Imperial College London

Exploring the impact of food product reformulation on population food choice and diet quality

Mathilde Gressier

January 2022

Department of Metabolism, Digestion and Reproduction

Imperial College London

Submitted in part fulfilment of the requirements for the degree of

Doctor of Philosophy of Imperial College London and the Diploma of Imperial College

ABSTRACT

Background

Poor dietary habits have been recognized as playing a major role in non-communicable diseases. To improve population dietary intake, governments use food reformulation policies aimed at improving the nutrient profile of foods. This thesis aims at understanding how populations and individuals respond to the reformulation of foods.

Methods

Two types of data were used to analyse responses to food reformulation in the UK. The National Diet and Nutrition Survey was used to study the changes in dietary intakes following salt and fibre reformulations. Panels of household purchase were used to study households' responses to sugar reformulation. Adjusted time trends were used to study changes over time. A decomposition method was used to understand how changes in the nutrient density of foods consumed or purchased can be explained by changes in consumer demand for, and supply of, foods.

Results

Food reformulation was linked to improved dietary intake or purchase. These improvements were rather small, but similar across socio-demographic groups. The different decomposition analyses showed that the change in the nutrient density of foods purchased or consumed came mostly from supply-driven effects. Changes in consumer choices had a marginal mean effect, except in the presence of a tax. Further, the extent to which households consumed reformulated products did not influence their change in sugar purchases. Lastly, stronger incentives such as taxes were more effective in promoting reformulation than voluntary initiatives.

Conclusions

Reformulating foods leads to improved dietary intake. Despite being small, these improvements are not negligible and don't widen existing disparities. Taxing unhealthy products produced a change in consumer food choices, while it did not happen in the absence of such taxes. Given the gap between current and recommended dietary intake, policies to incentivise reformulation should be used alongside other policies aimed at improving food choices at the population level.

Declaration of Originality

I hereby certify that this thesis constitutes my own work, supervised by Professors Gary Frost and Franco Sassi. The research presented in chapters 2, 3, 4 and 5 have been published in peer-reviewed journals.

Copyright Declaration

ACKNOWLEDGEMENTS

I would like first to thank my two supervisors: Gary Frost and Franco Sassi, for the invaluable advice, guidance, and mentoring you gave me during these years. Thank you for your time invested in my learning and understanding of how research should be done. This thesis would not have been possible without your support.

I also would like to thank Boyd Swinburn, Karen Watson, and Olivier Allais with whom I had the chance to collaborate during this PhD. Thank you for taking the time to share with me your knowledge and experience, I have learnt a lot from each of you.

“Thanks” should also go to my colleagues Tim Chambers, Charlotte Vrinten, Jack Olney, Elisa Pineda, Tara Li and Harry Tang for your advice on data analyses, writing papers or preparing for conferences. And I also enjoyed spending time with you in the office, kitchen, and virtually!

I also would like to thank the staff of Imperial College and the Graduate School. Special thanks to Lorraine and Dorota, your help was precious during this PhD!

I very much appreciated sharing this PhD journey with Alexa, Anna, Claire, Justine, and Enora. Your advice on PhD-related topics and others helped me to pursue this journey. And I am also grateful for your friendship!

Last and not least, ‘Thank you’ to my family and friends, who supported and encouraged me in this PhD journey.

Acknowledgement of funding:

The first three years of this PhD was funded by an unconditional PhD Studentship grant from Nestlé. Nestlé had no role in the study design, data collection and analysis, or preparation of the protocol and research paper. Thank you to Patrick Detzel, without whom this project would have not started; thanks for giving me the freedom to carry out this research in full independence.

Part of this PhD was funded via a research project commissioned by Public Health England to the Centre for Health Economics and Policy Evaluation (Imperial College Business School). A part of chapter 6 presents the results of a component of this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS/ACRONYMS

BMI	Body mass index
CVD	Cardiovascular disease
EAR	Estimated average requirements
EU	European Union
FAO	Food and Agriculture Organization
FOP	Front-of-pack
FSA	Food Standards Agency (UK)
HHI	Herfindahl-Hirschman index
HIC	High-income country
LMIC	Low- and medium-income countries
NCD	Non-communicable disease
NDNS	National Diet and Nutrition Survey
NGO	Non-governmental organization
NHS	National Health Service
NOS	Newcastle-Ottawa Scale
NPS	Nutrient profiling system
NSP	Non-starch polysaccharide
PHE	Public Health England
PICO	Population, Intervention, Control, Outcome
PPP	Public-Private Partnership
RCT	Randomised controlled trial
SD	Standard deviation
SDIL	Soft Drinks Industry Levy
SE	Standard error (of the mean)
SES	Socio-economic status
SFA	Saturated fatty acids
SRP	Sugar Reduction Programme
SSB	Sugar-sweetened beverage
TFA	*Trans*-fatty acids
UK	United Kingdom
US	United States of America
WHO	World Health Organization

1. CHAPTER 1: BACKGROUND

Firstly, in this chapter, I explore the role of the diet in the prevalence of non-communicable diseases (NCDs) today and in the past century. Secondly, I describe how recent changes in the diet explain the changes in NCDs observed are. Thirdly, I describe how the food system is an important feature to consider in efforts to improve population diets. Fourthly, I introduce the process of food reformulation as a way to improve food products. I then expose the different levers that exist to promote reformulation. Lastly, I review the use and effectiveness of these different levers.

1.1. Dynamics and causes of non-communicable diseases

1.1.1 The recent rise in non-communicable diseases

Non-communicable diseases represent the first leading cause of death worldwide (GBD 2017 Risk Factor Collaborators et al., 2018). The most prevalent NCDs are cardiovascular diseases (CVDs) (such as stroke, myocardial infarction), cancers, and type 2 diabetes. Globally, the rate of deaths caused by NCDs increased by 7.9% between 1990 and 2017 (GBD 2017 Risk Factor Collaborators et al., 2018). The burden of NCDs has overtaken the burden of communicable diseases in most regions of the world, even in developing countries where communicable diseases and neonatal deaths were until recently causing most deaths. For example, while in 1990 the leading cause of death was communicable diseases (infections) in South-East Asia, by 2017 it was NCDs (mostly cardiovascular diseases). Improvements in sanitation, hygiene, education, and medicine contributed to reducing the mortality from infections, hence resulted in a decreased rate of deaths from these diseases. Conversely, the combination of only small improvements in the mortality from NCDs and the growth and ageing of the global population increased the prevalence of NCDs, thus the burden of deaths from these NCDs (GBD 2017 Risk Factor Collaborators et al., 2018).

