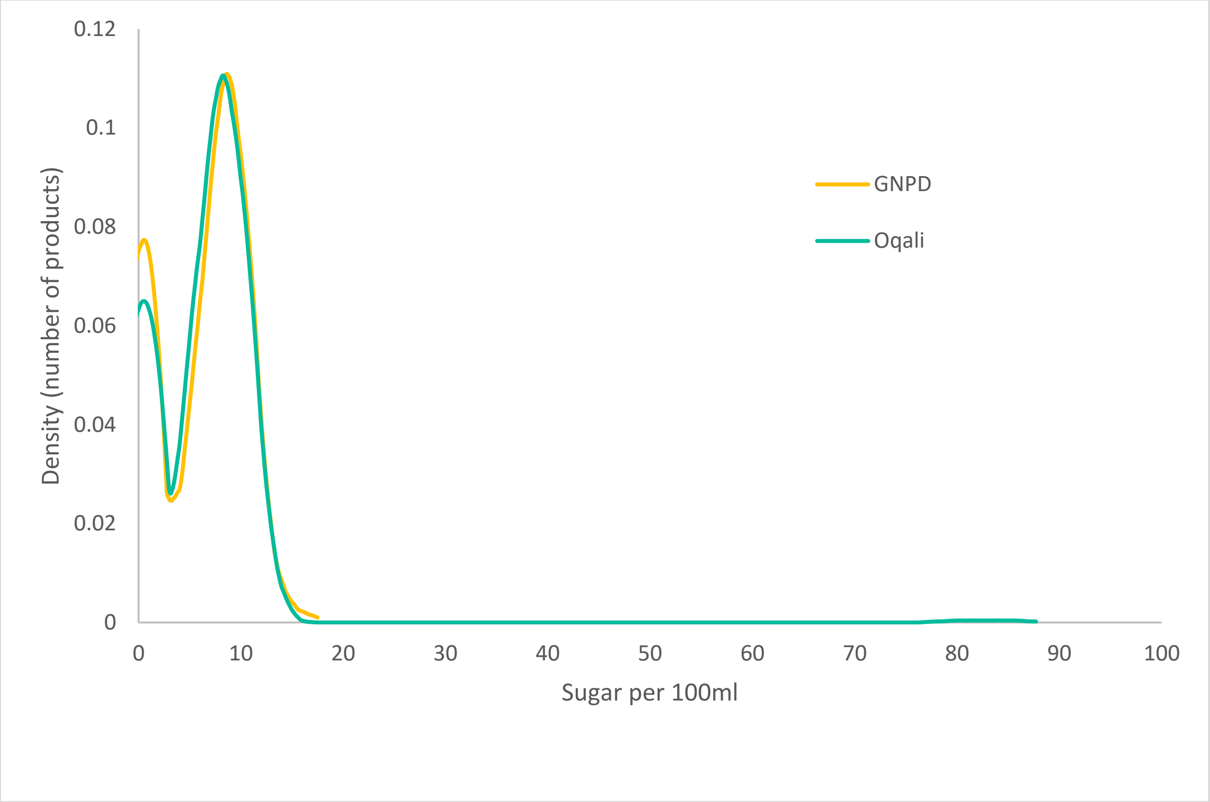
Note: Figure 1 is from the latest progress report on the sugar reduction programme implemented in the United Kingdom between 2015 and 2019.(1) It shows how the distribution of products purchased by their sugar content has changed over time. The curves show the number of products sold by their total sugar content per 100ml for baseline (2015) and year 3 (2019), and the vertical lines show the sales weighted average sugar content for the same time periods.

Figure 2: Number of SSBs subject to the Soft Drinks Industry Levy by total sugar per 100ml in 2015 (red) and 2019 (green) in the United Kingdom from GNPD database



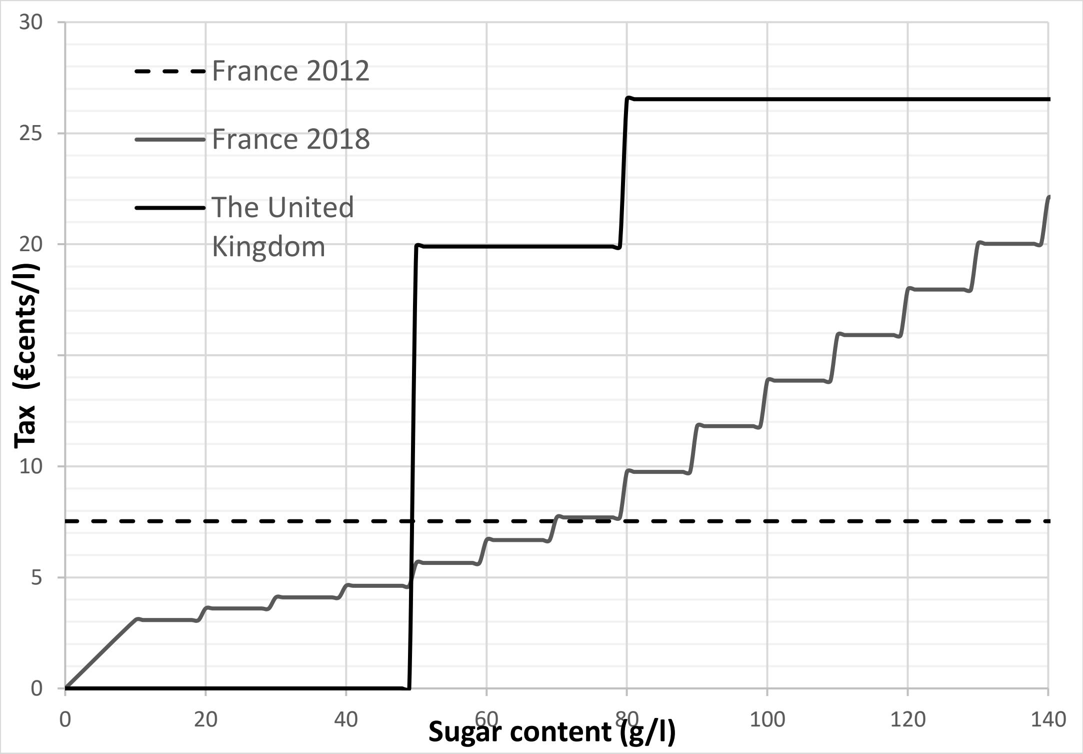
Note: Figure 2 shows the number of newly marketed SSBs subject to the Soft Drinks Industry Levy by total sugar per 100ml in the United Kingdom in 2015 and 2019 obtained from GNPD data.

Figure 3: Number of SSBs by total sugar per 100ml in France in 2013 from GNPD (yellow) and French Oqali (green) database



Note: Figure 3 shows the number of SSBs by total sugar per 100ml in France in 2013 obtained from Mintel GNPD and Oqali database. The French database Oqali collects precise data on processed food on the market (including new, existing, and removed ones).(35) Only SSBs sold in 2013 were freely available from Oqali.

Figure 4: Tax level with respect to sugar content in the French (2012 and 2018) and UK soda tax designs (in euro cents per litre)



Portugal, Norway (both in 2017) and Ireland (in 2018) also introduced a SSB tax, but due to the limited data available in the dataset used for these two countries their effects have not been assessed (see data section below). Autonomous Catalonia’s government implemented a tax on soft drinks in May 2017, but it is currently a local action.

Data and empirical strategy

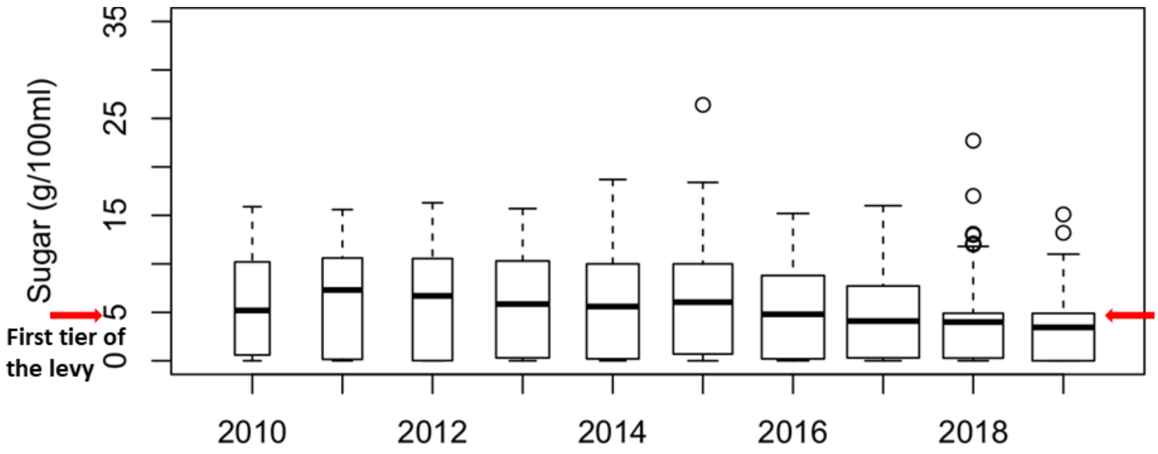
Data

The analysis was performed using information about brand level product innovations provided by the private Global New Products Database (GNPD) developed by Mintel,(38) an online database that monitors worldwide product introductions in consumer packaged good markets from year to year. It records a product when an innovation is highlighted on the package or communicated by the firm. Five types of product innovations are registered: new product, new variety/range extension, new packaging, new formula and relaunch. Below, we refer a product innovation as a newly marketed product, although a new packaging does not involve a new drink in terms of flavour, taste, and sugar content. The Mintel GNPD documents more than 80 product characteristics to classify food items (e.g., category, subcategory, distribution channel, launch type, date of introduction in the market) and information on packaging (e.g., brand, company, bar code, ingredients list, format, serving size, claims, nutritional composition). Brand level data are collected on the basis of a standardised data collection protocol involving a network of shoppers, and items are categorised into a common classification across countries. The sugar content per 100ml of products in four Mintel GNPD soft drink categories (fruit-flavoured still drinks, carbonated soft drinks, flavoured waters, and iced teas), launched in six Western European countries (France, Germany, Italy, the Netherlands, Spain and the United Kingdom) each year from January 1, 2010 to December 31, 2019, was analysed. We use the ingredients list to determine whether a SSB contains non-caloric sweeteners. Missing values were completed when available on the package images provided by Mintel GNPD; serving data were converted to a per 100ml measurement; outliers were corrected or confirmed by package images. Consistency of sugar content was also checked using energy value and carbohydrate content. Products that required reconstitution or dilution were excluded from the dataset. We limited our analysis to these Western countries because they are the countries for which the data provider had collected the largest number of soft drink observations during the period. The dataset contains information for 12,577 soft drinks, but only 10,695 have sugar content information.

Descriptive statistical analysis

Carbonated soft drink category accounted for more than 45% of newly marketed soft drinks for each country, and up to 59% for Germany (details are provided in Supplemental Table 1). The average content of all new soft drinks in the 2010--2019 period in the six studied countries was 6.02g of sugar per 100ml. Italy was the country with the highest level of average sugar content, 7.60 g/100ml. The Netherlands and the United Kingdom had the lowest average sugar content (5.30 and 4.85 g/100ml, respectively). The evolution of the sugar-content distribution of soft drinks over time in the United Kingdom is notably singular. Most of British newly marketed SSBs (above 75%) in 2018 and 2019 were under 5 g/100ml (i.e., below which no levy applies), while the first and third quartile distributions were between 0 and around 10 g/100ml for each year in the 2010--2015 period and between around 0 and 8 g/100ml in 2016 and 2017 (Figure 5). Newly marketed SSB over 8 g/100 ml accounted for only 8% of total product innovations in the sector in 2019, compared to 67% and 41% in 2010 and 2015, respectively. The levels and changes in proportion are consistent with those found in studies evaluating the UK soft drinks levy.(1,16) In contrast, no clear evolution was noticeable in other studied countries (see supplemental Figures 4--8). The sugar-content distribution by country and country/category are displayed in supplemental Tables 2 and 3. The evolutions of the average sugar content of SSBs launched every year in each country and country/category are presented in supplemental Figures 9 and 10.

Figure 5: Evolution of the sugar content distribution of newly marketed soft drinks in the United Kingdom (in g/100ml)



Empirical strategy

As SSB tax was implemented nationally, it was not possible to construct a true experimental design in France or the United Kingdom to study its effects on the sugar content of SSBs. Our identification strategy was based on a pre-post quasi experimental approach using countries in which no tax was implemented as counterfactuals, the control countries group. We used a difference-in-differences (DID) strategy to estimate tax policy's instantaneous and dynamic effects.(39) Specifically, we calculated the DID estimator of the lth dynamic effect, denoted below $DID_{c,t,l}$, that compares the evolution of the sugar content in grams per 100ml of SSBs from period t-l-1 to t in a treated country c that have announced/implemented the tax (either France or the United Kingdom) for the first time in year t-l, and in countries that have not from 2010 to year t. It provides the effect of having announced/implemented the tax for the first time l years ago. We estimated SSB tax's instantaneous $(l = 0)$ and dynamic effects $(l \geq 1)$ on the sugar content of all SSBs and for each SSB category. We also allowed for different linear trends across SSB categories, by including SSB category fixed effects. Under common trends assumption, this estimator is robust to heterogeneous and dynamic effects.(39) The supplemental materials provide additional details on the DID estimators used.

Plausibility of common trends assumption

Our strategy has the advantages and disadvantages of a DID strategy. On the one hand, it allows us to control for country, SSB category and time-period fixed effects so that all time-invariant differences across countries—such as food and beverage preferences or population health conditions (to the extent that they change slowly over time)— and soft drink categories over time were controlled for. On the other hand, the identification strategy relies on the assumption that the trends of the mean sugar content would have been the same in both the countries control groups and treated country in the absence of SSB tax. In other words, any selection bias implied by using data from Germany, Italy and Spain to build the counterfactual and not captured by the fixed effects is either constant over time, or, if it does evolve over time, the evolution is linear. It is also possible that France or the United-Kingdom and countries control group experience different evolution of SSBs sugar content over time, but the DID approach can still produce unbiased estimators provided that those differential evolutions are accounted for by the change in country's covariates. Thus, we also integrate in regressions time- and country-varying covariates that may affect SSBs sugar content. Specifically, we control for a number of time varying country characteristics that can be correlated with firms' product reformulation strategy, such as country's variable indicators of health (childhood obesity rate,(39) share of out-of-pocket medical expenses over total health spending,(40) death rate due to NCDs among populations aged 30--70 years (41) and dietary and high body mass index risks (42)); the consumer price index of mineral waters, soft drinks and fruit and vegetable juices; and the proportion of SSBs with non-caloric sweeteners in each country over time. However, health indicators except the share of out-of-pocket medical expenses, and price index were not significant in all regressions investigated. It was difficult to distinguish their effects with our DID estimation strategy given their weak variability over time. In our estimations below, the share of out-of-pocket medical expenses controlled for sugar content variations caused by changes in a country's health context. For example, if out-of-pocket medical expenses increase (i.e., the health care system becomes less protective), an individual might become more inclined to adopt health promoting habits, furthering the likelihood of their purchasing more healthful food items, which in turn might encourage firms to improve the health profile of their products. The proportion of SSBs with non-caloric sweeteners controlled for company- (aggregated at the country level) and time-varying reformulation strategies regarding the use of non-caloric sweeteners in SSBs recipes.

Unfortunately, this critical assumption is not directly testable, but to assess its plausibility, estimations can be implemented using pre-policy observations.(39,40) The assessment consists in comparing the mean evolution of the sugar content in grams per 100ml of SSBs from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{c,t,l}$: France or the United Kingdom that have announced/implemented the tax for the first time in year t-l, and countries that have not from 2010 to year t (Germany, Italy and Spain). The estimator of this comparison is the lth placebo DID estimator, denoted below $DID_{c,t,l}^{pl}$. If common trends assumption holds, then $E[DID_{c,t,l}^{pl}] = 0$. So finding an estimation of $DID_{c,t,l}^{pl}$ significantly different from 0 would imply that the common trends assumption is violated: France or the United Kingdom experienced different trends before announcement/implementation of the tax than countries belonging to the countries control group used to reconstruct France or the United Kingdom counterfactual trend when France or the United Kingdom has announced/implemented the tax. Thus, the lth placebo estimator assesses if common trends assumption holds over l+1 years, the number of years over which the assumption has to hold for the lth dynamic effect, $DID_{c,t,l}$, to be unbiased. Contrary to the standard common trends test in event-study regressions, the test is robust to heterogeneous and dynamic effects. These estimators are called long-difference estimators. They differ from the first-difference estimators, denoted $\widetilde{DID}^{pl}_{treated,t,k}$, that compare the t-k-1 to t-k outcome evolution in groups treated for the first time at year t and groups untreated from 2010 to year t, for $k \geq 1$.(40) The supplemental materials provide additional details on placebo estimators used.

All the standard errors of the estimators were computed using a block bootstrap at the country level (1000 replications). The Stata 15 module DID_multiplegt was used for all analyses.(41,42)

Results

Main results

The estimates of British SSB tax's instantaneous and dynamic effects (and their standard errors) on the sugar content of SSBs (in g/100ml) are displayed in Table 1. The countries control group was made up of Germany, Italy, and Spain for all estimations. We also allowed for different linear trends across SSB categories (columns 4 and 5). We also controlled for the share of out-of-pocket medical expenses over total health spending and the proportion of SSBs with non-caloric sweeteners in each country over time. To assess the unbiasedness of the estimates, we also computed (also reported in Table 1) the placebo estimators, $DID^{pl}_{UK,t,l}$, $l = \{0, 1, 2\}$. $DID^{pl}_{UK,2016,0}$ compares the mean evolution of the sugar content in grams per 100ml of SSBs from 2014 to 2015 in the United Kingdom that announced the tax for the first time in 2016 and countries belonging to the countries control group that have not since 2016. We also computed $DID^{pl}_{UK,2017,1}$ and $DID^{pl}_{UK,2018,2}$, the two other placebo estimators performing the same comparison but between 2013 and 2015, and 2012 and 2015, respectively. Their standard errors are also reported.