1.1.2 The role of diet in NCDs

In 2017, poor dietary behaviours were responsible for 11 million deaths worldwide, or 22% of global deaths (Afshin et al., 2019). They were responsible for 38% of deaths in Central Asia, 27% in central Europe, 22% in Southeast Asia but 15% in Australasia or sub-Saharan Africa (Afshin et al., 2019). In the UK, 15% of deaths were attributable to dietary risks in 2017 (Afshin et al., 2019). Causes of NCDs are genetic, metabolic, behavioural, or at the intersection between the three types. Metabolic causes come from an impairment of the metabolism, such as insulin resistance causing diabetes, or impairments of the circulatory system causing high blood pressure. Behavioural causes include tobacco or alcohol use, low physical activity, or poor dietary behaviours. Examples of poor dietary behaviours responsible for a high number of NCDs are a diet high in sodium, low in whole grains, or low in fruits (Afshin et al., 2019). High sodium intake is a risk factor for high blood pressure, and thus CVDs. A diet low in whole grains is at increased risk for diabetes and CVDs. A diet low in fruits is a risk for several cancers, type 2 diabetes and CVDs (Afshin et al., 2019).

1.2. Changes in diet explain the rise in NCDs

The increase in NCDs caused by poor dietary behaviours can be explained by changes in dietary behaviours. These global changes occurred mostly in the 20th century. Such changes are linked to transformations in food production, changing in turn food availability and diets.

1.2.1 Changes in food production and availability

(1) Changes in food production

Advances in agricultural techniques during the 20th century contributed to changing the composition of the diet. Improvements in fertilization, irrigation, and pest control increased production yields. As a result, the energy from foods available per day and per person increased in both high-income countries and low- and middle-income countries (Global Panel on Agriculture and Food Systems for Nutrition, 2016). In particular, the yields of cereals, a staple food providing most calories in traditional diets across the world, greatly improved in the 20th century. Increasing production of cereals was also encouraged by governments to ensure food security.

More recently, the production of agricultural products used as ingredients in processed foods increased (Baker et al., 2020). The use of these agricultural products as ingredients in processed foods made them cheap and accessible. For example, raw sugar productions tripled between 1961 and 2013, while the production of the four major vegetable oil crops (soybean, rapeseed, sunflower and palm) increased by about 20-fold (Baker et al., 2020).

(2) Changes in food availability

The improvement in agricultural productivity meant that the quantity of foods produced increased. In parallel, the average income rose. The number of people living with extreme poverty (defined as people living below the poverty line of US$1.9 per day, valued in purchasing power parity) went from >37% of the world population in 1990 to 12.7% in 2012 (FAO, 2017). Increasing income meant an increased ability to buy food. It also meant being able to buy foods of better quality. Together with increased income, the consumption of foods of a better nutrition quality increased in the world (FAO, 2017).

In addition, increasing income enabled access to other factors that can improve diet quality, such as refrigeration to preserve perishable foods including meat or dairy. However, this increasing income was also linked to increasing access to convenience foods, including discretionary foods, that are high in energy, sugar or saturated fats, but not in vitamins or minerals. In most regions, the consumption of such foods increased faster than the consumption of fresh and nutritious foods (FAO, 2017).

(3) The resulting decline in diet quality

As a result of these changes in food production and availability, the composition of diets in both high- and low or medium-income countries (HIC and LMIC) changed in the second half of the 20th century. The share of daily calories coming from cereals decreased between 1961 and 2011, in favour of an increased proportion of calories from fruits, vegetables, and animal-sourced products (meat, milk and eggs) (FAO, 2017). While in HIC the quantity of cereals consumed stayed stable and the consumption of animal-based products and processed food increased, LMIC experienced an increase in the calories consumed from all sources.

In the early 2000s, around 85% of the world population had enough (or excessive) energy and protein supply (McMichael et al., 2007). Energy and protein supply is a simple indicator of the quantity and quality of foods available to a population. Proteins are an essential macronutrient to the development and maintenance of a healthy body. However, this estimator is not enough to estimate diet adequacy. At the same time that 85% of the world population had enough (or too many) calories and proteins, only 66% of the population had a satisfying level of micronutrients (McMichael et al., 2007). In addition, the increase in calories available did not benefit all parts of the world. The prevalence of undernourishment, defined as dietary energy under the level compatible with a normally active and healthy life, was 8.9% in 2019 (FAO et al., 2020).

1.2.2 Increase in the consumption of processed foods in the 20th century

(1) What are processed foods, and their place in current diets

The term processed food is used to define foods that have been altered “from the state in which they are harvested or raised to better preserve them and feed consumers” (Weaver et al., 2014). Such alterations can include peeling, cooking, or various preservation techniques such as putting the product in brine, smoking, or drying. More complex transformations can also characterise processed foods, involving the mixing of different ingredients or heating. Although some processing can be homemade (such as baking bread) and has existed for thousands of years, the term ‘processed foods’ is mostly used for foods manufactured by food companies.

Today, processed foods represent a major calorie source for all populations, in both LMIC and HIC. For example, 57% of calories consumed in the US in 2003-2008 came from processed foods (Weaver et al., 2014). In the UK, processed foods represented 60% of energy intake in the early 2000s (Slimani et al., 2009). The consumption of processed foods increased between 2006 and 2019 in all parts of the world except in Western Europe and is expected to rise further (Baker et al., 2020). In 2008-14, processed foods contributed to 70% of UK calorie intake (Rauber et al., 2018).

(2) The composition of processed foods

The processing itself does not degrade the quality of foods. As a result, some processed foods are the equivalent of fresh foods or homemade recipes. Frozen vegetables (with no addition of salt) can even have a higher level of certain vitamins or minerals than fresh products as freezing preserves some vitamins (Li et al., 2019). However, most frequently consumed processed foods are not such vegetable-based products, but products with high salt, sugar or fat that are more palatable than homemade foods (Rauber et al., 2018). As a result, most processed foods consumed today are energy-dense and nutrient-poor foods.

Processed foods can be used as a carrier of micronutrients. Some foods such as flour or salt are commonly fortified to bring shortfall nutrients to the diet. Salt is often fortified with iodine, a micronutrient found in marine foods that is often insufficiently consumed in populations living away from oceans. An inadequate intake of iodine can provoke thyroid dysfunction. As such, processed foods are believed to have helped to curb some nutrient deficiencies (Allen et al., 2006).

(3) Concerns about the high consumption of processed foods

The consumption of processed foods is associated with unhealthy diets. Several studies conducted in different parts of the world found that the nutrition quality of food purchases decreased with the proportion of processed foods purchased (Poti et al., 2015; Rauber et al., 2018). Further, a growing number of studies has shown an association between processed food consumption and the health status of a population. The increase in the consumption of processed foods has been linked to an increase in the prevalence of obesity and non-communicable diseases (Swinburn et al., 2019). Observational studies has shown that there were a clear correlation between the consumption of processed foods and deteriorated health outcomes, such as obesity or cancers (Elizabeth et al., 2020).

The nutrient profile of processed foods is not the only factor responsible for the harm their consumption causes, as evidenced by the fact that the associations mentioned above often hold while the nutrient composition of the diet and energy intake are controlled for (Dicken & Batterham, 2021). In addition, an experimental study showed that the consumption of ultra-processed foods was linked to weight gain, independently of their nutrient composition (Hall et al., 2019). This study also tested if factors other than the nutrient composition of processed foods could make them responsible for the rise in obesity and NCDs observed. One hypothesis evoked is their palatability and convenience, increasing the risk of being over-consumed (Hall et al., 2019). In addition to being eaten at a quicker eating rate, processed foods are often low in fibre, a macronutrient known to be linked to satiety and the regulation of the gut microbiota (Tobias & Hall, 2021a).

1.2.3 How changes in the diet explain increases in NCDs

(1) Changes in poor dietary behaviours in LMIC

An increase in the prevalence of poor dietary behaviours explained the shift in the cause of deaths seen in LMIC during the last decades (Popkin, Corvalan & Grummer-Strawn, 2020). An example of this increase in dietary risk factors for cardiovascular diseases can be observed through a shift in blood cholesterol levels. In low- and middle-income countries, non-high-density lipoprotein (a lipid fraction of the blood that is positively associated with CVDs) increased between 1980 and 2018 (NCD Risk Factor Collaboration (NCD-RisC), 2020). This increase was linked to the transition from a starch-based diet to a diet with higher amounts of fat (NCD Risk Factor Collaboration (NCD-RisC), 2020).

(2) Changes in obesity rates, as an indicator of a decline in diet quality

Rates of obesity are increasing in the world (Popkin, Adair & Ng, 2012). This problem was first noticed in the United States and Europe in the 1980s but also affects LMIC (Popkin, Adair & Ng, 2012). The overweight and obesity prevalence in women living in developing countries increased by 0.7 percentage points per year between 1989 and 2007 (Popkin, Adair & Ng, 2012). The prevalence of obesity was strongly correlated with socio-economic status and demographics: in most LMIC included in the study, having a higher socio-economic status was associated with an increase in obesity prevalence (Jones-Smith et al., 2011).

This increase in obesity rates is believed to have been caused by changes in the environment (Rodgers et al., 2018). Changes in the environment included changes in agriculture production making food cheaper, and changes in the built environment resulting in fewer opportunities for physical activity. In industrialized countries, during the second half of the 20th century, the increase in dietary energy available happened simultaneously to changes in lifestyles characterised by a decreasing level of physical activity (World Health Organization, 2002). This shift from manual occupations to desk-based occupations increased sedentary time. The increase in income enabled both the access to more calories and individual cars. In addition, there was a rise in city designs promoting the use of individual cars and the development of entertainment on screens (Sallis & Glanz, 2009).

The influence of the built environment and the food environment on obesity can explain the differences in obesity levels observed in LMIC. In 2007, urban women were more likely to be overweight or obese than rural women, with a prevalence of 37.2% and 19%, respectively (Popkin, Adair & Ng, 2012). In opposition to this trend, a more recent study found that the current rise in obesity levels in LMIC was explained by a rise in obesity in rural areas, areas that had before a lower prevalence of obesity (NCD Risk Factor Collaboration, 2019). That suggests that the health status of rural areas of LMIC is following similar patterns to the changes in urban settings, where changes in food availability and in the built environment have contributed to the increasing levels of obesity (NCD Risk Factor Collaboration, 2019)..

1.3. The role of the food system and the food environment in shaping diets

Any intervention aimed at improving the diet of populations should take into consideration the way foods are produced and distributed, i.e., the food system. The Food System is defined by the Food and Agriculture Organization (FAO) as:

> *"[the] entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food products that originate from agriculture, forestry or fisheries, and parts of the broader economic, societal and natural environments in which they are embedded"* (FAO, 2018)

The food environment is defined by what is linking the food system to diets:

> *"Food environment refers to the physical, economic, political and socio-cultural context in which consumers engage with the food system to make their decisions about acquiring, preparing and consuming food"* (High Level Panel of Experts on Food Security, 2017)

1.3.1 The role of the food system in our diets

The food system currently favours unhealthy diets (FAO & WHO, 2018). The change in dietary patterns discussed in the previous section occurred concurrently with changes in the food system. For example, the rise in the share of purchases done in supermarkets contributed to the increase in processed food purchases. After an important growth in the

1960s and 1970s, large and global retailers now dominate purchases in developed countries (Popkin, 2017). The shift from small and specialised shops to large supermarkets happened in the 1990s in Latin America and from the 2000s in Asia (Popkin, 2017; Baker et al., 2020; Reardon, Timmer & Minten, 2012). For example, in Chile, supermarkets made up 10-20% of the retail space in 1990, 50-60% in 2000 and it is now estimated to make 60-80% (Corvalán et al., 2017). While the growth of supermarkets can be praised to have brought safer foods to populations (supermarkets are behind some food safety standards), it was also linked with an increased availability of foods with low nutritional quality (Popkin, Adair & Ng, 2012). Indeed, in the early phase of supermarket growth, their shelves are filled with long-lasting products not traditionally found in smaller shops, meaning that processed foods are the products that make the supermarket gain market shares (Baker et al., 2020).