We found significant drop at 1% significance level in the average sugar content of newly marketed soft drinks as early as 2016, the year of the announcement of that tax, in all estimated models. The highest effect (-1.1 and 1.8 g/100ml in the model with no category fixed effect and with category fixed effects) was estimated in 2018 in the two models, when the British soft drink industry levy came into effect. We still found a strong and significant decrease (above -1.1 g/100ml) in 2019. These reductions relate to a 31% and 21% reduction from the average sugar level observed in 2015 in the model with category fixed effects (19% and 18% in with no category fixed effect). We also found that all placebo estimators are insignificant in both regression models, meaning that the common trends assumption is not rejected.

We also estimated the effects of the SSB tax implemented in France in 2012 (see supplemental Table 4). No statistically significant decrease in the average sugar content of newly marketed soft drinks in France was found in 2012. We also found that the common trends assumption is not rejected when no category fixed effects were considered, at 5% significance level. We also estimated the dynamic effects of the tax, $DID_{FR,2013,1}$, $DID_{FR,2014,2}$, and $DID_{FR,2015,3}$. Although, it was not possible to test the plausibility of the common trends assumption for these estimators, due to the absence of data before 2010, we found significant increases in the sugar content of SSBs in 2013, 2014 and 2015 if no category fixed effects is considered. However, the significance of these estimates was not confirmed if SSB category fixed effects are included in the regression model. Overall, our results indicate that the French SSB tax implemented in 2012 has not encouraged the formulation of more healthful innovations in the SSB sector.

Table 1: British SSB tax's instantaneous and dynamic effects on the sugar content of SSBs (in g/100ml), and placebo estimators of the common trends assumption

	# obs	Estimate	Standard error	Estimate	Standard error
$DID_{UK,2016,0}$	979	-0.793***	0.058	-0.999***	0.045
$DID_{UK,2017,1}$	1070	-0.741***	0.093	-0.774***	0.236
$DID_{UK,2018,2}$	799	-1.107***	0.125	-1.811***	0.545
$DID_{UK,2019,3}$	839	-1.089***	0.233	-1.215***	0.461
Placebo estimator					
$DID^{pl}_{UK,2016,0}$	979	0.090	0.076	0.169	0.221
$DID^{pl}_{UK,2017,1}$	1070	0.132	0.169	0.325	0.404
$DID^{pl}_{UK,2018,2}$	799	0.038	0.154	0.633	0.459
Fixed effects					
Category		N		Y	

Notes: $DID_{UK,t,l}$ is the DID estimator comparing the evolution of the sugar content in grams per 100ml of SSBs from period t-l-1 to t in the United Kingdom, that announced the tax in the year t-l=2016 and in countries belonging to the countries control group (Germany, Italy, and Spain) from 2010 to year t. $DID^{pl}_{UK,t,l}$ stands for the placebo estimator that compares the mean evolution of the sugar content in grams per 100ml of SSBs from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{UK,t,l}$. $DID^{pl}_{UK,t,l}$ significantly different from 0 would imply that the common trends assumption is violated. # obs is the number of observations in *t* used to calculate $DID_{UK,t,l}$. The inclusion of SSB category fixed effects is indicated by Y; N indicates that is not included in the model. All estimations integrated the share of out-of-pocket medical expenses over total health spending and the proportion of SSBs with non-caloric sweeteners in each country over time. All standard errors were clustered at country level (1000 replications). * p<0.01, ** p<0.05, *** p<0.001.

Table 2 displays the estimated instantaneous effect and its standard error, $DID_{FR,2018,0}$, and the effect one year after the implementation, $DID_{FR,2019,1}$, of the 2018 French SSB tax on the sugar content of SSBs (in g/100ml). As in Table 1, we also reported results when SSB category fixed effects are considered (columns 4 and 5). The share of out-of-pocket medical expenses over total health spending and the proportion of SSBs with non-caloric sweeteners in each country over time were no significantly different from zero, and so they were not integrated in models considered. We assumed that our estimates of 2018 SSB tax's effects were not affected by the first SSB tax design. It does not seem to be a strong assumption given we found no significant reduction in the sugar content of SSBS from 2012 to 2015. All estimations were conducted using a countries control group made up with Germany, Italy, and Spain. We found significant instantaneous drops in the average sugar content of newly marketed soft drinks in both regression settings (ranging from -0.371 to -0.735 g/100ml or from -6% to -11% drop in sugar levels from the average sugar content observed in 2017). However, the reduction was not confirmed one year after the implementation of the tax. It was not possible to calculate the long-difference placebo estimator since our data end in 2019, one year after the second French tax implementation. To assess the plausibility of common trends assumption, we computed the first-difference placebo estimators, $\widetilde{DID}^{pl}_{FR,t=2018,k}$ for $k = \{1, 2\}$. It compares the mean evolution of the sugar content in grams per 100ml of SSBs from t-k-1 to t-k in France and countries belonging to the countries control group. The placebo estimators $\widetilde{DID}^{pl}_{FR,2018,1}$ are small and insignificant at 5% significance level in the two models, so the common trends assumption seems to hold from 2016 to 2017. However, $\widetilde{DID}^{pl}_{FR,2018,2}$ is significant at 10% significance level when soft drink category fixed effects were considered. We also implemented a joint test that all placebo estimators are equal to 0. We also found that the null hypothesis is not rejected. The p-values were equal to 0.27 and 0.17 in models without fixed effect and with category fixed effects, respectively. All these results suggest that our estimates of 2018 SSB tax effects would be unbiased.

Table 2: French 2018 SSB tax's instantaneous and dynamic effects on the sugar content of SSBs (in g/100ml), and placebo estimators of the common trends assumption

	# obs	Estimate	Standard error	Estimate	Standard error
$DID_{FR,2018,0}$	764	-0.735***	0.246	-0.371***	0.034
$DID_{FR,2019,1}$	764	0.049	0.193	0.656	0.497
Placebo estimator					
$\widetilde{DID}^{pl}_{FR,2018,1}$	764	-0.072	0.075	0.291	0.198
$\widetilde{DID}^{pl}_{FR,2018,2}$	764	0.296	0.225	0.659*	0.364
Fixed effects					
Category		N		Y	

Notes: $DID_{FR,t,l}$ is the DID estimator comparing the evolution of the sugar content in grams per 100ml of SSBs from period t-l-1 to t in the France, that implemented a new design of the tax in the year t-l=2018 and in countries belonging to the countries control group (Germany, Italy, and Spain) from 2015 to year t. $\widetilde{DID}^{pl}_{FR,t=2018,k}$ for k={1,2} stands for the first-difference placebo estimator that compares the mean evolution of the sugar content in grams per 100ml of SSBs from *t-k-1* to *t-1* in the two sets of groups used to calculate $DID_{FR,t,0}$. $\widetilde{DID}^{pl}_{FR,t,k}$ significantly different from 0 would imply that the common trends assumption is violated. # obs is the number of observations in *t* used to calculate $DID_{FR,t,l}$. The inclusion of SSB category fixed effects is indicated by Y; N indicates that is not included in the model. All standard errors were clustered at country level (1000 replications). * p<0.01, ** p<0.05, *** p<0.001.

We also estimated the effects of the tax on the sugar content of each SSB category. Results are reported in Table 3 for the United Kingdom. The effects of the levy on iced tea category were not estimated given their limited number in the United Kingdom over the period (15, 24 and 19 in 2016, 2017 and 2018, and 2019 for iced tea category, respectively). Table 3 follows the same structure as Table 1, except that we have no fixed effect. All estimations integrate the share of out-of-pocket medical expenses over total health spending and the proportion of SSBs with non-caloric sweeteners in each country over time. The countries control group was made up of Germany, Italy, and Spain for all estimations. We found a 13% significant reduction in the sugar content of fruit-flavoured still drinks only in 2016 (compared to the average sugar content observed in the category in 2015). The tax has also encouraged companies to reduce the sugar content of flavoured waters, but only in 2019 (-0.53 g/100ml or a 22% reduction from the average sugar level observed in the category in 2015). In contrast, we estimated significant drops in the carbonated soft drinks sugar content for each after tax announcement. The reduction was the strongest in

2019. We assessed a drop in their sugar content equal to -1.04 and -1.28 g/100ml in 2018 and 2019, respectively. These reductions relate to 16% and 20% reductions from the average sugar level observed in the category in 2015. The null hypothesis that common trends assumption holds was not rejected for carbonated soft drinks and flavoured water. The placebo estimators are all not significantly different from zero. However, the unbiasedness of tax policy's dynamic effects $DID_{UK,2017,1}$ can be questioned, for fruit-flavoured still drinks, although that its estimate was not significant.

The effects of the implementation of the 2012 French SSB tax could only be estimated for carbonated soft drinks, given the limited number of observations collected by GNPD for fruit-flavoured still drink, flavoured water and iced teas categories in France in 2012. No statistically significant decrease over time in the average sugar content of carbonated soft drinks was found (see supplemental Table 5). The effects of the implementation of the second design of the French SSB tax for fruit-flavoured still drink, carbonated soft drink and iced tea categories are reported in Table 4. The effects of the tax on flavoured water category are not reported given their limited number in France over the period (25 and 22 in 2018 and 2019, respectively). Table 4 follows the same structure as Table 2, except that we have no fixed effect. The countries control group was made up of Germany, Italy, and Spain for all estimations. Estimations for iced tea category integrated the share of out-of-pocket medical expenses over total health spending and the proportion of SSBs with non-caloric sweeteners in each country over time. Estimations for fruit-flavoured still drinks and carbonated soft drinks did not integrate these control variables. They were no significantly different from zero for these two categories.

A decreasing trend of the sugar content emerged for the newly marketed fruit-flavoured still drinks. We found significant decreases found both in 2018 and 2019, at 1% significance level. The fall was even stronger in 2019, the second year of the implementation of the tax. We estimated a 14% and 15% reduction in their sugar content from the average sugar level observed in the category in 2017 (-1.17 and -1.22 g/100ml in 2018 and 2019, respectively). We estimated an almost similar significant reduction (at 1% significance level) in carbonated soft drinks sugar content only in 2018 (-12% from the average sugar level observed in the category in 2017). For the category of iced tea, significant drops were found in 2018, at 10% significance level. The reduction relates to 16% in sugar content from the average sugar level observed in the category in 2017.

As in Table 2, we also computed first-difference placebo tests. The placebo estimators $\widetilde{DID}^{pl}_{FR,2018,1}$ and $\widetilde{DID}^{pl}_{FR,2018,2}$ were all insignificant at 5% significance level. All these results suggest that our estimates of SSB tax effects would be unbiased.

Table 3: British SSB tax's instantaneous and dynamic effects on the sugar content of each SSB category (in g/100ml), and placebo estimators of the common trends assumption

SSB category	Fruit-flavoured still drink			Carbonated soft drink			Flavoured water		
	# obs	Estimate	Standard error	# obs	Estimate	Standard error	# obs	Estimate	Standard error
$DID_{UK,2016,0}$	207	-0.841***	0.105	530	-0.676***	0.102	88	-0.175	0.542
$DID_{UK,2017,1}$	185	-0.077	0.346	596	-0.609***	0.196	125	-1.071	1.046
$DID_{UK,2018,2}$	148	0.088	0.657	432	-1.038***	0.387	87	-0.665	1.017
$DID_{UK,2019,3}$	126	-0.488	0.435	463	-1.280***	0.141	111	-0.533***	0.184
Placebo estimator									
$DID^{pl}_{UK,2016,0}$	207	-0.072	0.359	530	-0.356	0.233	88	0.413	0.382
$DID^{pl}_{UK,2017,1}$	185	0.470*	0.248	596	0.071	0.346	125	-0.848	0.705
$DID^{pl}_{UK,2018,2}$	148	-0.320	0.295	432	0.194	0.190	87	0.139	0.295

Notes: $DID_{UK,t,l}$ is the DID estimator comparing the evolution of the sugar content in grams per 100ml of SSBs from period t-l-1 to t in the United Kingdom, that announced the tax in the year t-l=2016 and in countries belonging to the countries control group (Germany, Italy, and Spain) from 2010 to year t. $DID^{pl}_{UK,t,l}$ stands for the placebo estimator that compares the mean evolution of the sugar content in grams per 100ml of SSBs from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{UK,t,l}$. $DID^{pl}_{UK,t,l}$ significantly different from 0 would imply that the common trends assumption is violated. # obs is the number of observations in t used to calculate $DID_{UK,t,l}$. All estimations integrated the share of out-of-pocket medical expenses over total health spending and the proportion of SSBs with non-caloric sweeteners in each country over time. All standard errors were clustered at country level (1000 replications). * p<0.01, ** p<0.05, *** p<0.001.

Table 4: French 2018 SSB tax's instantaneous and dynamic effects on the sugar content of each SSB category (in g/100ml), and placebo estimators of the common trends assumption

SSB category	Fruit-flavoured still drink			Carbonated soft drink			Iced tea		
	# obs	Estimate	Standard error	# obs	Estimate	Standard error	# obs	Estimate	Standard error
$DID_{FR,2018,0}$	132	-1.168***	0.239	399	-0.861***	0.381	177	-0.793*	0.457
$DID_{FR,2019,1}$	130	-1.224***	0.314	374	0.292	0.337	192	-0.051	0.297
Placebo estimator									
$\widetilde{DID}^{pl}_{FR,2018,1}$	132	0.597	0.631	399	0.402	0.261	177	0.160	0.210
$\widetilde{DID}^{pl}_{FR,2018,2}$	132	-0.181	0.399	399	0.363	0.319	177	0.087	0.306

Notes: $DID_{FR,t,l}$ is the DID estimator comparing the evolution of the sugar content in grams per 100ml of SSBs from period t-l-1 to t in France, that implemented a new design of tax in the year t-l=2018 and in countries belonging to the countries control group (Germany, Italy, and Spain) from 2015 to year t. $\widetilde{DID}^{pl}_{FR,t=2018,k}$ for k={1,2}stands for the first-difference placebo estimator that compares the mean evolution of the sugar content in grams per 100ml of SSBs from t-k-1 to t-1 in the two sets of groups used to calculate $DID_{FR,t,0}$. $\widetilde{DID}^{pl}_{FR,t,k}$ significantly different from 0 would imply that the common trends assumption is violated. # obs is the number of observations in t used to calculate $DID_{FR,t,l}$. Estimations for iced tea category integrated the share of out-of-pocket medical expenses over total health spending and the proportion of SSBs with non-caloric sweeteners in each country over time. All standard errors were clustered at country level (1000 replications). * p<0.01, ** p<0.05, *** p<0.001.

Effects of the SSB tax on the sugar content of newly marketed SSBs without non-caloric sweeteners

We investigated to what extent the drops found in France and the United Kingdom resulted from a total or partial replacement of sugar by non-caloric sweeteners or from a firms' voluntary effort to reduce the sugar content with no compensation to preserve the sweet taste. The analysis was done by restricting the data to soft drinks without non-caloric sweeteners. We integrated in all estimations the share of out-of-pocket medical expenses over total health spending.

The British levy has encouraged firms the formulation of SSBs with lower sugar content. The reductions in the sugar content of SSBs found in Table 1 are all validated (see supplemental Table 6). However, the effects of the levy in magnitude are much higher and steadily increased from 2016 to 2019 (-1.32, -1.99, -2.70 and -3.11 g/100ml in 2016, 2017, 2018 and 2019, respectively). These variations relate to a 14%, 21%, 28% and 32% sugar reduction in 2016, 2017, 2018 and 2019, respectively, from the average sugar content level of SSBs without non-caloric sweeteners in 2015.

Regarding the effects by soft drink category in the United Kingdom, the effects of both the announcement and the introduction of the levy are now confirmed for fruit-flavoured still drinks and carbonated soft drinks (see supplemental Table 6 for all results). The former category experienced a sugar reduction in 2016, 2018 and 2019. Furthermore, the drops were much stronger than the one obtained when all fruit-flavoured still drinks were considered: We estimated 17%, 23% and 31% reductions in the sugar content of the category in 2016, 2018 and 2019, respectively, from the average sugar content level of fruit-flavoured still drinks without non-caloric sweeteners in 2015. The latter category would have experienced 10%, 16%, 24%, and 34% reductions in sugar content in 2016, 2017, 2018, and 2019, respectively, compared to the average sugar content of carbonated soft drinks without non-caloric sweeteners in 2015. The placebo estimators are all insignificant at 5% significance level, except $DID_{UK,2016,0}^{pl}$ for fruit-flavoured still drinks. The effects of the levy on iced tea and flavoured water categories were not estimated given their limited number of observations registered in the United Kingdom (for the former, 11, 21, 11 and 10 in 2015 and 2016, 2017, 2018, and 2019, respectively; and for the latter 10, 25, and 21 in 2015, 2016, and 2018, respectively). Overall, the results indicated that the SSBs sector in the United-Kingdom has made a significant effort in reducing the sugar content of soft drinks by limiting the use of non-caloric sweeteners to preserve their sweet taste.

The drops found in Table 2 for France could not be validated. We did not find a regression setting and/or a countries control group for which the common trends assumption was met. Supplemental Table 7 presents the coefficient estimates for fruit-flavoured still drink, carbonated soft drink and iced tea categories. The effects of the tax on flavoured water category are not reported given their limited number in France over the period. We no longer found significant reduction in the sugar content of fruit-flavoured still drinks. This result suggests that French companies have replaced sugar by non-caloric sweeteners to preserve sweet taste in response to the tax. No significant effect was now obtained for carbonated soft drinks. Whereas the estimated reduction in the sugar content of iced teas was higher in 2018 (-1.22 g/100ml or a 23% reduction from the average sugar content level of iced teas without non-caloric sweeteners in 2017). However, the effect in 2019 was no longer significant

Tax effects magnitude in comparison with public-private partnerships policy

Tax is not the unique policy that has received singular attention from public health authorities to encourage change in the nutrient composition of products. Public-private partnerships (PPPs) policy was also deemed a promising action in that respect.(43–47) They are voluntary agreements between public authorities and manufacturers involving the joint setting of reformulation objectives to improve the nutritional quality of their products. They are potentially less tight since based on voluntary commitments, which has made them a more attractive option for manufacturers.