Given that dietary risks are leading risks of NCDs worldwide, commercial food systems are deemed to be the most important influence on population health globally (White et al., 2020). Changes in the current food system are necessary to make it more compatible with public health, societal and environmental goals (White et al., 2020; FAO & WHO, 2018). Given the food system is complex, the measures to improve it can act at different parts of the food system. Measures can aim at changing food production, from incentivizing crop diversification to favour nutrient-rich commodities (legumes, fruits, vegetables), to changing the way agricultural commodities are transformed before reaching consumers' plates. Measures to incentivize short food supply-chains or reduce food losses are also important for both public health and environmental health. Lastly, food accessibility and availability should be ensured, while the availability of unhealthy foods should be controlled (e.g., by limiting fast foods around schools, or taxing unhealthy foods). The approach of improving each sub-system of the food system is called the 'farm to fork' approach (FAO & WHO, 2018).

1.3.2 Consumer choices in the food environment

The food system defines the food environment people live in; the food environment is the combination of all foods available to people (from shops to canteens and restaurants) and the elements that drive consumer choice, such as cultural background, advertisement, price and promotions (Nutrition and Food Systems Division, 2016). Hence, helping people make healthier choices amongst the food products they are facing should help them have a better diet. There are different means to help people make healthier choices, from education to more subtle nudges such as reducing portion sizes. Education can have various forms (part of schools' curriculum, in product labels or phone applications), and target various elements of the diet. Education is needed to inform people about healthier choices or to learn how and what to cook to have a healthy diet. The time used to cook is reducing (Plessz & Étilé, 2019), while the knowledge appears to be lost in younger generations of some countries (Utter, Fay & Denny, 2017). As cooking skills is associated with better food choices (Hartmann, Dohle & Siegrist, 2013; Monsivais, Aggarwal & Drewnowski, 2014), developing cooking skills in young generations seems to be a necessary investment for their future good health.

Education is also needed to help people choose better processed food. Front-of-Pack (FOP) labelling and nutrition labelling have that aim. FOP labels simplify the information present on traditional back-of-pack nutrition tables. Several studies found that in test conditions, consumers made healthier choices when FOP labels were present (Ducrot et al., 2016; Ares et al., 2018b). However, the ability for consumers to make healthier purchases in real conditions was limited and of a lower magnitude (Dubois et al., 2020). A meta-analysis found that overall, labelling (of all types) decreased energy and total fat intake, as well as the choice of unhealthy options (such as sugar-sweetened beverages (SSB), alcohol, products high in salt, SFA or sugar) but had no effect on saturated fatty acids (SFA) intake (Shangguan et al., 2019). Labels were also linked to an increase in vegetable consumption but had no effect on whole grain and fruit consumption (Shangguan et al., 2019). However, these results need to be nuanced because few studies were found and included that investigated the effect of labelling on SFA, fruits and whole grains.

Other methods to change consumer behaviour are taxes and subsidies. As price is a key driver in the choice of food products, increasing the price of unhealthy foods with taxes and subsidizing the purchase of healthier commodities for the least affluent households can potentially change consumers' diet (Hawkes et al., 2015). Taxation of SSB has gained interest in the past 10 years. A recent meta-analysis found that a 10% increase in price led to a 10% decrease in volume of taxed SSB purchased (with a confidence interval of -5% to -14.7%, showing that differences in policy design or food environment created different consumer responses) (Teng et al., 2019). On the other hand, taxes had a non-significant impact on non-taxed beverages, meaning that consumers were not compensating for the decrease in the purchase of SSB by purchasing more non-taxed products (Teng et al., 2019). The taxation of other foods is less popular. Denmark introduced in 2011 a tax for products high in SFA. It was estimated to be effective in reducing population purchase of SFA and total fat by 4%, to increase vegetable and fibre purchases, but at the same time led to a small increase in salt intake (Smed et al., 2016). The tax was stopped after 15 months for economic motives before its impact on health could have been observed. Hungary introduced a tax on "junk foods", foods having high levels of sugar or salt. The tax has led to a decrease in the quantity of taxed sweets and processed foods in general (Bíró, 2015). The effect of the tax was only visible in the poorest households and disappeared when the economy recovered from the recession (Bíró, 2021).

Some of the strategies described here to help consumers have a healthier diet also have an impact on manufacturers practices. Those are discussed in section 1.5.2.

1.4. Improving food products as a way to improve the food environment

The rise of NCDs has been linked to recent changes in the food environment. One major change is the increasing consumption of processed products, some of which are not nutritionally balanced. An answer to this problem could be to improve the nutritional quality of foods consumed, by reformulating them.

1.4.1 Food reformulation in general

Food reformulation is plainly the action of changing the recipe of a food product. Food manufacturers can reformulate their food products for various reasons, such as to answer consumer trends, optimise production processes or to respond to new legislation (see section 1.5). By design, reformulation is only possible for processed foods made from a recipe with the mixing of different ingredients. Some argue that reformulation is only possible for highly processed foods, and question the fact that these foods could possibly be healthful (Popkin, 2017).

1.4.2 Food reformulation in the context of public health

Recently, the term food reformulation has been mainly used to describe the process done by manufacturers to improve the recipe of their products in a public health context. In that context, reformulation is done to improve the nutrient profile of foods. In the absence of an endorsed definition for reformulation in a public health context, several have been proposed in the literature (Table 1-1). Some definitions focus on the nutrients/components that are consumed in excess (e.g. fats, sugar, salt) (EU Platform on Diet Physical Activity and Health, 2009) while others include nutrients/components that should be consumed more (unsaturated fatty acids, fibre) (Van Raaij, Hendriksen & Verhagen, 2009; National Heart Foundation of Australia, 2012; Popkin & Kenan, 2016). Newer definitions include reducing the use of additives (Srour et al., 2019). Existing definitions of reformulation often exclude nutrient fortification, enrichment, or supplementation (Van Raaij, Hendriksen & Verhagen, 2009; National Heart Foundation of Australia, 2012). Definitions also vary in terminology: the term ‘positive’ reformulation has been used to note changes in composition going in the direction of an improvement of population health (e.g. sodium reduction), versus ‘negative’ reformulation used for changes going in the opposite direction (Savio et al., 2013). The terms ‘covert’, ‘stealth’ or ‘silent’ have also been used to differentiate reformulation efforts that make small improvements often not advertised to consumers from larger changes in products recipe that are often advertised (Popkin & Kenan, 2016).

Table 1-1: Characteristics of food reformulation definitions found in the literature and in texts from health organisations

		Characteristics of reformulation						
Reference	**definition or example***	**health profile / nutrition quality**	**reduction of nutrients/energy**	**increase of nutrients**	**fortification/ supplementation**	**portion size reduction**	**others (flavour, texture, shelf life)**	**specific vocabulary used**
(RIVM National institute for Public Health and the Environment, 2016)	definition		X					
(WHO global co-ordination mechanism on the prevention and control of noncommunicable diseases (GCM/NCD), 2014)	examples		X			X		
(EU Platform on Diet Physical Activity and Health, 2009)	examples		X					
(Van Raaij, Hendriksen & Verhagen, 2009)	examples	X	X	X	X			
(Buttriss, 2013)	examples		X		X			
(Leroy et al., 2016)	examples		X	X				
(Savio et al., 2013)	definition	X	X	X		X	X	positive- and negative-reformulation
(National Heart Foundation of Australia, 2012)	definition		X	X				
(Van Gunst, Roodenburg & Steenhuis, 2018)	definition (adapted from National Heart Foundation of Australia, 2012)		X		no**			
(Popkin & Kenan, 2016)	definition		X	X				stealth vs. Overt reformulation
(Federici et al., 2019)	definition (from Scott, 2017)	X	X	X				
(Scott, Hawkins & Knai, 2017)	definition	X	X					health-specific reformulation
(Kaldor, 2018)	definition	X	X	X				in the context of diet-related NCDs

(Srour et al., 2019)	examples	X			X	
(Jensen & Sommer, 2017)	examples		X	X		silent reformulation

*Some papers used a formal definition of reformulation, others used examples to explain what reformulation means
**it was specified that fortification is not included in reformulation

Improving the nutrient profile of foods has been deemed necessary as some studies link the unbalanced nutrient composition of processed foods to inadequate nutrient intake (Poti et al., 2015; Rauber et al., 2018; Da Costa Louzada et al., 2018). For example, the study by Poti et al. (2015) found that 60.4% of purchases of highly processed foods in the US exceeded at the same time the SFA, sugar and sodium recommendations per 2000kcal, while only 5.6% of purchases of less processed foods exceeded these recommendations (Poti et al., 2015). In the UK, diets with a higher contribution of ultra-processed foods to energy intake were found to have a lower compliance to free sugars, SFA, fibre, sodium and potassium recommendations (Rauber et al., 2018).

1.4.3 Food diversification

To improve the quality of foods available to a population, some manufacturers diversify their product range with more nutritious products, a process called food diversification. Examples include the launch of sugar-free drinks mimicking sugar-sweetened drinks, low-fat yoghurts in the same range as full-fat yoghurts. More recently, food diversification was done in categories that are known not to be healthful, such as confectionery products, or ice-creams. New snack bars were launched with fruits and nuts and positioned as “healthier” alternatives to traditional confectionary or cereal bars. Low-fat and/or high-protein ice cream were launched as a low-calorie, healthier alternative to ice cream.

Several studies questioned the healthiness of these new ‘healthier’ products. Studies found that this type of product, labelled as being healthy, were not always more nutritious than products with no claim (Rodrigues et al., 2016; Breen et al., 2020). In addition, products with ingredient claims such as ‘containing whole grain’, or ‘no artificial sweetener’ can create a ‘health halo’ where consumers perceive the product to be healthier (Kleef & Dagevos, 2015). The promotion of these products as ‘healthier’ may make consumers believe that these products can be consumed regularly, or in bigger quantities (Cleeren et al., 2016). Using a panel of purchases, Cleeren et al. (2016) studied the effect of the introduction of a new low-fat crisp product in the Netherlands. Confirming lab studies, they found that the introduction of the new product led to a short-term increase in crisps purchases (and of calories from crisps) (Cleeren et al., 2016). Consumers purchased the new product introduced as an addition to their food basket, and not as a replacement to the crisps they were usually buying. They found that this over-purchasing effect lasted in time, with an increase in volume and calories from crisps purchased one year after the introduction of the new product. Further, the abundance of choices may provoke unhealthy eating behaviours (Cohen & Babey, 2012). The multiplication of food product choices creates a stimulating environment, in which decision making requires an effort that can decrease self-control while eating (Cohen & Babey, 2012).

1.4.4 Gradual versus abrupt food reformulation

(1) Effect of gradual or abrupt food reformulation on consumer preference

Reformulating a food product can be done with various levels of intensity. The concept of gradual reformulation means that the improvement of the recipe is done by successive small steps, as opposed to a more radical or abrupt change. In the example of sodium reduction, gradual reformulation means to create successive recipes with a lowered sodium amount, instead of directly creating a recipe with the targeted sodium content. Gradual reduction is intended at reducing the risk that consumers notice the change in recipe, and hence conserving consumers' loyalty. An experimental study tested if the liking of reduced salt products (tomato juices) was different when consumers were facing an abrupt versus a gradual reduction in sodium content (Bobowski, Rendahl & Vickers, 2015). Although the acceptability of the final product (that had the same sodium content in the two arms) was similar in the two groups, the liking was different *during* the trial. After facing for the first time the product that was abruptly reformulated, participants declared more dislike for the product. On the other hand, participants in the gradual reformulation arm showed no change in the liking of the product (Bobowski, Rendahl & Vickers, 2015).

(2) Consumer acceptability of reformulated products

The study by Bowbowski et al. (2015) also showed that the liking of the reduced-salt product was dependent upon consumers' sensitivity to salt. This meant that the extent to which a food can be acceptably reformulated has to be tested on a panel of consumers (Salles et al., 2017). These tests are often done in sensory labs, with a small number of consumers. But they can also be tested at larger scales. In 2016, a French retailer chose to test the acceptability of reformulated versions of its own-brand dessert in selected stores. Consumers were invited to taste a set of four chocolate desserts with different sugar contents (with reductions from 5% to 50% in sugar compared to the commercialized version) (Harel, 2016). The idea was to give consumers the choice regarding what version was "acceptable" for them. Although there was no formal evaluation of this trial, a 30% sugar reduced version is now sold by the retailer, suggesting this version was preferred by consumers.