A PPP policy to reduce sugar content in SSBs have been deployed in the Netherlands in 2014.(48) Dutch health authorities have concluded agreements with the entire soft drinks sector to define percentage-calorie-reduction targets for a designated period. They were published in 2015. Specifically, the signatories of the soft drink sector have committed to decrease SSBs' contribution to children's total energy intake by 10%, and by an additional 5% by 2020. The progress made in improvements to SSBs composition is monitored at the product level by the Dutch National Institute for Public Health and the Environment (RIVM) using the food database LEDA as a basis. Such structured programmes to reduce sugar content in SSBs have also been deployed in France in 2014,(49) and in Spain in 2018.(50) However, the French public authorities did not define the sugar reduction guidelines and no progress monitoring was planned; and only a limited involvement of the beverage sector was achieved by Spanish health authorities.

The estimates of Dutch PPPs policy's instantaneous and dynamic effects (and their standard errors) on the sugar content of SSBs (in g/100ml) are displayed in Table 5. The countries control group was made up of Germany, Italy and Spain for all estimations. We also allowed for different linear trends across SSB categories (columns 4 and 5). We integrated in all estimations the share of out-of-pocket medical expenses over total health spending. To assess the plausibility of the common trends assumption, we also reported the placebo estimators. We only get significant estimations when we consider category fixed effects. We found a slight significant increase in the sugar content of SSBs in 2014, when consultations were held with SSBs operators and public health authorities. However, we estimated significant reductions in sugar content in 2015 (at 1% significance level), when the agreements were published, and in 2016 (at 10% significance level). This relate to 8% and 13% reductions in sugar content in 2015 and 2016, respectively, compared to the average sugar content of SSBs in the Netherlands in 2013. No significant decrease was found in subsequent years.

$DID^{pl}_{DU,201,0}$ are highly significant in the two regression settings, meaning that the Netherlands has experienced a differential pretrend from 2012 to 2013 than those in Germany, Italy and Spain. Our estimates of the instantaneous effect are biased. On the other hand, our estimates of $DID^{pl}_{DU,2015,1}$ and $DID^{pl}_{DU,2016,2}$ are insignificant. These tests indicate that parallel trends holds over 2 and 3 years. Our estimates of $DID_{DU,2015,1}$ and $DID_{DU,2016,2}$ would be unbiased. The robustness of the estimates of the 3rd, 4th, and 5th effects cannot be tested due to the absence of data before 2010. We found no significant variation in the sugar content of carbonated soft drink. The effects of the Dutch PPPs policy on the sugar content of the other three categories were not estimated given the limited number of observations for each category. Estimations with fixed effects suggest that Dutch PPPs policy's was not as effective as the United Kingdom tax policy in reducing the sugar content of newly marketed SSBs.

Table 5: Dutch SSB tax’s instantaneous and dynamic effects on the sugar content of SSBs (in g/100ml), and placebo estimators of the common trends assumption

	# obs	Estimate	Standard error	Estimate	Standard error
$DID_{DU,2014,0}$	670	0.257	0.154	0.276***	0.058
$DID_{DU,2015,1}$	938	-0.645	0.409	-0.467***	0.133
$DID_{DU,2016,2}$	771	-1.101	0.823	-0.745*	0.412
$DID_{DU,2017,3}$	787	-1.065	0.818	-0.543	0.411
$DID_{DU,2018,4}$	651	-0.938	0.892	-0.246	0.580
$DID_{DU,2019,5}$	678	-0.668	0.940	0.264	0.748
Placebo estimator					
$DID^{pl}_{DU,2014,0}$	670	1.041***	0.327	1.058***	0.388
$DID^{pl}_{DU,2015,1}$	938	0.161	0.387	0.101	0.338
$DID^{pl}_{DU,2016,2}$	771	-0.001	0.483	-0.268	0.530
Fixed effects					
Category		N		Y	

Notes: $DID_{DU,t,l}$ is the DID estimator comparing the evolution of the sugar content in grams per 100ml of SSBs from period t-l-1 to t in the Netherlands, that public-private partnerships to reduce SSBs sugar content in the year t-l=2014 and in countries belonging to the countries control group (Germany, Italy, and Spain) from 2010 to year t. $DID^{pl}_{DU,t,l}$ stands for the placebo estimator that compares the mean evolution of the sugar content in grams per 100ml of SSBs from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{DU,t,l}$. $DID^{pl}_{DU,t,l}$ significantly different from 0 would imply that the common trends assumption is violated. # obs is the number of observations in t used to calculate $DID_{DU,t,l}$. All estimations integrated the share of out-of-pocket medical expenses over total health spending. The inclusion of SSB category fixed effects is indicated by Y; N indicates that is not included in the model. All standard errors were clustered at country level (1000 replications). * p<0.01, ** p<0.05, *** p<0.001.

Conclusion

This study assessed and compared the impact of SSBs tax on the sugar content of newly marketed SSBs in France and the United Kingdom. We used a DID empirical strategy using Germany, Italy and Spain as countries control group to achieve our goal.

We found that the UK soft drink industry levy was successful in improving the health profile of newly marketed SSBs. The average sugar content of soft drinks continued to significantly decrease from the year of tax announcement (2016) to 2019. The highest effects, -1.8 g/100ml (a 31% reduction relative to observed average sugar content in the year before announcement), were estimated in 2018 when the levy came into effect. This decreasing trend was mainly due to the reductions in the sugar content of carbonated soft drinks. They have been the most impacted SSB category since 2016. We also found that the drops found in the United Kingdom have resulted from a firms’ genuine effort to reduce the sugar content with no compensation to preserve the sweet taste in SSBs since 2016. It was particularly the case for carbonated soft drinks and fruit-flavoured still drinks. We found no significant effect of the 2012 French SSB excise tax. In contrast, the 2018 French tax brought about a reduction in the sugar content of SSB tax in 2018 but not in 2019. The estimated effect in 2018 was lower than that found in the United Kingdom (ranging from -6% to -11% in 2018, relative to observed average sugar content in the year before implementation). Nevertheless, significant drops in the sugar content of fruit-flavoured still drinks were found in both 2018 and 2019. We estimated 14% and 15% reductions in their sugar content in 2018 and 2019, respectively from the average sugar level observed in the category in 2017. We also found that PPPs policy is not as effective as the United Kingdom SSB tax. We found that the effects of the Dutch voluntary sugar reduction policy resulted in an average reduction in the SSBs sugar content equal to 13% in 2016, but the effects were not persistent in subsequent years.

Comparison with other studies

Our results are consistent, although our estimated effects are lower, with those obtained in the two existing evaluations of the impact of the SDIL on SSBs sugar content. To the best of our knowledge, there is still no such evaluation for the French tax. PHE in their assessment of the SDIL found a 44% reduction in sales-weighted average total sugar content between 2015 and 2019.(1) A separate analysis, using data collected from UK supermarket websites, found a 38% reduction from average levels in September through December 2015.(16) The latter study also found a gradual and accelerating significant trend in the reduction of the proportion of drinks on sale that were over the lower levy threshold (5g/100ml sugar) over 2015-2019 period. In February 2019, the proportion of levy-eligible soft drinks had fallen by 34 percentage points. Our equivalent analysis found a 17 or 13 percentage points reduction in the percentage of SSBs over the lower levy sugar threshold in 2019 (see supplemental Table 9). We estimated that 62% of this decline came from an increase in the number of SSBs with a sugar content between 4.5 and 5.0 g per 100 ml, suggesting that many manufacturers have chosen to make soft drinks just below this threshold.

Despite these similarities in results, the two previous studies differ from ours in three important aspects. First, they considered all SSBs covered by the SDIL, not just new beverages in the market. However, we have shown that newly marketed SSBs are relevant to explain changes in sugar content observed in the SSBs sector: the distributions of sugar content in newly marketed beverages were almost similar to those of all marketed SSBs for both the United Kingdom and France. Second, the results were sales-weighted average for PHE’s analysis. So, we were not able to estimate the impact of our estimated changes on sugar consumption. Third, the identification methods were different (comparison between average outcomes in 2019 and the baseline year 2015 (1) and controlled interrupted time series analysis (16)). Our approach is a quasi-experimental approach. We also compared the effects of the tax with PPPs policy ones. We also provided the effects of the tax for each SSBs category. We extended their analysis by first providing a comparison of French and the United Kingdom tax effects using not only a database with a harmonised data collection methodology and SSBs classification across countries, but also the same statistical method.

Policy implications

Overall, the UK soft drink industry levy design seems to have been the most efficient in favouring lowered sugar innovations in the SSB sector. By comparing the British and the French tax effects, we can first conclude that a tax design in tiers according to the sugar concentration of drinks encourages more healthier innovations than an excise tax design, as demonstrated in other studies.(51,52) Second, the comparison of their effects over 2018-2019 suggests that the levels of the tiers are critical to encourage healthier innovations. The level of the first tier above which a tax is levied is likely to be a key factor in encouraging a reduction in the sugar content of SSBs. The relatively low level of the French tax may explain its lower impact than that found for the British levy.

The study also suggests that PPPs policy is not as effective as tax. Although we cannot explain why and draw recommendations for the design of this policy, we can point out that the Dutch PPPs policy meets the key conditions of success identified in several studies: a strong government leadership and pressure; the involvement of a large number of manufacturers; the publication of guidelines or reduction targets; and an effective monitoring and evaluation.(6,53,54)

Limitations

We must acknowledge that the effects of the United Kingdom SSBs tax could also be partly imputed to the PPPs policy launched in England in 2016, the childhood obesity plan. It challenges all sectors of the food industry to reduce the amount of sugar in the foods that contribute most to children’s intakes by 20% by 2020. Although no guidelines were published for soft drinks in it, the plan may have indirectly affected the drinks industry. It may have created an incentive environment that has encouraged SSBs sugar reductions. However, we could not assess whether and to what extent it has strengthened sugar reduction for SSBs.

Only a partial evaluation of food policies was possible with Mintel GNPD data. Although we think that the proposed method can be applied to comprehensively assess the effects of a tax on the nutrient composition of products, only the effects on the sugar content of newly marketed SSBs could be assessed. Many other reactions--for example, drink industry reactions to product withdrawals, and changes in the health profiles of existing products in response to sugar reduction policies--still need to be included to formulate a comprehensive evaluation. Assessing such factors would involve collecting nutrient composition data at the product or brand level in different countries from year to year in a standardised format. This would allow us to follow the complete food supply evolution resulting from product removals, roll out of new products and reformulation of already existing products. It is also crucial to analyse how firms adjust their prices in response to sugar reduction policies, which in turn strongly conditions consumer reaction. Effects on consumers were also not assessed in this study, nor did we evaluate how changes in the drink supply might have improved a population’s diet. Assessing these effects would imply matching branded food databases to purchase data or, ideally, consumption data. Given the acknowledged central role of the food supply in the causation of chronic diseases, nutrient composition data collection for branded foods in different countries, from year to year, matched to individuals’ purchases or consumption data, based on a similar data collection and food classification, to allow powerful comparisons and objective monitoring of product changes and individuals’ nutrient intakes over time should be a priority for academics, stakeholders and private users active in the area of food, nutrition and health in next years.

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General Conclusion

Children in the Western world are currently consuming more sugar than is recommended. Its contribution to the total energy intake is largely above the 10% of total energy intake recommended by the WHO. This excessive consumption can have severe consequences on health in adulthood and in some cases in childhood: obesity and diabetes. To address these public health issues, governments and public health agencies have been implementing policies intended to promote preventive behaviours thanks to education and information campaigns and food product labelling. However, their impacts remain small, at least in the medium term. Given their modest impacts, public health agencies and policy makers have implemented additional policies targeting changes in the quality and variety of foods and beverages sold in market. Two of them have received singular attention from public health authorities: Public-Private Partnerships (PPP) policy and taxation of unhealthful products/nutrients.[8]

Food reformulation and how it can be encouraged are central to these policies. It may be a feasible way to reduce children's sugar intake and to improve the nutritional quality of their diets, even if they continue eating the same products. However, despite the high potential for food reformulation among many product categories capacities for reformulation remains unexploited. One of the objectives of this report was to better exploit the potential for reformulation by showing further pathways to the industry and government in order to reinforce food reformulation as an impactful lever against childhood obesity. A multi-criteria approach, including nutritional composition, physicochemical, textural, sensory and liking dimensions, was performed to identify pertinent reformulation levers and experimentally evaluate their influence on product properties, perceptions, digestion indicators and children behavior.

Second, we assessed whether and to what extent PPPs policy and tax lead to changes in the nutrient composition of foods available on the market. Comparing the effects of the same type of policy implemented in different countries allowed us to offer guidance to policy makers in designing effective policies to encourage food companies to improve the nutrient composition of their products. This ultimate goal turns out to be crucial. Depending on the design of the policy, companies can strategically react more or less to the policy and amplify or weaken its impacts.

Our main results are the following:

- We identified experimental pathways to make healthier cookies, while improving or maintaining their characteristics and liking. They consist in reducing the sugar (-19%), fat (-29%) and chocolate chip (-20%) content and increasing the fiber content with oat bran (+6.5%). We also found promising results for the reduction of the glycemic index by the means of reformulation, while maintaining the sensory perception and the liking by children, which can be some recommendations for industrials and public authorities.
- PPPs policy targeting the sugar content of products can encourage the formulation of less sugar-sweetened products without unhealthy nutritional compensations. For example, we have shown that both Dutch and British voluntary product reformulation policies brought about significant reductions in the sugar content of dairy products and

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[8] Changes in advertising and marketing were also considered by policy marker. Marketing and advertising policies are analysed in WP4

no unhealthy compensation (e.g. increase in fat and/or saturated fat content) has taken place. Although, it was not possible to explain why sugar reductions were lower in England than in the Netherlands, we pointed out that both policies meet the key conditions of success identified in several systematic reviews: a strong government leadership and pressure; the involvement of a large number of manufacturers; the publication of guidelines or reduction targets; and an effective monitoring and evaluation. Nevertheless, we have underlined that the Dutch plan published reduction guidelines in terms of maximum added sugar contents while the obesity plan they are in terms of SWA of total sugar. However, we could not conclude that publishing a reduction guideline in terms of maximum content provides a greater incentive for companies to improve the nutrient composition of products than publishing a reduction guideline in terms of SWA content. Answering this question will require additional research.

- Tax can be also effective in reducing SSBs' sugar content if a tax design in tiers according to the sugar concentration of product is implemented. By comparing the British and the French soda tax effects and design, we have also shown that the level of tax, and in particular the level of the first tier above which a tax is levied is likely to be a key factor in encouraging reductions in the sugar content of SSBs. The relatively overall low value and the low value of the first tier of the current French tax may explain its lower impact than that found for the UK levy.
- PPPs policy would not be as effective as tax in reducing SSBs' sugar content. We found that the effects of the Dutch voluntary sugar reduction policy for SSBs resulted in an average reduction in the SSBs sugar content equal to 13% in 2016 vs. 31% for the SDIL, and the sugar reductions estimated were not persistent in subsequent years. However, although it seems more complex to change the recipe of a dairy product than that of a soft drink, we found that the Dutch voluntary product reformulation plan can lead to a reduction of up to 30% of sugar in dairy products.
- A possible solution to strengthen PPPs policy impact would be to set a credible threat such as a tax implementation if insufficient progress is made in reducing targeted nutrients. We provided empirical evidences showing that PPPs policy with the publication of guidelines or reduction targets associated with a tax threat can drive larger reductions in the sugar content of milk-based drinks than a PPPs policy without a tax threat.