The gradual reformulation approach is recommended by research (Van Gunst, Roodenburg & Steenhuis, 2018), and adopted by governments and non-governmental organisations (NGOs). The UK salt reformulation is one example of such gradual reformulation, where successive sets of guidelines were published in 2009, 2011 and 2014 to promote a gradual reformulation (Public Health England, 2020c). In Austria, an NGO publishes a “checklist” with beverages having a sugar content below a certain threshold. The criteria to be in that checklist is planned to be regularly updated to promote gradual reformulation (Luger et al., 2018). Based on a similar theory of consumer behaviour, researchers showed that a gradual reduction in the portion size of discretionary foods would lead to a reduction in energy consumption (Hollands et al., 2015).

Although gradual reduction looks more promising than an abrupt reduction in not disrupting consumer behaviour, it may be difficult to implement for manufacturers. In the study by Bobowski et al. (2015), 13 different tomato juices were created in the gradual reduction arm. This may be not feasible in an industrial context, given the time to industrially produce a new version of a product, plus the time needed to adapt the supply-chain for the new version.

(3) Combining gradual and abrupt reformulation in practice

Gradual reformulation is a lengthy process, and governments could choose to combine both gradual and more abrupt reformulation to combine the benefits of both approaches. The Danish Whole Grain partnership is an example of such. The most visible action from this campaign was the launch of new products with the whole grain logo or the reformulation of existing products to make them compliant with the whole grain logo (Lourenço et al., 2019). At the same time, manufacturers committed to add gradually whole grain flour in products made of refined grains (Watson, 2019). This silent improvement aimed to bring the benefit of whole grains to consumers reluctant to switch from refined to whole grains. This second action was deemed necessary as some consumers were reluctant to switch to whole grains and prefer “white” products. The “taste cost” of changing habits should not be neglected, and gradual reformulation could contribute to lower this cost (Cobiac et al., 2019).

1.5. The levers of food reformulation

1.5.1 Changing food products’ recipes is a familiar process for manufacturers

Food manufacturers are used to renovating their products by changing their recipes. Renovation of food products is part of the usual functioning of food producers.

Manufacturers renovate their products' recipes to answer consumer trends, optimize their production chains, or anticipate regulations.

(1) Answering consumer trends

First, manufacturers update their recipes to respond to consumer trends. An example of a change in product recipes driven by consumer trends is the move towards packaged foods with reduced fat contents. This trend started in the 1970s when consuming low-fat products was perceived as the solution to the growing obesity rates the US was facing (Mozaffarian, Rosenberg & Uauy, 2018). Manufacturers answered that trend by renovating their products' recipes and introducing low-fat products.

Consumer trends can also promote reformulation that modifies the type of recipe used. In the last decade, manufacturers answered the consumer trend for a 'clean label' by reducing the use of additives in their food products (Mintel Press Team, 2015). The 'clean label' trend is a consumer-driven trend and appeared in the 2010s with a change in consumers' priority while food shopping. An increasing number of consumers declared paying attention to the ingredient list of products they were buying, favouring products that contained no (or the least amount of) artificial ingredients such as artificial preservatives, flavours, colourings (Sloan, 2015). Examples of product renovation to get a food product with a 'clean label' are products renovated to have "no additives" or "no preservatives." The 'clean label' trend also pushed manufacturers to introduce new products in the market, for example, the launch of Coca-Cola Life sweetened with sugar and Stevia, a natural sweetener.

(2) Reaction to regulation

The second reason manufacturers may change the recipe of their products is to answer or anticipate safety regulations. In 2007, a molecule found in several food colourings was found to be linked to hyperactivity in children. The use of such colouring was hence discouraged by the Food Standard Agency (FSA) (University of Southampton, 2007). The European Parliament adopted a similar approach by requiring products containing those colourings to have a claim about the risk of the food colouring with hyperactivity in children (European Parliament, 2008). The media reported that some manufacturers *voluntarily* decided to change the recipe of their products to avoid having to claim the possible health risk of the ingredients they were using (Ball, 2009). In that example, not changing the recipe of their products represented a risk of losing consumers, as the claim could refrain parents to buy products representing a health risk to their children.

(3) Changing a product recipe to reduce production costs

Lastly, manufacturers are known to update their recipes to optimize their production process and cost. For example, manufacturers may update their recipes so that different products use the same ingredients. The reduction of the number of ingredients used in a factory can represent an economy of scale as fewer ingredients are needed. Also, retailers could change the manufacturer of their private label products to get a product with a lower cost (Bourlakis & Weightman, 2008).

(4) Dynamics between brands

In a competitive market, manufacturers follow closely what their competitors are doing. If reformulating a food creates a competitive advantage, the fact that a manufacturer reformulates its product could incentivize other manufacturers to reformulate their products. The dynamics of reformulation are not well understood, and the influence of competitors' actions on reformulation dynamics has not been investigated. Many studies have noted a wide range of nutrient content for similar products (Ziauddeen et al., 2015; Vin et al., 2020). Such variations demonstrated that reformulation was feasible for these products, as optimized recipes existed in the market. Also, studies comparing the content of private labels vs. branded products did not find a clear pattern: most found no difference in nutrient content between the two segments. There were few differences in specific products or categories, but they were not the norm (Lappi et al., 2020; Perrin et al., 2018). This can be the result of reformulation from both private labels and branded products to keep the nutrient profile of similar foods alike.

(5) The cost of reformulation

However, changing recipes has a cost for manufacturers. First, there is a direct cost linked to the development of the new recipe itself as product developers spend time developing different recipes. Those different recipes are tested with a panel of consumers to ensure the reformulated products are satisfying. Production processes might need to be adapted to the production of the new recipe, and the procurement and distribution of new ingredients might need to be included in supply chains.