SUPPLEMENTAL MATERIALS PART 2

1/ Descriptive statistics on average fat, saturated fat, and calorie contents by country and category (Table 1)

2/ Average fat content evolution of newly-marketed dairy products in the Netherlands, France Germany, Italy, Spain and England (Figure 1)

3/ Average saturated fat content evolution of newly-marketed dairy products in the Netherlands, France Germany, Italy, Spain and England (Figure 2)

4/ Average energy content evolution of newly-marketed dairy products in the Netherlands, France Germany, Italy, Spain and England (Figure 3)

5/ Average fat content evolution of newly-marketed drinking yogurts, flavoured milk, soft cheese desserts and spoonable yogurts in the Netherlands, France Germany, Italy, Spain and England (Figures 4-7)

6/ Average saturated fat content evolution of newly-marketed drinking yogurts, flavoured milk, soft cheese desserts and spoonable yogurts in the Netherlands, France Germany, Italy, Spain and England (Figures 8-11)

7/ Average calorie content evolution of newly-marketed drinking yogurts, flavoured milk, soft cheese desserts and spoonable yogurts in the Netherlands, France Germany, Italy, Spain and England (Figures 12-15)

Descriptive statistics on average fat, saturated fat, and calorie contents by country and category

Table 1: Average fat, saturated fat and calorie contents by country and category

	Category				All
	Drinking yogurts	Flavoured milk	Soft cheese desserts	Spoonable yogurts	
Fat content in g/100g					
The Netherlands	0.80	1.64	3.04	3.60	2.58
France	1.71	1.67	3.96	3.38	2.98
Germany	1.38	2.45	4.28	4.00	3.54
Italy	1.25	1.45	4.41	2.87	2.53
Spain	1.28	1.47	3.42	3.13	2.55
The United Kingdom	1.50	1.75	2.46	3.79	2.96
All countries	1.37	1.90	3.71	3.55	3.00
Saturated fat content in g/100g					
The Netherlands	0.50	1.13	1.78	2.24	1.59
France	1.06	0.99	2.56	2.14	1.88
Germany	0.86	1.59	2.81	2.58	2.28
Italy	0.76	0.97	2.95	1.76	1.54
Spain	0.70	0.92	2.17	1.95	1.57
The United Kingdom	0.82	1.12	1.56	2.33	1.82
All countries	0.81	1.22	2.36	2.24	1.88
Energy content in Kcal/100g					
The Netherlands	55.10	70.62	107.38	104.48	88.58
France	76.58	73.80	111.42	99.72	94.47
Germany	72.40	78.75	122.97	111.30	104.25
Italy	71.24	72.03	123.21	100.69	94.32
Spain	69.53	71.44	110.37	96.18	88.28
The United Kingdom	71.87	72.68	97.84	110.77	96.91
All countries	70.66	74.39	113.58	105.22	96.46

Average fat content evolution of newly-marketed dairy products in the Netherlands, France Germany, Italy, Spain and England

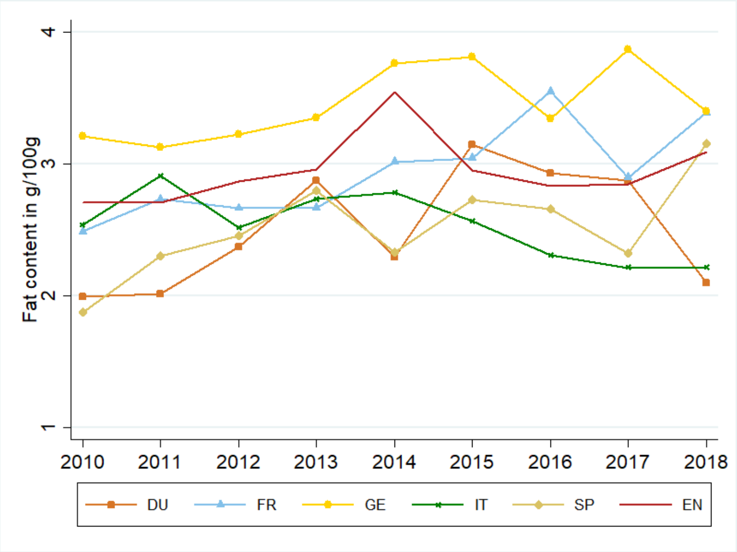

Figure 1: Average fat-content evolution of newly-marketed dairy products in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

Average saturated fat content evolution of newly-marketed dairy products in the Netherlands, France Germany, Italy, Spain and England

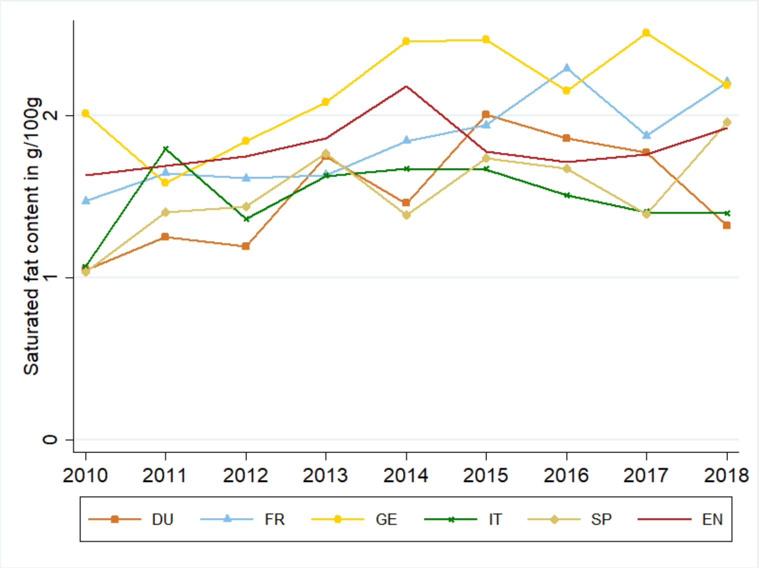

Figure 2: Average saturated fat content evolution of newly-marketed dairy products in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

Average calorie content evolution of newly-marketed dairy products in the Netherlands, France Germany, Italy, Spain and England

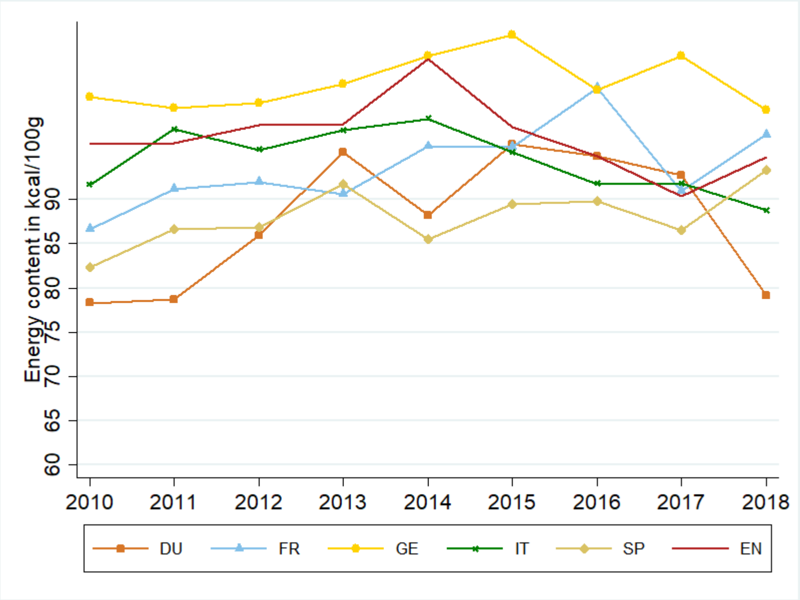

Figure 3: Average calorie-content evolution of newly-marketed dairy products in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

Average fat content evolution of newly-marketed drinking yogurts, flavoured milk, soft cheese desserts and spoonable yogurts in the Netherlands, France Germany, Italy, Spain and England

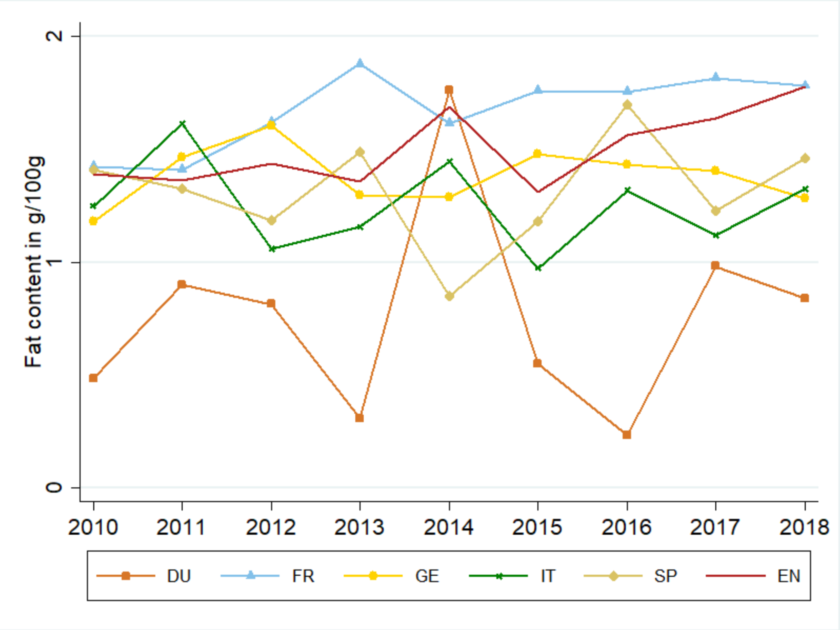

Figure 4: Average fat-content evolution of newly marketed drinking yogurts in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

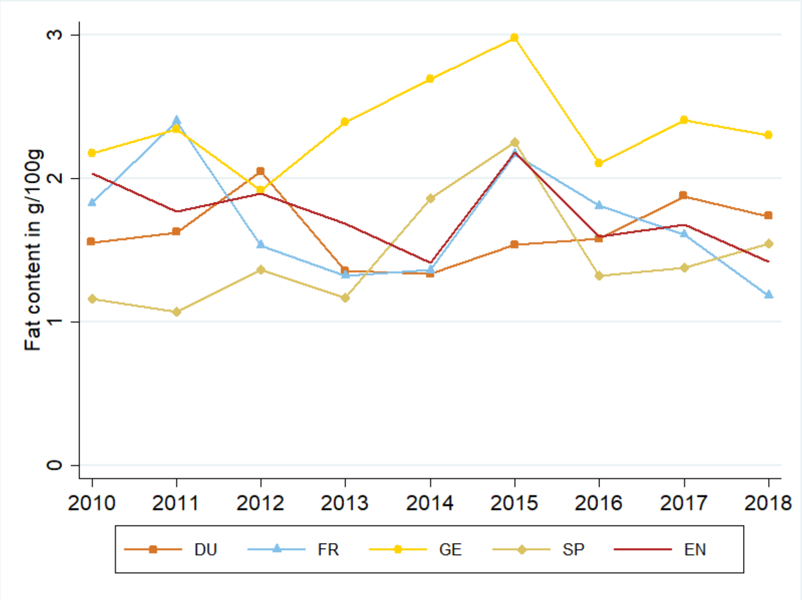

Figure 5: Average fat-content evolution of newly marketed flavoured milk in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

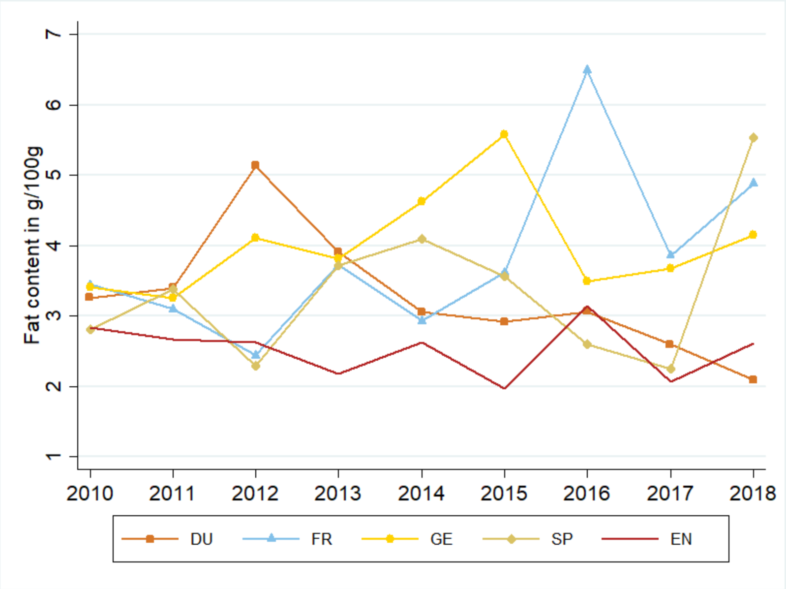

Figure 6: Average fat-content evolution of newly marketed soft cheese desserts in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

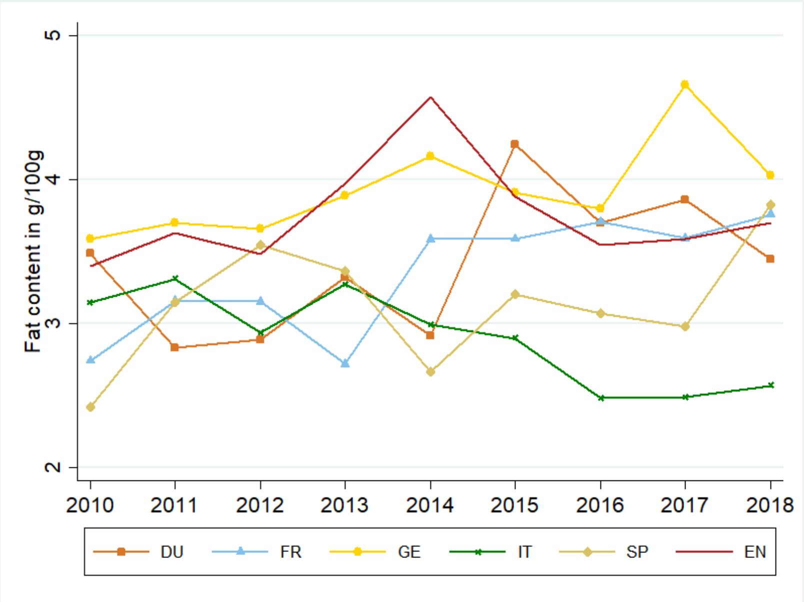

Figure 7: Average fat-content evolution of newly marketed spoonable yogurts in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

Average saturated fat content evolution of newly-marketed drinking yogurts, flavoured milk, soft cheese desserts and spoonable yogurts in the Netherlands, France Germany, Italy, Spain and England

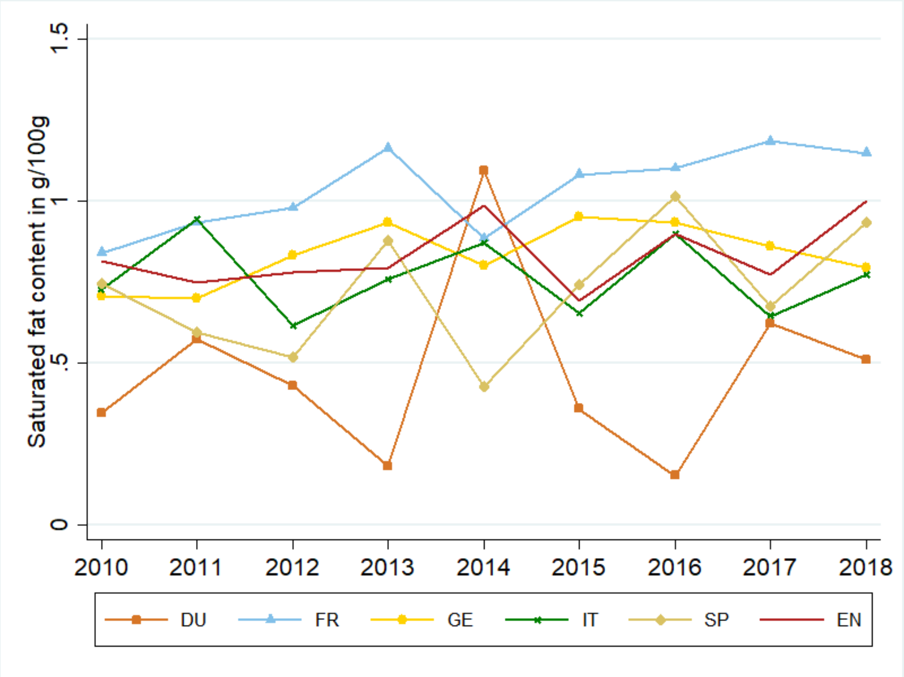

Figure 8: Average saturated fat-content evolution of newly marketed drinking yogurts in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

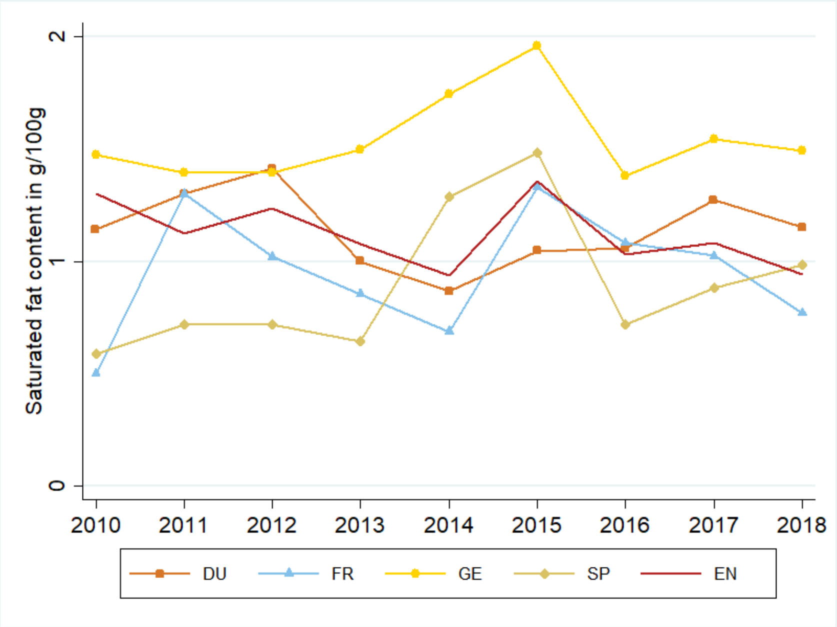

Figure 9: Average saturated fat-content evolution of newly marketed flavoured milk in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

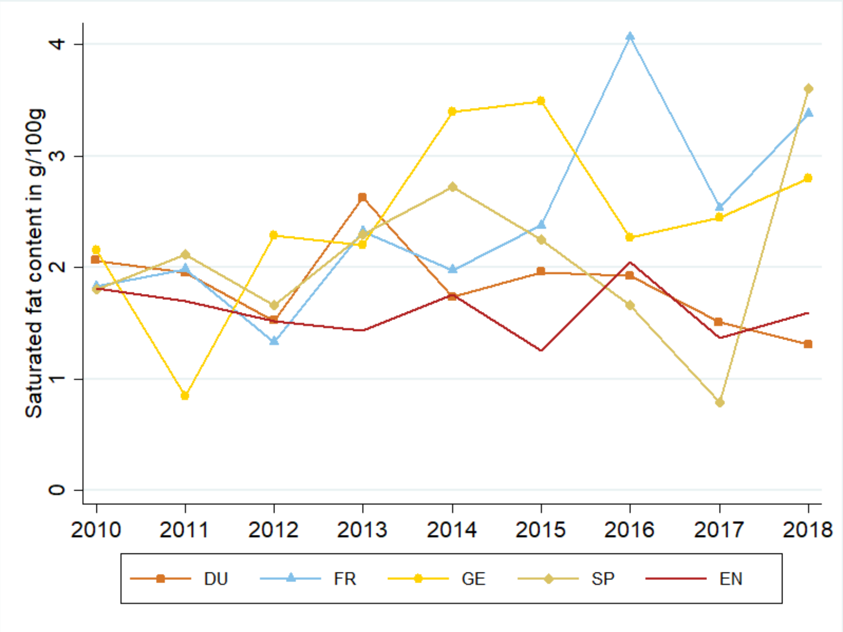

Figure 10: Average saturated fat-content evolution of newly marketed soft cheese desserts in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

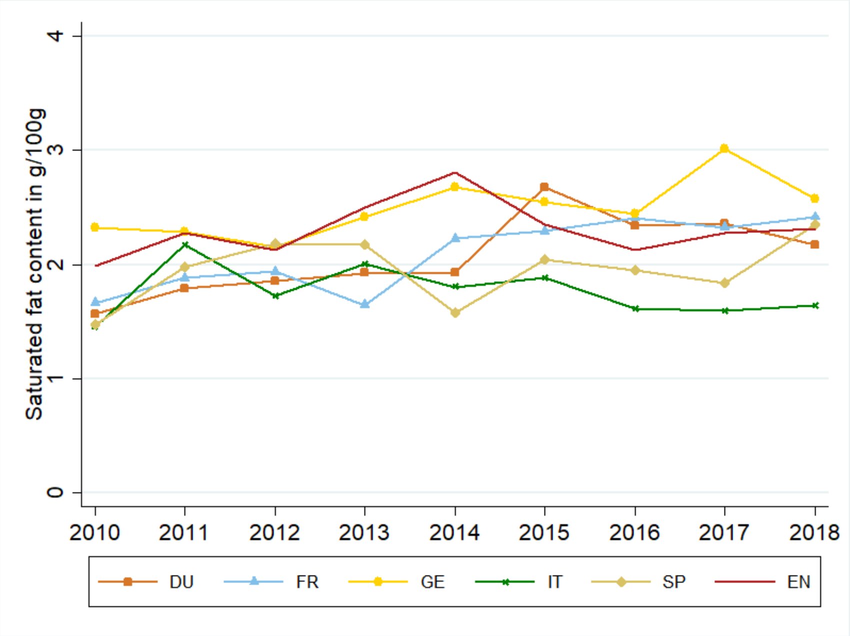

Figure 11: Average saturated fat-content evolution of newly marketed spoonable yogurts in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

Average calorie content evolution of newly-marketed drinking yogurts, flavoured milk, soft cheese desserts and spoonable yogurts in the Netherlands, France Germany, Italy, Spain and England

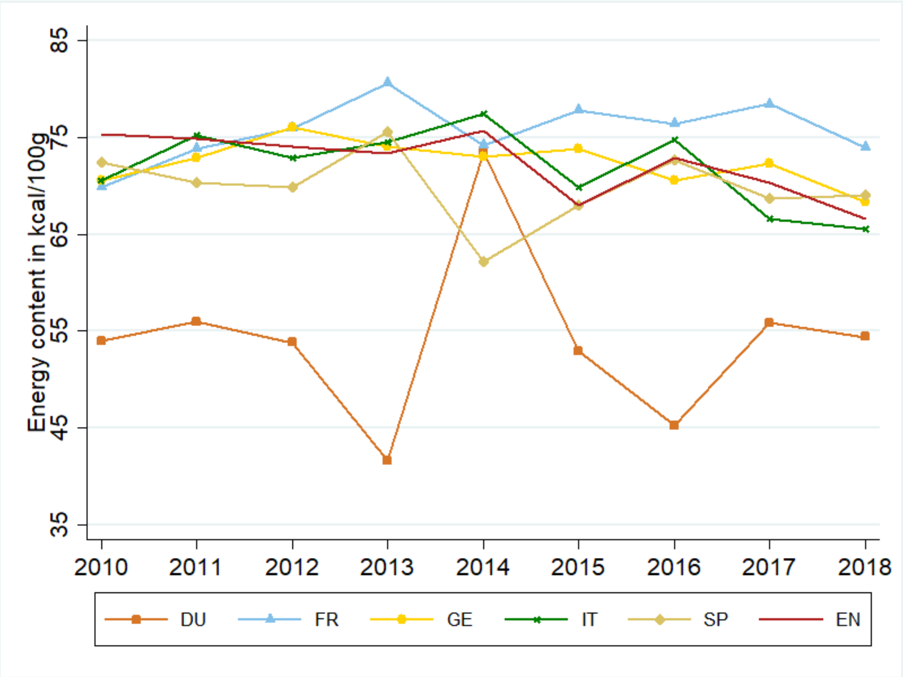

Figure 12: Average calorie-content evolution of newly marketed drinking yogurts in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

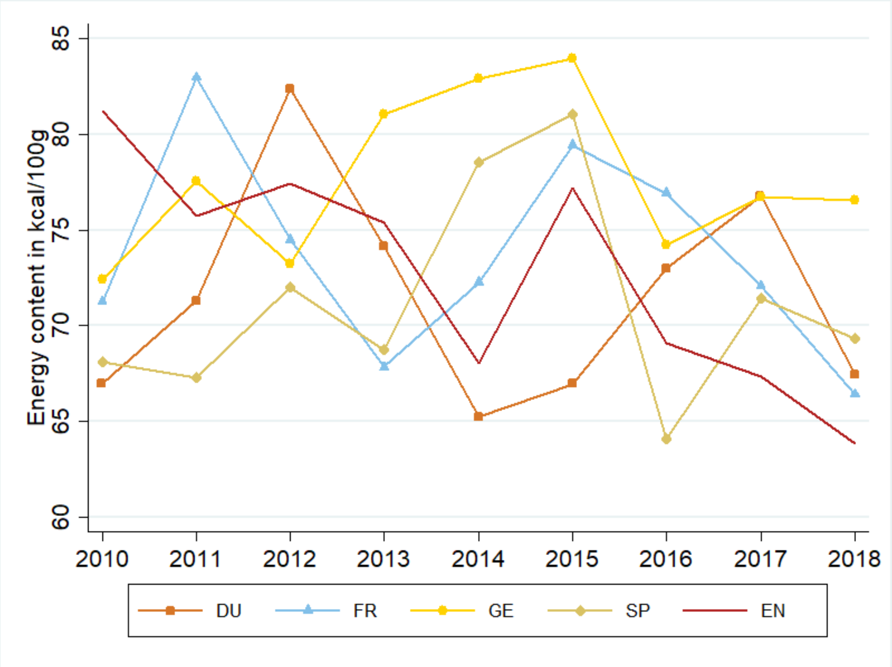

Figure 13: Average calorie-content evolution of newly marketed flavoured milk in the

Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

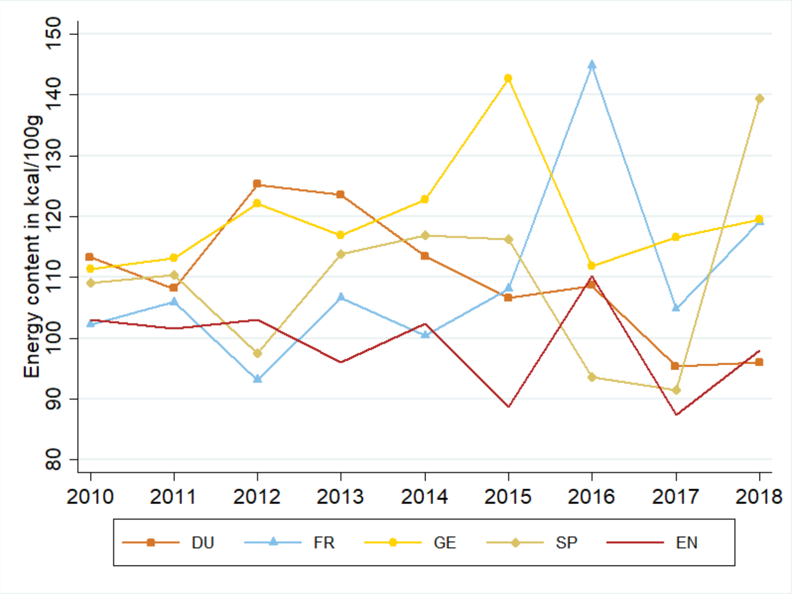

Figure 14: Average calorie-content evolution of newly marketed soft cheese desserts in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

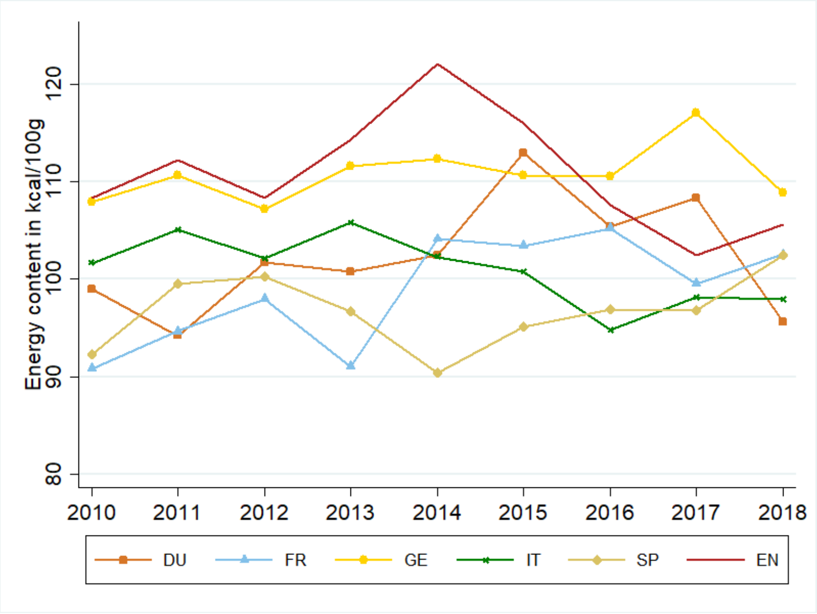

Figure 15: Average calorie-content evolution of newly marketed spoonable yogurts in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP), and England (EN)

SUPPLEMENTAL MATERIALS PART 3

1/ Comparison of the sugar content distribution in PHE and GNPD database use to evaluate UK SDIL (Figures 1—2)
2/ Comparison of the sugar content distribution in Oqali and GNPD database use to evaluate French SSB tax (Figure 3)
3/ Descriptive statistics on the number of newly marketed beverages and their average sugar content over the 2010--2019 period (Table 1)
4/ Sugar-content distribution by country and country/category (Tables 2 and 3)
5/ Sugar-content distribution of soft drinks over time (Figures 4—9)
6/ Average sugar-content evolution by country and by country/soft drink category (Figures 10 and 11-14)
7/ Empirical method
8/ Placebo estimators: Plausibility of common trend hypothesis
9/ Effects of French SSB tax implemented in 2012 on the sugar content of newly marketed SSBs (Table 4)
10/ Effects of French SSB tax implemented in 2012 on the sugar content of newly marketed carbonated soft drinks (Table 5)
11/ Effects of British SSB tax on the sugar content of newly marketed SSBs without non-caloric sweeteners (Table 6)
11/ Effects of the British and French 2018 SSB tax on the sugar content of newly marketed SSBs without non-caloric sweeteners by soft drink category (Tables 7 and 8)
12/ Effects of the British tax on the percentage of SSBs over the lower levy sugar threshold

Comparison of the sugar content distribution in PHE and GNPD database use to evaluate UK SDIL. (1,2)

Figure 1 was taken from the latest progress report on the sugar reduction programme implemented in the United Kingdom between 2015 and 2019.(1) It shows how the distribution of products purchased by their sugar content has changed over time. The curves show the number of products sold by their total sugar content per 100ml for baseline (2015) and year 3 (2019), and the vertical lines show the sales weighted average sugar content for the same time periods. Figure 2 shows the number of newly marketed SSBs subject to the Soft Drinks Industry Levy by total sugar per 100ml for 2015 and 2019 obtained from GNPD data for the United Kingdom.

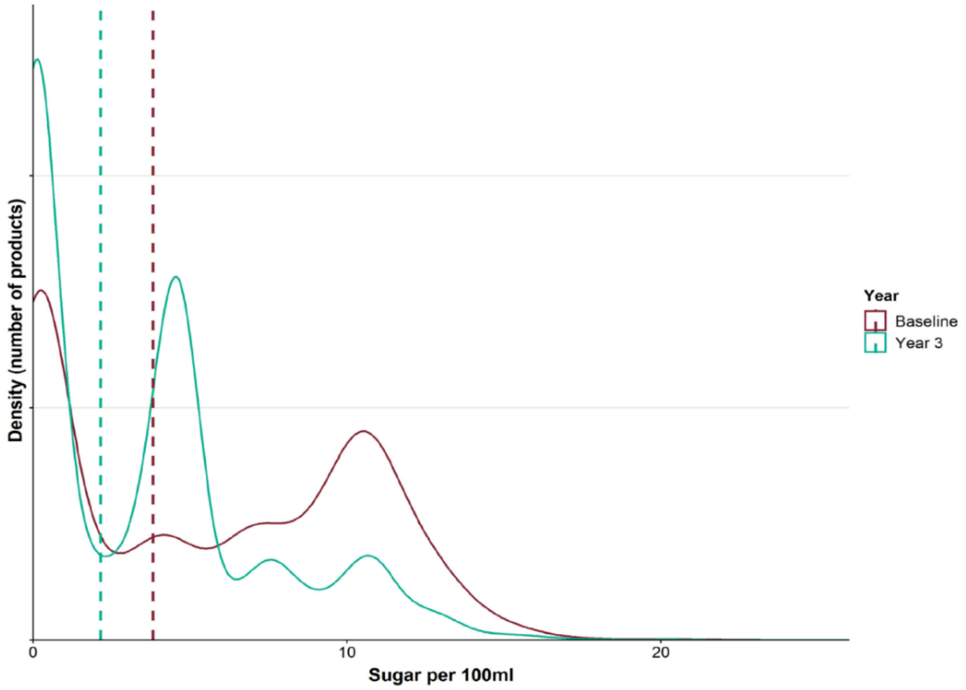

Fig 1: Number of drinks subject to the Soft Drinks Industry Levy purchased by total sugar per 100ml for baseline (2015) and year 3 (2019) for retailers and manufacturer branded products (source: PHE, 2020, fig 29)(1)

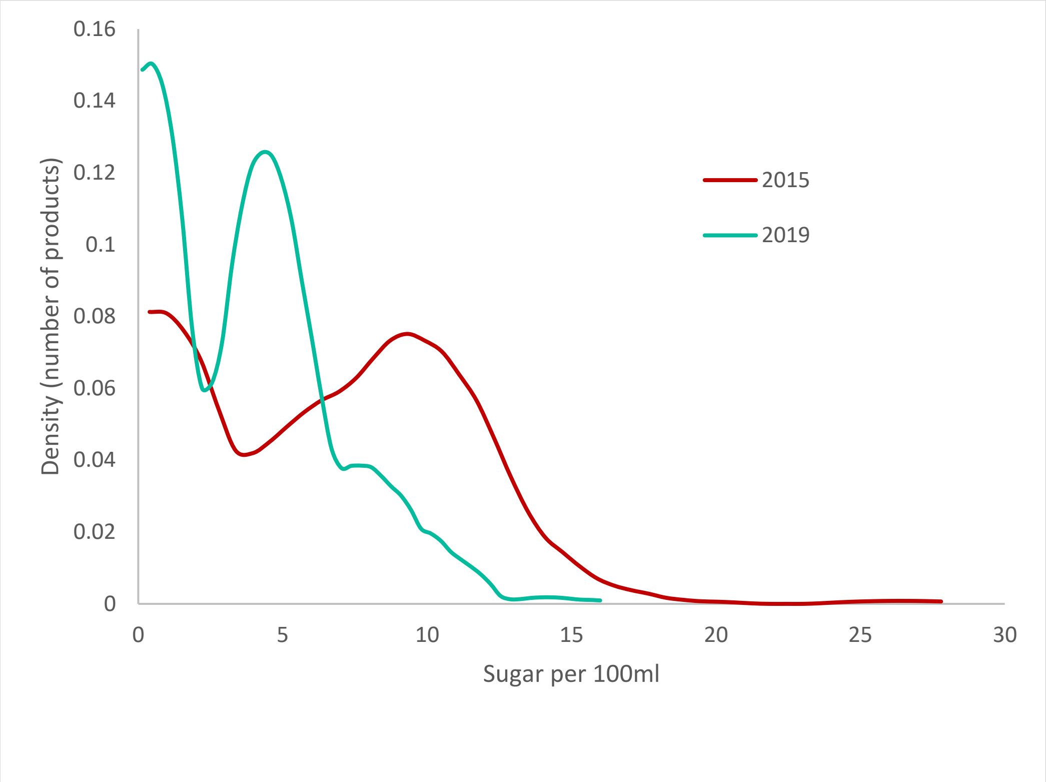

Fig 2: Number of drinks by total sugar per 100ml in 2015 (red) and 2019 (green) from GNPD database

Comparison of the sugar content distribution in Oqali and GNPD database use to evaluate French SSB tax

Figure 3 shows the number of SSBs subject to the French SSB taxes by total sugar per 100ml in 2013 obtained from Mintel GNPD and Oqali database. (2,3) The French database Oqali collects precise data on processed food on the market (including new, existing, and removed ones). (4) Only SSBs sold in 2013 were freely available.