Secondly, changing a recipe may represent a cost to manufacturers as it may be a risk of losing consumers if they dislike the new product. When manufacturers change the recipes of their products as part of their usual renovation cycle, they expect that the cost of changing the recipe will be compensated by the sales of the new product. Changing recipes to follow consumer trends is expected to create a new market for consumers or attract new consumers. Hence, the cost of changing recipes is expected to be covered by increased sales of the newly developed products. When the renovation is driven by the aim of reducing production costs, the cost of reworking the recipe is expected to be covered by the economy of scale obtained. Similarly, recipes may be reworked to change a product's size to manufacture it in the production line of a similar product. The costs linked to the update of the recipe are supposed to be met with the savings from an optimized production process.

1.5.2 How governments and civil society can incentivize manufacturers to reformulate their foods in a public health context

Given that manufacturers are used to the process of changing the recipe of their products, reformulating them in a public health context should be technically possible. However, as reformulation is costly to manufacturers, it is unlikely to happen in the absence of financial consequences. Some manufacturers voluntarily reformulate their products as part of their corporate political responsibility, either alone or in associations of manufacturers (Scott, Hawkins & Knai, 2017). However, the efficiency of such industry-led actions is debated, one reason being that industry pledges often relates to actions that are already implemented. For example, 91% of companies signing the part of the UK responsibility deal on removing TFA had already removed TFA from their products (Knai et al., 2017). Similarly, some US companies signed a pledge to reduce calories in drinks while their sales of sugary drinks were declining (Ng & Popkin, 2014)(see a detailed explanation in section 1.5.3). As a result, external incentives for reformulation are suggested to promote reformulation (Requillart & Soler, 2014). Different types of incentives can promote reformulation, and they can be implemented by various actors: governments, civil society, or NGOs.

(1) Praising reformulation efforts, and denouncing the absence of reformulation

In the absence of sufficient reformulation by manufacturers, civil society has some power to make them reformulate their product through a 'blame and shame' approach. Such an approach consists in making adverse publicity for manufacturers whose products are less nutritious while praising the action of manufacturers having more nutritious products. This can incentivize reformulation, for manufacturers who care about their image. The UK NGO Action on Salt and Sugar uses this approach by frequently denouncing brands performing worse in a category (He, Brinsden & MacGregor, 2014). Another example from civil society that uses the principle of blame and shame is the Access to Nutrition initiative that ranks the world's biggest food companies according to the nutrition quality of their products and their actions to promote nutrition (Access to Nutrition Foundation, 2018). The initiative evaluates at the same time the reformulation efforts from manufacturers and the nutritional profile of food products in each manufacturer portfolio. The index is said to be used by investors and hence could incentivize manufacturers to revise their products or commitments to get investors' money (Access to Nutrition Foundation, 2018). Similarly to the Access to Nutrition

Initiative, the Business Impact Assessment – Obesity and population nutrition (BIA-Obesity) initiative benchmarks food and beverage companies on their nutrition strategies (Robinson, Blake & Sacks, 2020). An evaluation of the Australian BIA-Obesity initiative found that approximately 50% of companies in Australia participated in the evaluation by providing data. There was a bias in participation as participating companies had a higher score (i.e., a better nutrition strategy) than companies that declined to participate. A participating company declared that participating in the benchmark led them to focus on reformulation strategies (Robinson, Blake & Sacks, 2020). This shows that such public evaluations of companies can incentivize reformulation.

(2) Dietary guidelines

Governments can issue regulations to incentivize manufacturers to reformulate, with different levels of incentives. A way that can subtly incentivize reformulation is through dietary guidelines. The primary aim of dietary guidelines is to educate populations about healthy diets. Most of them are giving recommendations about food groups, guiding populations about the adequate portions that should be eaten of food groups such as vegetables, meat, grains, or legumes. Some recommendations guide consumers to choose healthier products in a range of foods. For example, in Slovenia and the UK, the population is asked to prefer low-fat dairy when consuming dairy products (Herforth et al., 2019). These examples of guidelines encouraging a specific type of (processed) product inside a food group can encourage manufacturers to reformulate so that their products match the recommendations. An example of such dietary guideline triggering reformulation is the recommendation for whole grain in the US. In 2005, the US Dietary Guidelines for Americans introduced for the first time in US dietary guidelines a recommendation about whole grain consumption (Mancino, Kuchler & Leibtag, 2008). The guideline recommended consuming whole grain products instead of the refined grain products usually consumed. For example, Americans were suggested to consume wholegrain bread instead of white bread, or whole grain rice instead of white rice. The guidelines were effective to change consumer purchases: a 13% increase in purchases of whole grain products was observed two months after the release of the guidelines (Mancino, Kuchler & Leibtag, 2008). Also, the number of products in the market with whole grains increased, showing that the guidelines were effective to promote reformulation and the launch of new products with whole grains (Mancino, Kuchler & Leibtag, 2008).

(3) Labelling laws

Labelling laws provide a low level of incentive for reformulation, but a stronger level than dietary guidelines (Kaldor, 2018). Contrarily to dietary guidelines that create an incentive as the result of a hybrid market and policy approach to reformulation, labelling creates a more direct incentive as labels are present on all food products (Kaldor, 2018). Labels provide information to consumers, who can choose a product according to its nutritional characteristics. In particular, FOP logos provide simplified information to consumers to help them choose the healthier option between similar products. Labels (whatever the place or format) have been shown to improve consumer choices (Shangguan et al., 2019). Given this ability that labelling has to steer consumer choice towards healthier products, manufacturers can answer by reformulating their products such as they appear with a favourable label. A systematic review showed that labelling (both as detailed nutrition information and FOP labels) made manufacturers reformulate their products (Shangguan et al., 2019). Logos can either highlight products with better or lesser nutritional quality. A system using the latter principle is the one implemented in 2016 in Chile where products with high levels of sugar, sodium or SFA are labelled with a black warning signal. Research showed that after 6 months of implementation, 10% of products were reformulated to avoid the logo (Reyes et al., 2020). A system using the former principle of highlighting products with a better nutritional quality is the Danish Whole Grain Partnership logo. Its aim was to both drive reformulation and consumer demand towards whole grain products (Lourenço et al., 2019). The logo was created by the government via the national public health agency. It was used in educational campaigns about the health benefits of whole grains, and on products satisfying criteria defined to identify whole grain products that also had a favourable nutrient profile. The logo enabled manufacturers to advertise the added value of their products with a better nutrient profile, so it made manufacturers reformulated their products to comply with the logo criteria.