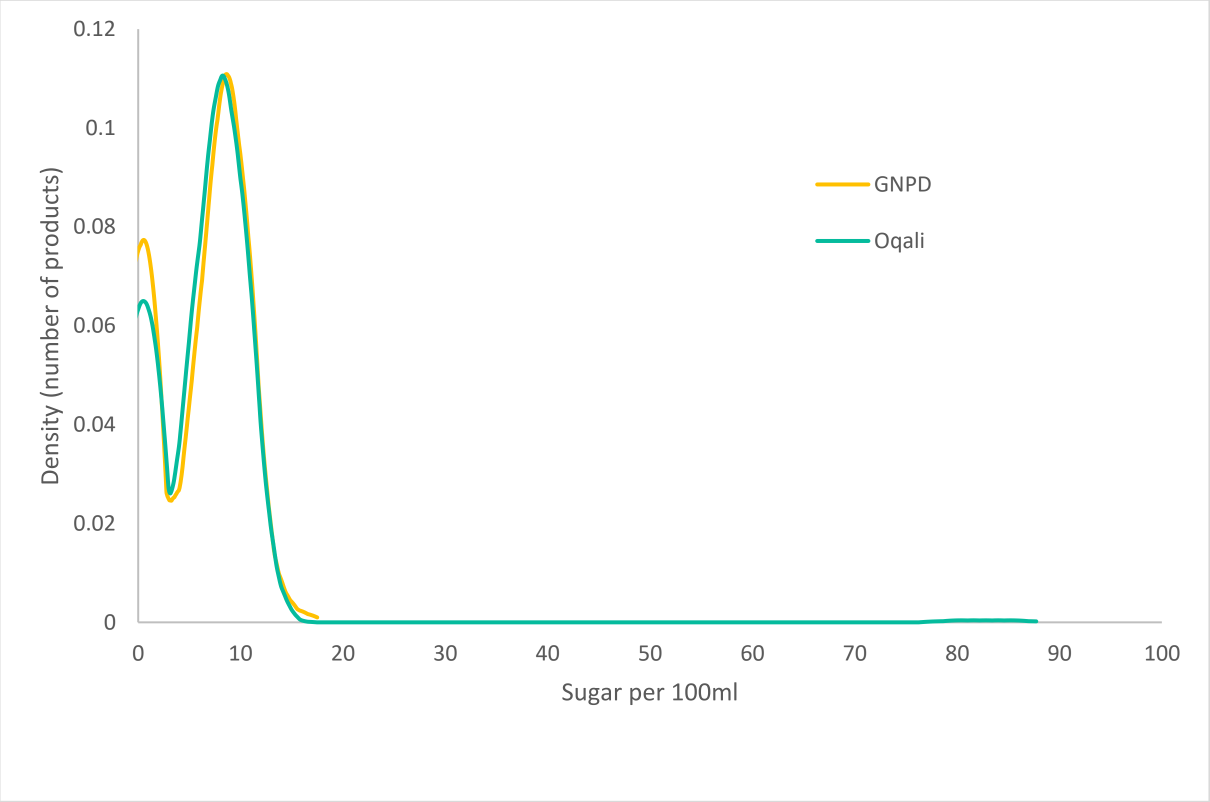

Fig 3: Number of drinks by total sugar per 100ml in 2013 from GNPD (yellow) and Oqali (green) database

Descriptive statistics on the number of newly marketed beverages and their average sugar content over the 2010--2019 period

Table 1 presents descriptive statistics on the number of newly marketed beverages and their average sugar content over the 2010--2019 period in each of the six countries studied. All statistics are displayed per soft drink category. Germany, the United Kingdom and France were the most dynamic soft drink markets, with 2986, 2884 and 2667 new items, respectively. The carbonated soft drink category was the most important category for all countries considered, accounting for more than 45% of newly marketed soft drinks for each country (up to 59% for Germany). Fruit-flavoured still drinks were the second most important category for France, the Netherlands, Spain and the United Kingdom (from 25% to 33% of newly marketed soft drinks, according to the country considered). Flavoured waters and iced teas in France and the Netherlands had quite similar proportions, 9% and 17% for France, 16% and 15% in the Netherlands, respectively. In Spain, the third most important category was iced teas (16% of the data) and the flavoured water category was the least important (5%). In the United Kingdom, flavoured waters (18%) and iced teas (5%) were the third and the fourth most important categories, respectively, in terms of number of newly marketed soft drinks. For Italy, iced teas were the second most important category (28%) followed by fruit-flavoured still drinks (16%); the flavoured water category was seldom newly marketed (only 1%). The iced tea, fruit-flavoured still drink and flavoured water categories had relatively similar proportions in Germany (17%, 14% and 10%, respectively).

Table 1: Descriptive statistics

	Category				All
	Fruit flavoured still drinks	Carbonated soft drinks	Flavoured waters	Iced tea	
			Number of soft drinks		
The Netherlands	281	535	190	175	1181
France	683	1280	251	453	2667
Germany	408	1772	307	499	2986
Italy	225	801	19	403	1448
Spain	461	652	77	221	1411
The United Kingdom	734	1495	506	149	2884
All countries	2792	6535	1350	1900	12577
			Sugar content in g/100ml		
The Netherlands	6.29	6.21	1.47	4.91	5.30
France	8.27	6.93	1.70	4.99	6.43
Germany	7.56	7.16	3.36	5.38	6.51
Italy	8.45	8.09	2.52	6.40	7.60
Spain	6.51	5.74	2.48	4.52	5.60
The United Kingdom	6.37	5.28	1.43	4.85	4.85
All countries	7.19	6.58	1.99	5.30	6.02

Source: authors' own calculations based on data from Mintel GNPD data, January 2010 to December 2019

The average content of all new soft drinks was 6.02g of sugar per 100ml. Italy was the country with the highest level of average sugar content, 7.60g/100ml, regardless of category, except for its rarely marketed flavoured waters (only 19 Italian flavoured waters were collected over the entire period, and sugar content was reported for only 15 of them). German and French markets had the second and third highest levels, with an average sugar content of 6.51 and 6.43g/100ml, respectively, followed by Spain, with an average sugar content of 5.60g/100ml. The Netherlands and the United Kingdom had the lowest average sugar content (5.30 and 4.85g/100ml). Among categories, flavoured waters had the lowest sugar content (1.99g/100ml), iced teas had an intermediate sugar-content average of 5.30g/100ml, and carbonated soft drinks and fruit-flavoured still drinks had the highest levels (6.58g/100ml and 7.19g/100ml, respectively). The level of average sugar content in fruit-flavoured still drinks was highest in Italy and France, 8.45g/100ml and 8.27g/100ml, respectively. For carbonated soft drinks, the level was highest in Italy, 8.09g/100ml, followed by Germany, 7.16g/100ml and France, 6.93g/100ml; for flavoured waters, in Germany, 3.36g/100ml. For iced teas, Italy had the highest level, 6.40g/100ml, followed by Germany, 5.38g/100ml

Sugar-content distribution by country and country/category

Table 2: Descriptive statistics of sugar content (in g/100ml) by country (in g/100ml)

Country	N	Min	Max	p25	p50	p75	Mean
The Netherlands	984	0.00	15.00	1.80	4.90	8.55	5.30
France	2,346	0.00	21.00	3.76	6.98	9.60	6.43
Germany	2,517	0.00	20.00	4.12	6.70	9.10	6.51
Italy	1,192	0.00	25.30	5.10	8.40	10.70	7.60
Spain	1,174	0.00	17.00	1.10	6.00	8.80	5.60
The United Kingdom	2,482	0.00	26.40	0.20	4.50	8.70	4.85
All countries	10,695	0.00	26.40	2.80	6.40	9.30	6.02

Table 3: Descriptive statistics of sugar content by country and soft drink category (in g/100ml)

	N	Min	Max	p25	p50	p75
Fruit-flavoured still drinks						
The Netherlands	219	0.00	14.30	4.20	6.30	9.00
France	604	0.00	16.25	6.56	8.80	10.00
Germany	328	0.00	20.00	4.76	8.20	10.00
Italy	158	0.00	15.70	6.10	9.53	10.60
Spain	382	0.00	17.00	3.45	6.50	9.60
The United Kingdom	626	0.00	26.40	1.36	6.05	10.44
Carbonated soft drinks						
The Netherlands	461	0.00	15.00	2.10	7.00	10.00
France	1,111	0.00	21.00	3.90	8.21	10.20
Germany	1,487	0.00	19.21	5.20	7.60	9.70
Italy	688	0.00	25.30	4.70	10.00	11.36
Spain	530	0.00	16.40	0.10	7.20	9.00
The United Kingdom	1,285	0.00	18.40	0.20	4.90	9.00
Flavoured waters						
The Netherlands	150	0.00	9.70	0.00	0.00	3.50
France	228	0.00	10.10	0.00	0.10	3.16
Germany	259	0.00	10.00	2.80	3.50	4.40
Italy	15	0.00	6.03	0.00	2.00	5.20
Spain	66	0.00	8.40	0.00	1.60	4.20
The United Kingdom	441	0.00	9.00	0.00	0.10	2.30
Iced tea						
The Netherlands	154	0.00	9.44	4.30	4.57	6.30
France	403	0.00	10.40	4.10	4.84	6.70
Germany	443	0.00	12.00	3.90	5.80	7.10
Italy	331	0.00	11.20	4.80	7.00	8.20
Spain	196	0.00	14.40	3.20	4.70	6.70
The United Kingdom	130	0.00	10.00	3.70	4.65	6.60

Sugar-content distribution of soft drinks over time

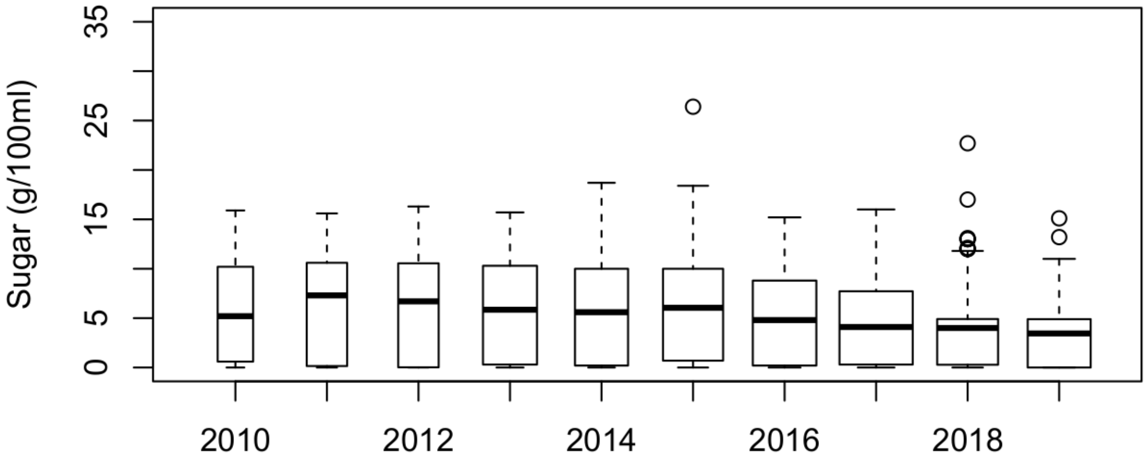

Fig 4: Evolution of the sugar content distribution of newly marketed soft drinks in the United Kingdom (in g/100ml)

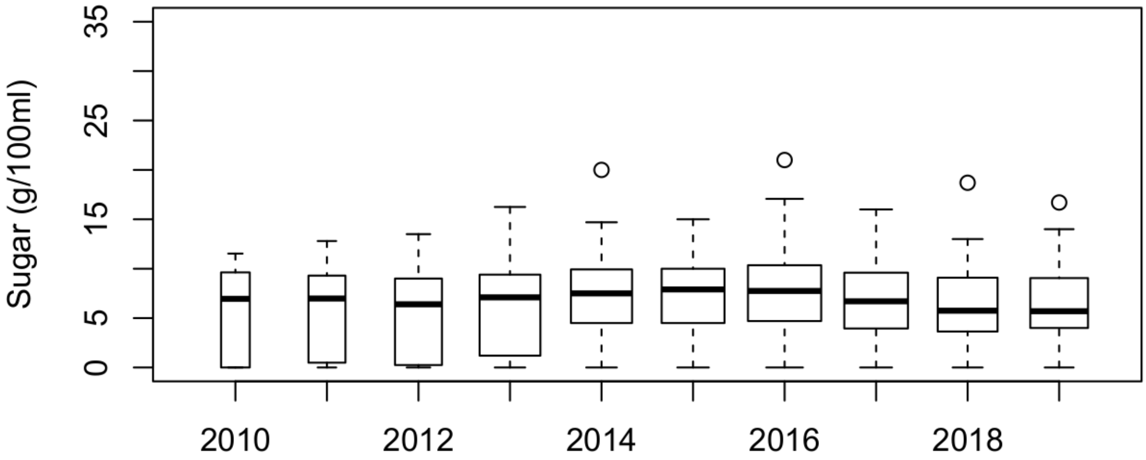

Fig 5: Evolution of the sugar content distribution of newly marketed soft drinks in France (in (in g/100ml)

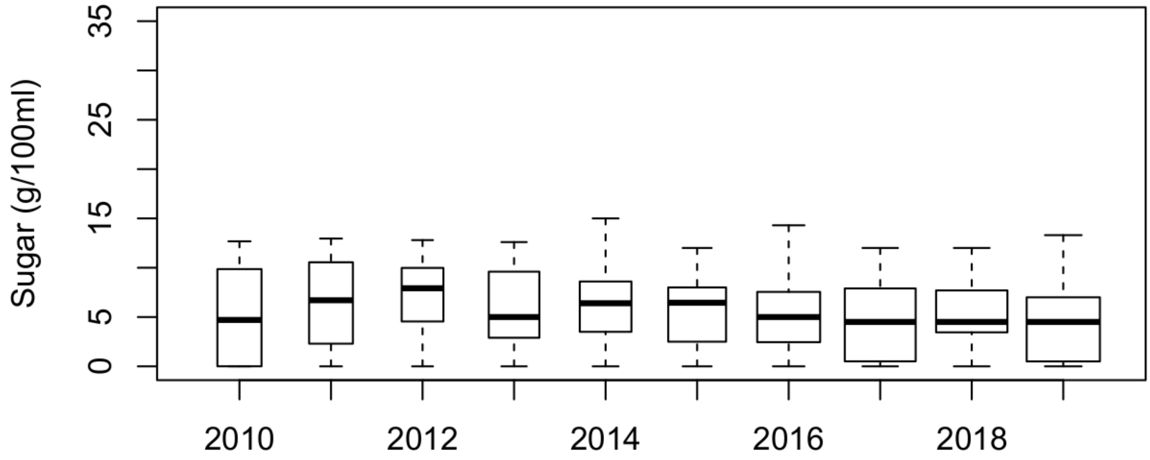

Fig 6: Evolution of the sugar content distribution of newly marketed soft drinks in the Netherlands (in g/100ml)

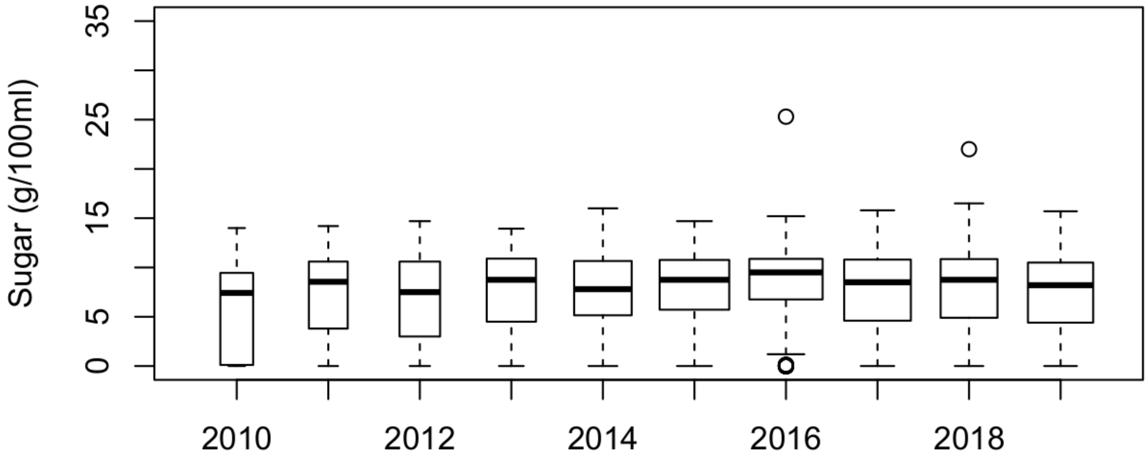

Fig 7: Evolution of the sugar content distribution of newly marketed soft drinks in Italy (in g/100ml)

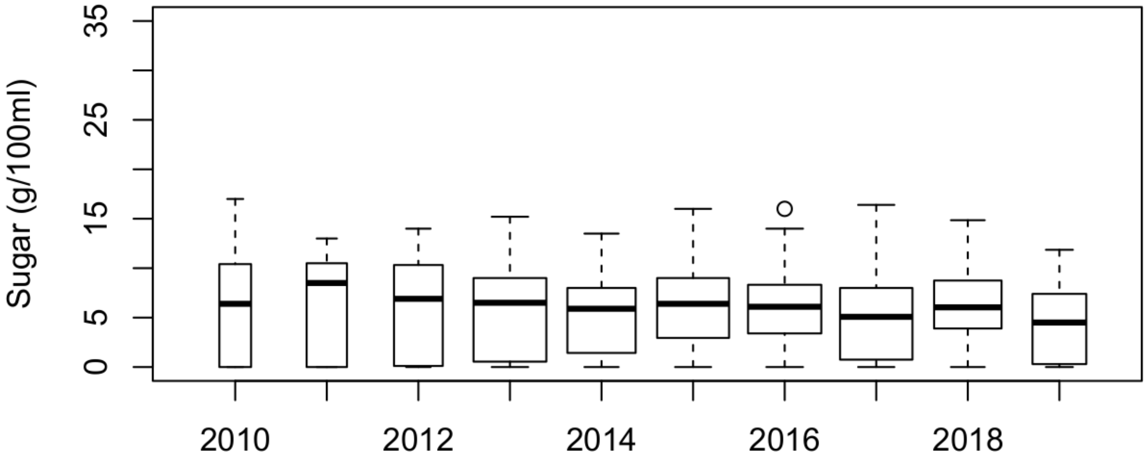

Fig 8: Evolution of the sugar content distribution of newly marketed soft drinks in Spain (in g/100ml)

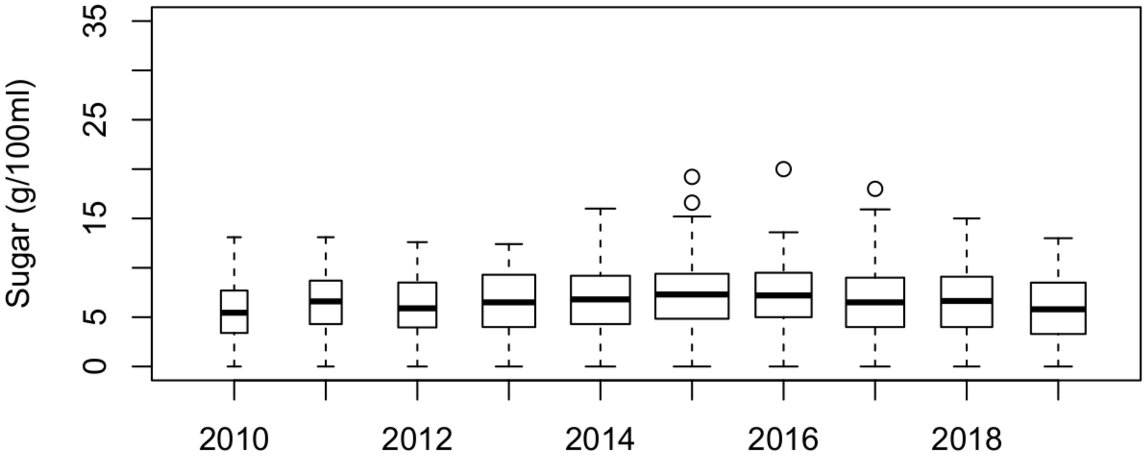

Fig 9: Evolution of the sugar content distribution of newly marketed soft drinks in Germany (in g/100ml)

Average sugar-content evolution by country and by country/soft drink categories

Figure 10 displays the average sugar content of new products launched each year in the soft drink market in the six countries. A key characteristic of this figure is that all average sugar contents were between 5g and 6g per 100ml in 2010. After 2010, we observe a strong heterogeneity across countries in the level of sugar content. The figure exhibits two different dynamics. First, the British soft drink market was unique in that a positive trend was not observed over the period. On the other hand, the Italian, German and French markets experienced positive trends until 2016. Spanish and Dutch markets, after one or two years of increase, have almost gone back to their 2010 levels. Second, a drop in average sugar content is observed for each country but has taken place at different periods. The Spanish and Dutch soft drink markets were the first markets in which the decrease occurred, in 2011 and 2012, respectively, followed by the United Kingdom in 2015. The average sugar content level of soft drinks in the three countries reached lower levels in 2017 than in 2010; however, only that of soft drinks newly marketed in the United Kingdom, with those of France, continued to decrease in 2018. Italy, France and Germany experienced the same decrease in 2016 only, but their average levels reached in 2019 were still higher than those in 2010. Finally, in 2019, all six countries experienced a drop in their average sugar content (very slightly for France).

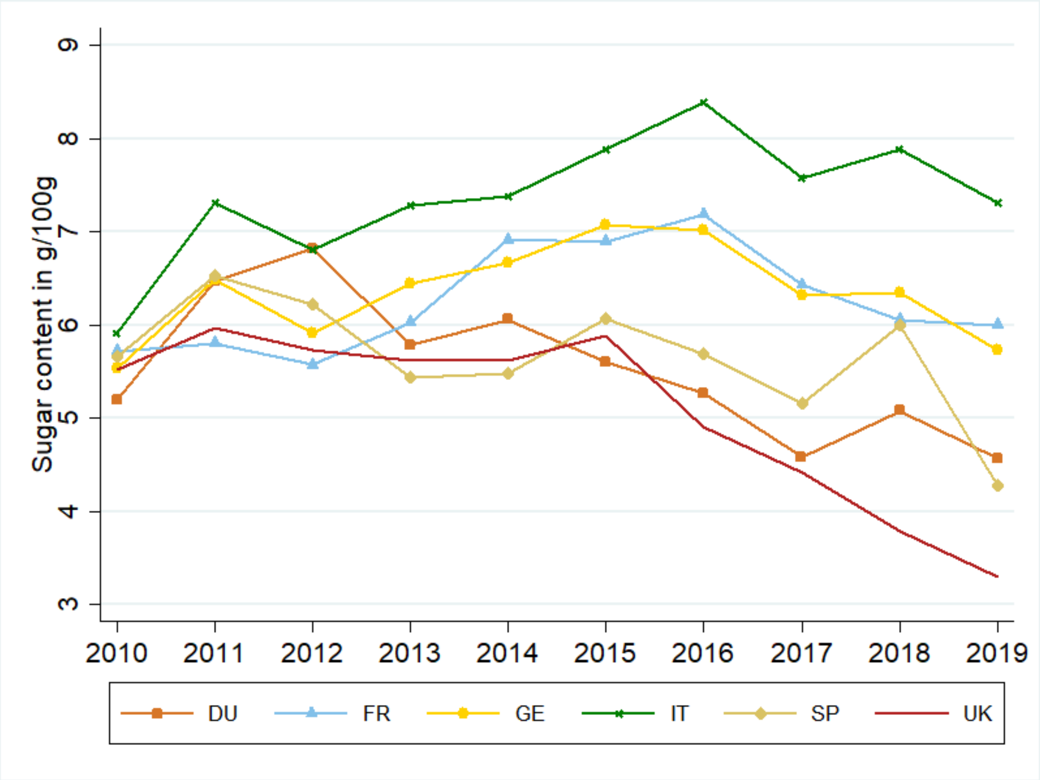

Fig 10: Average sugar content evolution of newly marketed soft drinks in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP) and the United Kingdom (UK)

Figure 11 displays the average sugar content of beverages launched every year in the four SSBs categories in the Netherlands, France, Germany, Italy, Spain and the United Kingdom. Overall, the United Kingdom has experienced a sharp drop in sugar content of each soft drink category after 2016. More precisely, an overall drop in average sugar content of newly marketed fruit-flavoured still drinks over 2010--2017 was observed in the United Kingdom, the Netherlands and Spain (3-1). This drop began in 2013; the drop slope became sharper between 2014 and 2015 in the United Kingdom, between 2013 and 2014 in the Netherlands and between 2012 and 2013 in Spain. Spain and the Netherlands experienced an increase of their sugar content in 2018, whereas the British fruit-flavoured still drinks sugar content remained quite stable between 2017--2018. Finally, the largest decrease in the average sugar content for these three countries was observed between 2018 and 2019 (except for Spain for which a huge decrease was also highlighted between 2012 and 2013). For carbonated soft drinks (3-2), the average sugar content was similar in France, the United Kingdom, Germany and the Netherlands in 2010. However, only in the British market do we observe a lower level in 2019 than that obtained in 2010. A catching-up effect in the average sugar content of carbonated soft drinks is observed for Spain, Italy and France. However, a huge decrease was found during the last period of the study (2018-2019) for Spain. Figure 3-2 displays a relatively steady trend in Germany and the Netherlands after 2014 and 2012, respectively. Neither a positive nor a negative marketed trend was observed in the iced tea markets studied (3-4). In Germany, the Netherlands and the United Kingdom, slight negative trends occurred in the average sugar content of newly marketed flavoured waters, while a slight positive trend occurred in France.[9]

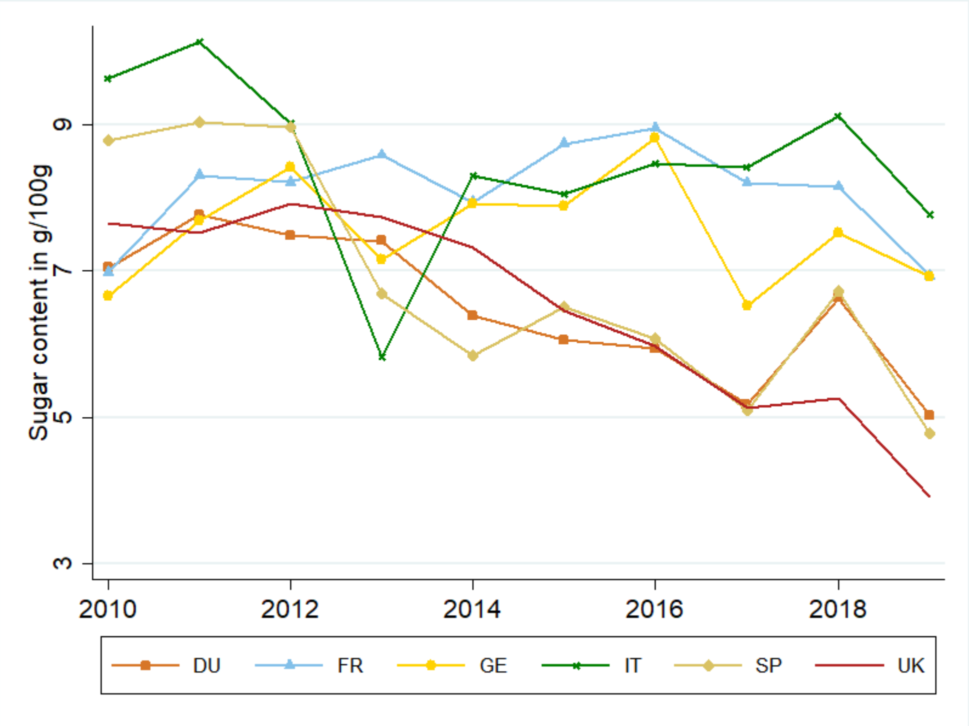

Fig 11: Average sugar-content evolution of newly marketed fruit-flavoured still drinks in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP) and the United

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[9] The Italian flavoured waters evolution was removed from Figure (3-3) given the weak number of Italian flavoured waters collected by Mintel GNPD.

Kingdom

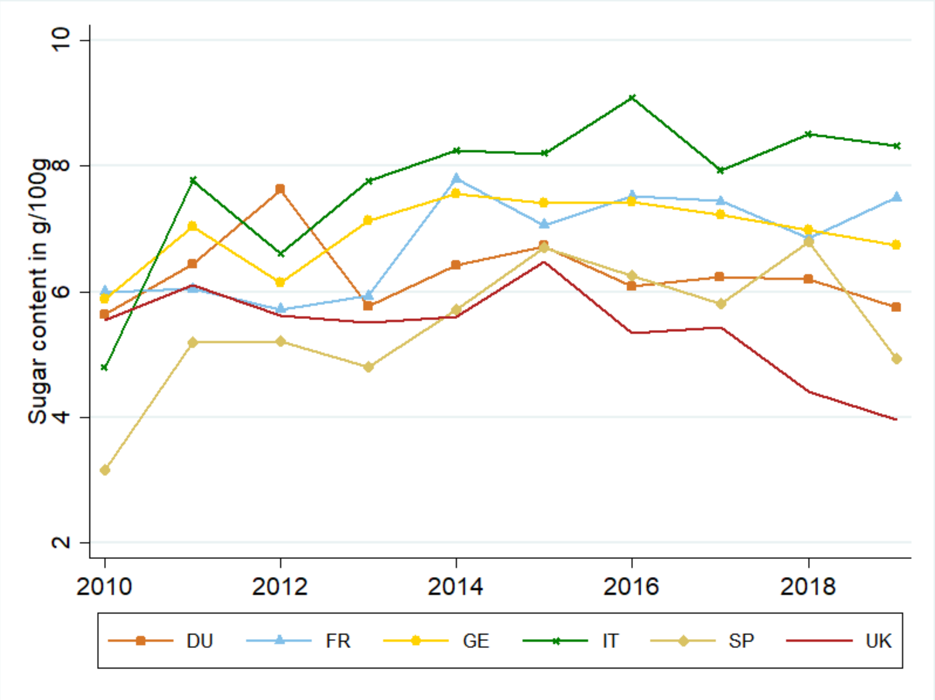

Fig 12: Average sugar-content evolution of newly marketed carbonated soft drinks in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP) and the United Kingdom

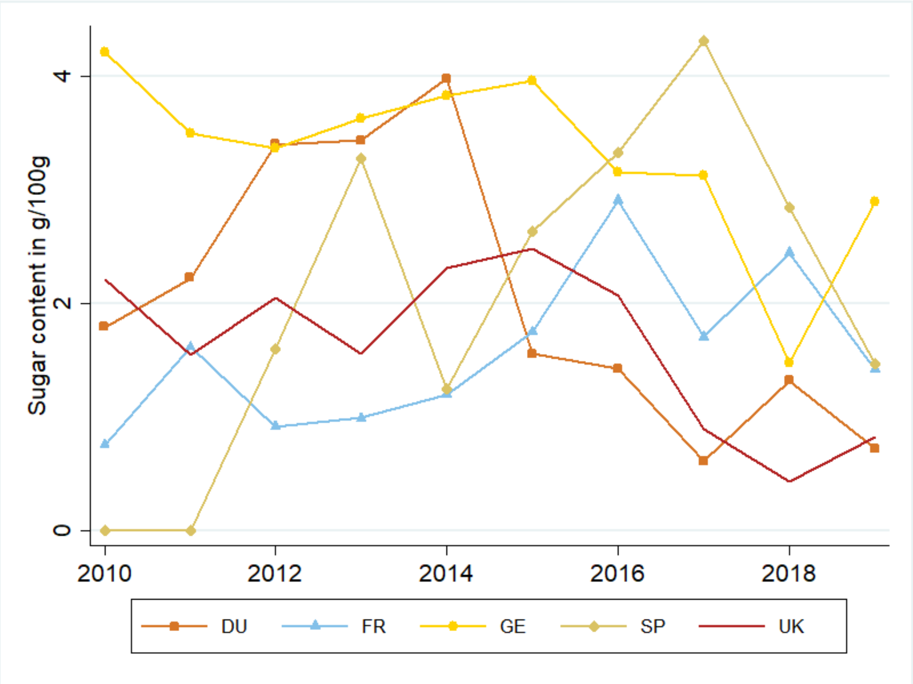

Fig 13: Average sugar-content evolution of newly marketed flavoured waters in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP) and the United Kingdom

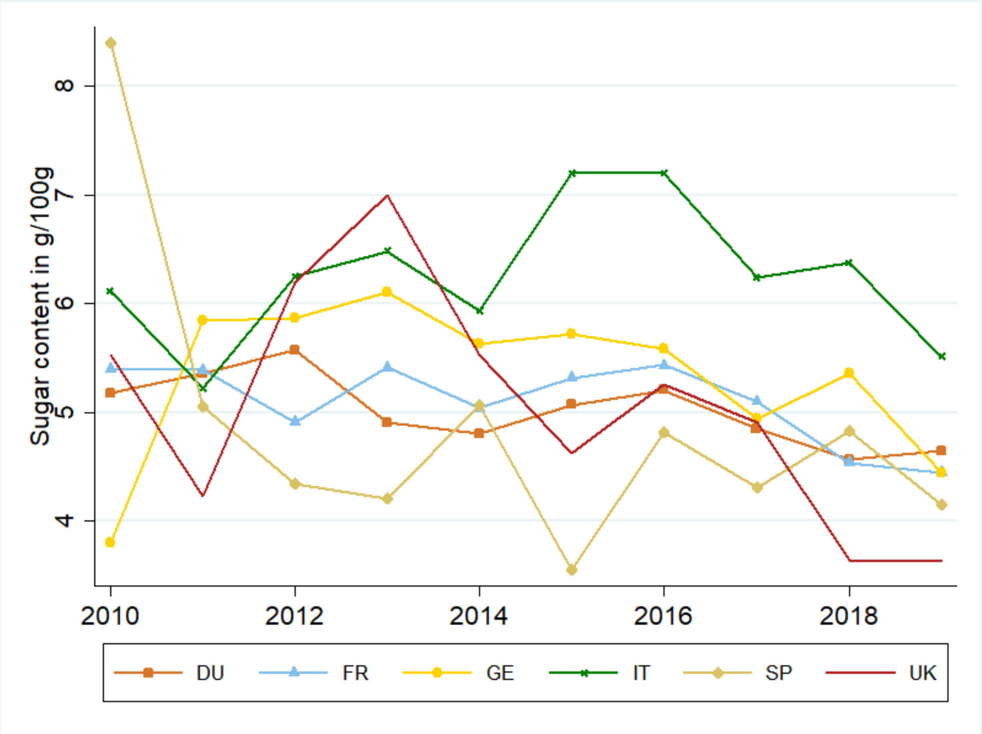

Fig 14: Average sugar-content evolution of newly marketed iced tea in the Netherlands (DU), France (FR), Germany (GE), Italy (IT), Spain (SP) and the United Kingdom

Empirical method

We used differences-in-differences (DID) estimators of intertemporal treatment effects to assess the effet of SSB tax on the sugar content of newly marketed soft drinks in France or the United Kingdom (our outcome).(5) We compared the outcome evolution in France or the United Kingdom that has announced/implemented the tax (the treated country) to that of countries that have not (the countries control group), from the last year before the tax has been announced/implemented to the *lth* year after that annoucement/implementation. It estimates the effect of having announced/implemented the tax for the first time *l* years ago. SSB tax's instantaneous is estimated for $l = 0$ and dynamic effects for $(l \geq 1)$.

Applying de chaisemartin and D'Hautefeuille (2021) to our sharp (treatment does not vary within country c and year t) and staggerred treatment adoption design (countries have maintained the tax after they have announced/implemented for the first time in year *t-l*), we first set the following notations. For any l ∈ $\{0, \ldots, 7\}$ and $t \in \{2012 + l, \ldots, 2019\}$, let $N^1_{c,t,l} = \sum_{i \in c, F_{c,1=t-l}} N_{i,c,t}$ denote the number of taxed SSBs *i* in France or the United Kingdom (c=FR, UK) for the first time at year *t-l*, where for any country *c*, $F_{c,1} = min\{t: Tax_{c,t} = 1\}$ denotes the first year at which country *c* has announced/implemented the SSB tax, $Tax_{c,t} = 1$. We have the convention that $F_{c,1} = 2020$ if country *c* has not announced/implemented it, $Tax_{c,t} = 0$. Let $N^{nt}_t = \sum_{c:F_{c,1>t}} N_{c,t}$ denote the number of untaxed SSBs in countries control group from period 2010 to *t*, where $N_{c,t}$ is the number of SSBs in country *c* at period *t*. In our setting, N^{nt}_t is always strictly positive. Finally, let $Y_{c,t} = 1/N_{c,t} \sum_{i \in c,t} Y_{i,c,t}$ denote the observed average of the sugar content in grams per 100ml of SSBs newly marketed in country *c* at period *t*. In our setting, $F_{UK,1}$=2016 and $F_{FR,1} = 2012, 2018$ for the United Kingdom and France, respectively. It results that $N^1_{UK,t,l} > 0$ for $(t, l) \in \mathcal{T}^{UK} = \{(2016{,}0),\ (2017{,}1),\ (2018{,}2),\ (2019{,}3)\}$, and $N^1_{UK,t,l} = 0$ otherwise. For the 2012 French tax, we have $N^1_{FR,t,l} > 0$ for $(t, l) \in \mathcal{T}^{FR} = \{(2012, l),\ l = \{0, 1, 2, 3\}\}$, and $N^1_{FR,t,l} = 0$ otherwise.[10] For the 2018 French tax, $N^1_{FR,t,l} > 0$ for $(t, l) \in \mathcal{T}^{FR} = \{(2018{,}0),\ (2019{,}1)\}$, and $N^1_{FR,t,l} = 0$ otherwise.

We define

$$DID_{treated,t,l} = \left(Y_{treated,t} - Y_{treated,t-l-1}\right) - \sum_{c:F_{c,1>t}} \frac{N_{c,t}}{N^{nt}_t} \left(Y_{c,t} - Y_{c,t-l-1}\right)$$

for $treated = UK, FR$ and if $(t, l) \in \mathcal{T}^{treated}$, and we let $DID_{treated,t,l} = 0$ otherwise. $DID_{treated,t,l}$ is the DID estimator comparing the evolution of the sugar content in grams per 100ml of SSBs from period $t - l - 1$ to t (e.g from 2019 to 2015 if $l = 3$ for the United Kingdom) in France or the United Kingdom and in countries belonging to the countries control group from 2010 to year *t*. De chaisemartin and D'Hautefeuille (2021) shows that the latter evolution is a counterfactual of the evolution that would have taken place in France or the United Kingdom if it had not announced/implemented the tax for the first time *l* years ago, under the assumption that the expectation of the outcome of countries that have not announced/implemented the tax follows the same evolution over time (*common trends assumption*). De chaisemartin and D'Hautefeuille (2021) shows that $DID_{treated,t,l}$ is an

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[10] Below, we will see the French excise tax had no effect in the 4 years following its implementation.

unbiased estimator of the cumulative effect of having announced/implemented the tax for *l+1* years.

Placebo estimators: Plausibility of common trend hypothesis

The key identification assumption behind our empirical strategy is that the trends of the mean sugar content would have been the same in both the countries control and France or the United Kingdom in the absence of SSB tax. In other words, any selection bias implied by using data from Germany, the Netherland, Italy and Spain to build the counterfactual and not captured by the fixed effects is either constant over time, or, if it does evolve over time, the evolution is linear. This critical assumption is not directly testable, but to assess its plausibility de Chaisemartin and D'Hautefeuille (2021) propose "long-difference" placebo estimators computed using pre-policy observations. (6) Following their analysis, we define

$$DID^{pl}_{treated,t,l} = \left(Y_{treated,t-2l-2} - Y_{treated,t-l-1}\right) - \sum_{c:F_{c,1}>t} \frac{N_{c,t}}{N^{nt}_{t}} \left(Y_{c,t-2l-2} - Y_{c,t-l-1}\right)$$

if $(t,l) \in \mathcal{T}^{treated}$, and we let $DID^{pl}_{treated,t,l} = 0$ otherwise. The *lth* placebo estimator, $DID^{pl}_{treated,t,l}$, compares the evolution of the sugar content in grams per 100ml of SSBs in a country *c* that has announced/implemented the tax (either France or the United Kingdom) for the first time in year *t-l*, and in countries that have not from 2010 to year *t, as* $DID_{treated,t,l}$, but between periods *t*−2*l*−2 and *t*−l−1 instead of *t*−*l*−1 and *t*. This comparison goes from the future towards the past, to be consistent with event-study regressions where everything is relative to the year prior tax policy announcement/implementation.

If common trend assumption holds, then de chaisemartin and D'Hautefeuille (2021) show that $E[DID^{pl}_{treated,t,l}] = 0$. So finding an estimation of $DID^{pl}_{treated,t,l}$ significantly different from 0 would imply that the common trend assumption is violated: France or the United Kingdom experienced different trend before announcement/implementation of the tax than the countries belonging to the countries control group used to reconstruct France or the United Kingdom counterfactual trend. Thus, the lth placebo assesses whether common trends assumption holds over *l+1* years, the number of years over which the assumption has to hold for the *lth* dynamic effect, $DID_{treated,t,l}$, to be unbiased. These estimators are called *long-difference estimators*.

They differ from the *first-difference estimators*, denoted $\widetilde{DID}^{pl}_{treated,t,k}$, that compare the *t-k-1* to *t-k* outcome evolution in groups treated for the first time at year *t* and groups untreated from 2010 to year *t,* for $k \geq 1$.(7) The long-difference placebos test if common trends holds over several years, while the first-difference ones only test if it holds over pairs of consecutive years. In our setting, $\widetilde{DID}^{pl}_{treated,t,1} = DID^{pl}_{treated,t,0}$. *"If treated and untreated groups follow different linear trends, differential trends will be larger, and easier to detect, over several periods than over two consecutive periods. Then, the long-difference placebos may lead to a more powerful test of common trends"* than the first-difference placebo estimators (citation from de Chaisemartin and D'Hautefeuille, 2021, p17).

Effects of French SSB tax implemented in 2012 on the sugar content of newly marketed SSBs

Table 4: French 2012 SSB tax's instantaneous and dynamic effects on the sugar content of SSBs (in g/100ml), and placebo estimator of the common trends assumption

	# obs	Estimate	Standard error	# obs	Estimate	Standard error
$DID_{FR,2012,0}$		0.078	0.107		-0.058	0.178
$DID_{FR,2013,1}$		0.477^{***}	0.124		0.206	0.695
$DID_{FR,2014,2}$		1.333^{***}	0.162		0.926	1.018
$DID_{FR,2015,3}$		0.971^{***}	0.262		0.428	1.404
Placebo estimator						
$\widetilde{DID}^{pl}_{FR,2012,1}$		-0.671^{*}	0.404		-0.807	0.689
Fixed effects						
Category		N			Y	
Countries control group		IT, UK			IT, UK	

Notes: $DID_{FR,t,l}$ is the DID estimator comparing the evolution of the sugar content in grams per 100ml of SSBs from period t-l-1 to t in France, that implemented the tax in the year t-l=2012 and in countries belonging to the countries control group (Italy, IT; and UK, the United Kingdom) from 2010 to year t. $\widetilde{DID}^{pl}_{FR,t=2012,1}$ stands for the first-difference placebo estimator that compares the mean evolution of the sugar content in grams per 100ml of SSBs from 2010 to 2011 in the two sets of groups used to calculate $DID_{FR,t,0}$. $\widetilde{DID}^{pl}_{FR,t=2012,1}$ significantly different from 0 would imply that the common trend assumption is violated. # obs is the number of long differences of the outcome and of the treatment used in the estimations. The inclusion of country or SSB category fixed effects is indicated by Y; N indicates that is not included in the specification. All standard errors were clustered at SSB level. * $p<0.01$, ** $p<0.05$, *** $p<0.001$.

Effects of French SSB tax implemented in 2012 on the sugar content of newly marketed carbonated soft drinks

Table 5: French 2012 SSB tax's instantaneous and dynamic effects on the sugar content of carbonated soft drinks (in g/100ml), and placebo estimator of the common trends assumption

	Estimate	Standard error
$DID_{FR,2012,0}$	0.399	0.277
$DID_{FR,2013,1}$	0.291	0.245
$DID_{FR,2014,2}$	1.919^{***}	0.409
$DID_{FR,2015,3}$	0.633^{***}	0.029
Placebo estimator		
$\widetilde{DID}^{pl}_{FR,2012,1}$	-1.346	0.999
Fixed effects		
# obs	*194*	
Countries control group	IT, UK	

Notes: $DID_{FR,t,l}$ is the DID estimator comparing the evolution of the sugar content in grams per 100ml of carbonated soft drinks from period t-l-1 to t in France, that implemented the tax in the year t-l=2012 and in countries belonging to the countries control group (Italy, IT; and UK, the United Kingdom) from 2010 to year t. $\widetilde{DID}^{pl}_{FR,t=2012,1}$ stands for the first-difference placebo estimator that compares the mean evolution of the sugar content in grams per 100ml of SSBs from 2010 to 2011 in the two sets of groups used to calculate $DID_{FR,t,0}$. $\widetilde{DID}^{pl}_{FR,t=2012,1}$ significantly different from 0 would imply that the common trend assumption is violated. # obs is the number of long differences of the outcome and of the treatment used in the estimations. The inclusion of country or SSB category fixed effects is indicated by Y; N indicates that is not included in the specification. All standard errors were clustered at SSB level. * $p<0.01$, ** $p<0.05$, *** $p<0.001$.

Effects of British SSB tax on the sugar content of newly marketed SSBs without non-caloric sweeteners

Table 6: British SSB tax's instantaneous and dynamic effects on the sugar content of the SSBs without non-caloric sweeteners (in g/100ml)

	Estimate	Standard error	Estimate	Standard error
$DID_{UK,2016,0}$	-1.495***	0.141	-1.630***	0.050
$DID_{UK,2017,1}$	-2.051***	0.156	-2.319***	0.092
$DID_{UK,2018,2}$	-2.994***	0.001	-3.397***	0.338
$DID_{UK,2019,3}$	-3.598***	0.420	-4.135***	0.863
Placebo estimator				
$DID^{pl}_{UK,2016,0}$	0.119	0.566	0.253	0.464
$DID^{pl}_{UK,2017,1}$	0.605	0.449	0.873***	0.249
$DID^{pl}_{UK,2018,2}$	0.848	1.150	1.250	0.844
Fixed effects				
Category	N		Y	
# obs	486		486	
Countries control group	DU, GE		DU, GE	

Notes: $DID_{UK,t,l}$ is the DID estimator comparing the evolution of the sugar content in grams per 100ml of SSBs without non-caloric sweeteners from period t-l-1 to t in the United Kingdom, that announced the tax in the year t-l=2016 and in countries belonging to the countries control group (the Netherland, DU; Germany, GE; Italy, IT; and Spain, SP) from 2010 to year t. $DID^{pl}_{UK,t,l}$ stands for the placebo estimator that compares the mean evolution of the sugar content in grams per 100ml of SSBs from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{UK,t,l}$. $DID^{pl}_{UK,t,l}$ significantly different from 0 would imply that the common trend assumption is violated. # obs is the number of long differences of the outcome and of the treatment used in the estimations. The inclusion of SSB category fixed effects is indicated by Y; N indicates that is not included in the specification. All standard errors were clustered at country level (1000 replications). * p<0.01, ** p<0.05, *** p<0.001.

Effects of the British and French 2018 SSB tax on the sugar content of newly marketed SSBs without non-caloric sweeteners by soft drink category

Table 7: British SSB tax's instantaneous and dynamic effects on the sugar content of the SSBs without non-caloric sweeteners (in g/100ml) by soft drink category

SSB category	Fruit-flavoured still drink		Carbonated soft drink	
	Estimate	Standard error	Estimate	Standard error
$DID_{UK,2016,0}$	-1.481^{***}	0.500	-1.087^{***}	0.318
$DID_{UK,2017,1}$	-0.812^{**}	0.378	-1.943^{***}	0.178
$DID_{UK,2018,2}$	-2.437^{***}	0.615	-2.628^{***}	0.314
$DID_{UK,2019,3}$	-3.030^{***}	0.865	-3.523^{***}	0.520
Placebo estimator				
$DID^{pl}_{UK,2016,0}$	-0.482	0.462	-0.136	0.261
$DID^{pl}_{UK,2017,1}$	0.484	0.326	0.249	0.638
$DID^{pl}_{UK,2018,2}$	-0.408	0.361	0.256	0.780
# obs	144		312	
Countries control group	DU, GE, IT, SP		DU, GE, SP	

Notes: $DID_{UK,t,l}$ is the DID estimator comparing the evolution of the sugar content in grams per 100ml of SSBs without non-caloric sweeteners from period t-l-1 to t in the United Kingdom, that announced the tax in the year t-l=2016 and in countries belonging to the countries control group from 2010 to year t. $DID^{pl}_{UK,t,l}$ stands for the placebo estimator that compares the mean evolution of the sugar content in grams per 100ml of SSBs from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{UK,t,l}$. $DID^{pl}_{UK,t,l}$ significantly different from 0 would imply that the common trend assumption is violated. # obs is the number of long differences of the outcome and of the treatment used in the estimation. All standard errors were clustered at country level (1000 replications). * p<0.01, ** p<0.05, *** p<0.001.

Table 8: French 2018 SSB tax's instantaneous and dynamic effects on the sugar content of the SSBs without non-caloric sweeteners (in g/100ml) by soft drink category

SSB category	Fruit-flavoured still drink		Carbonated soft drink		Iced tea	
	Estimate	Standard error	Estimate	Standard error	Estimate	Standard error
$DID_{FR,2018,0}$	-0.497^{**}	0.246	-0.418	0.436	-1.232^{***}	0.235
$DID_{FR,2019,1}$	-0.806^{*}	0.457	-0.321	0.379	-0.229	0.212
Placebo estimator						
$\widetilde{DID}^{pl}_{FR,2018,1}$	-0.746	0.909	-0.429^{*}	0.229	0.264	0.319
$\widetilde{DID}^{pl}_{FR,2018,2}$	0.839	0.851	0.051	0.199	-0.239	0.857
# obs	117		170		137	
Countries control group	DU, GE, IT		DU, IT		GE, IT, SP	

Notes: $DID_{FR,t,l}$ is the DID estimator comparing the evolution of the sugar content in grams per 100ml of SSBs without non-caloric sweeteners from period t-l-1 to t in France, that implemented a new design of tax in the year t-l=2018 and in countries belonging to the countries control group from 2015 to year t. $\widetilde{DID}^{pl}_{FR,t=2018,k}$ for k={1,2}stands for the first-difference placebo estimator that compares the mean evolution of the sugar content in grams per 100ml of SSBs from *t-k-1* to *t-1* in the two sets of groups used to calculate $DID_{FR,t,0}$. $\widetilde{DID}^{pl}_{FR,t,k}$ significantly different from 0 would imply that the common trend assumption is violated. # obs is the number of long differences of the outcome and of the treatment used in the estimations. All standard errors were clustered at country level (1000 replications). * p<0.01, ** p<0.05, *** p<0.001.

Table 9: British SSB tax's instantaneous and dynamic effects on the sugar content of SSBs (in g/100ml), and placebo estimators of the common trends assumption

	Estimate	Standard error	Estimate	Standard error
$DID_{UK,2016,0}$	-1.039	0.234	-0.999	0.048
$DID_{UK,2017,1}$	-0.821	0.165	-0.740	0.245
$DID_{UK,2018,2}$	-1.828	0.285	-1.706	0.538
$DID_{UK,2019,3}$	-1.437	0.360	-1.275	0.454
Placebo estimator				
$DID^{pl}_{UK,2016,0}$	0.210	0.052	0.169	0.219
$DID^{pl}_{UK,2017,1}$	0.351	0.008	0.269	0.425
$DID^{pl}_{UK,2018,2}$	0.635	0.356	0.513	0.503
Fixed effects				
Category	N		Y	
# obs	979		979	
Countries control group	GE, IT, SP		GE, IT, SP	

Notes: $DID_{UK,t,l}$ is the DID estimator comparing the evolution of the sugar content in grams per 100ml of SSBs from period t-l-1 to t in the United Kingdom, that announced the tax in the year t-l=2016 and in countries belonging to the countries control group (Germany, GE; Italy, IT; and Spain, SP) from 2010 to year t. $DID^{pl}_{UK,t,l}$ stands for the placebo estimator that compares the mean evolution of the sugar content in grams per 100ml of SSBs from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{UK,t,l}$. $DID^{pl}_{UK,t,l}$ significantly different from 0 would imply that the common trends assumption is violated. # obs is the number of long differences of the outcome and of the treatment used in the estimations. The inclusion of SSB category fixed effects is indicated by Y; N indicates that is not included in the specification. All standard errors were clustered at country level (1000 replications). * p<0.01, ** p<0.05, *** p<0.001.

Effects of the British tax on the percentage of SSBs over the lower levy sugar threshold

Table 10: British SSB tax's instantaneous and dynamic effects on the percentage of SSBs over the lower levy sugar threshold

	Estimate	Standard error	Estimate	Standard error
$DID_{UK,2016,0}$	0.081***	0.026	0.069***	0.005
$DID_{UK,2017,1}$	0.029	0.021	0.006	0.028
$DID_{UK,2018,2}$	0.229***	0.029	0.194***	0.037
$DID_{UK,2019,3}$	0.216***	0.033	0.169***	0.072
Placebo estimator				
$DID^{pl}_{UK,2016,0}$	-0.018	0.045	-0.006	0.029
$DID^{pl}_{UK,2017,1}$	-0.036***	0.013	-0.012	0.047
$DID^{pl}_{UK,2018,2}$	-0.082	0.074	-0.046	0.042
Fixed effects				
Category	N		Y	
# obs	1095		1095	
Countries control group	DU, GE, IT		DU, GE, IT	

Notes: $DID_{UK,t,l}$ is the DID estimator comparing the evolution of the percentage of SSBs over the lower levy sugar threshold from period t-l-1 to t in the United Kingdom, that announced the tax in the year t-l=2016 and in countries belonging to the countries control group (the Netherland, DU; Germany, GE; and Italy, IT) from 2010 to year t. $DID^{pl}_{UK,t,l}$ stands for the placebo estimator that compares the evolution of percentage of soft drinks over the lower levy sugar threshold from t-2l-2 to t-l-1 in the two sets of groups used to calculate $DID_{UK,t,l}$. $DID^{pl}_{UK,t,l}$ significantly different from 0 would imply that the common trends assumption is violated. # obs is the number of long differences of the outcome and of the treatment used in the estimations. The inclusion of SSB category fixed effects is indicated by Y; N indicates that is not included in the specification. All standard errors were clustered at country level (1000 replications). * $p<0.01$, ** $p<0.05$, *** $p<0.001$.

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