(4) Advertisement restriction

Regulation of advertising itself can also be a strong incentive for manufacturers to reformulate their products. Restricting marketing to children is growing, and some countries such as the UK use nutrient profiling models to classify products that can or cannot be marketed to children (Rayner, 2017). Such criteria incentivize food manufacturers to reformulate their products to comply with the criteria. In Chile, the definition of the FOP warning labels was used to discriminate foods that can or cannot be advertised to children: a food with a logo denoting a too high level of sugar, salt or SFA cannot be advertised to children under 14 years of age. The announcement of the law created a small incentive for reformulation, with less than 2% of products were reformulated enough to avoid the warning labels (Kanter et al., 2019). However, after 6 months of implementation, about 10% of products were reformulated (Reyes et al., 2020). In the UK, the introduction of advertisement restriction based on the nutrient profile of foods is currently debated, and reformulation is one benefit advanced to defend this measure (Department for Digital & Department of Health & Social Care, 2021).

In today's society, social media are a major support of advertising. In 2017, about 8 billion GBP was spent in the UK to advertise in traditional media (TV, newspapers, outdoors), while 10 billion GBP were spent on digital media (paid searches, displays) (Guttmann, 2021). Restricting advertisement of unhealthy commodities to children on these platforms is more challenging as children can use platforms that are not intended for such a young audience. In addition, influencers have a growing role in advertising, and they tend to replace advertising with celebrities (Schouten, Janssen & Verspaget, 2020). Their role should not be neglected as they have the capacity to reach lots of people via their high numbers of followers. Also, people feel closer to influencers, increasing the adoption of the product endorsed (Schouten, Janssen & Verspaget, 2020). This is particularly true for young adults who use massively social media. The role of social media influencers should be acknowledged in future regulations about marketing, to ensure broad coverage of the media and hence create strong incentives for reformulation.

(5) Taxation

More stringent incentives can be created by engaging the financial profitability of manufacturers, for example by implementing taxes. Excise taxes are taken directly from the manufacturer. An example is the UK Soft Drink Industry Levy (SDIL) that taxes soft drink businesses based on the amount of sugar in the product they sell. The tax has three tiers, based on the sugar content per litre of beverage. Also, taxes can be applied to consumers (at the point of purchase). Applying the tax on consumers intends to make taxed products more expensive than non-taxed products. This also creates a reformulation incentive, as the demand may be shifted towards cheaper products.

To effectively promote reformulation, the amount of the tax should vary with products' sugar content. A tax applied on all products from a category would not be effective in promoting reformulation as it would mean that reformulation does not allow to reduce or avoid the tax. A tiered tax (such as the UK SDIL) provides an incentive to reformulate, especially for products that are close to the threshold. Half of the energy drinks sold in both 2015 (before the announcement) and 2017 (after the announcement, pre-implementation) had been reformulated. Half of reformulated products changed their taxation category, representing 25% of products present in the market in 2015 and 2017 (Hashem, He & MacGregor, 2017). In South Africa, the tax on SSBs is based on the sugar content of drinks. Studies have not evaluated the impact of this tax on reformulation specifically yet. But early results showed that the tax was linked to a higher proportional reduction in sugar than in volume one year after the tax (Stacey et al., 2021).

However, if the thresholds are too strict, manufacturers could prefer launching new products rather than reformulating existing products. Focusing on new product development instead of reformulation is a response that manufacturers had for policies that they were opposed to. For example, manufacturers focused on new product development instead of reformulation in the consultation about the UK Responsibility deal on calorie reduction (Panjwani & Caraher, 2014). Indeed, performing major changes on best-selling products can create a risk of losing consumers. Manufacturers could mitigate the effect of the tax by launching a new product derived from the original one, formulated so that it will not be taxed. The new product is launched while the original product remains on the market, leaving consumers the choice between products. But this will mitigate the effect of the tax on consumers purchases as the less healthy product would be still available (see section 2.3.3).

A proportional tax (i.e., a tax which amount is set proportionally to the nutrient content) would create the best incentive for reformulation as even a small reformulation would have consequences on products price. A study found that taxing SSBs based on their sugar content (using either tiers or a proportional tax) led to higher decreases in sugar consumption than a tax based on volumes of SSB (Salgado Hernández & Ng, 2021).

(6) Promoting voluntary reformulation

Before implementing mandatory targets, governments may wish to try voluntary reformulation. Voluntary guidelines are more accepted by manufacturers, as they have more flexibility to reformulate at their own pace. The guidelines are often built in consultation with the food industry, under public-private partnerships (PPP). These consultations ensure that the targets are accepted by the food industry, which is asked to do the reformulation. Governments benefit from these consultations as setting unrealistic targets (i.e., too stringent) is a risk to see no reformulation happening. Because manufacturers participate in the initiative, they are accountable for the reformulation they implement.

Voluntary targets are criticised because they often fail to create enough incentive. Although the salt reduction programme of the UK government was successful to make manufacturers reformulate their products (Laverty et al., 2019), the similar UK sugar reduction campaign does not seem to be effective in reducing the sugar content of all food categories (Public Health England, 2020e). One element that could have worked in the salt reduction campaign is said to be the threat that these guidelines would become mandatory (He, Brinsden & MacGregor, 2014). If manufacturers did not reformulate enough their products to meet the voluntary targets, the UK Department of Health could have imposed mandatory standards (He, Brinsden & MacGregor, 2014). In comparison, the sugar targets are not discussed to become mandatory if not enough efforts are made by the food industry. But another threat exists as sugar taxation started in the UK with drinks, and is discussed to be expanded to other categories (Scheelbeek et al., 2019; Smith et al., 2018a).

(7) Implementing formulation standards

The strictest approach to incentivize reformulation is to make it mandatory. Different jurisdictions have launched mandatory regulation of industrially-produced *trans*-fatty acids (TFA) in foods, justified by their harmful effect on health. Denmark was one of the first countries to ban the use of TFA in foods in 2004 (even if it is called a ban, the law implements a limit at 2g TFA/100g of fat). In the US, New York City restricted the use of TFA in restaurant foods in 2007. Other countries and local jurisdictions followed these two examples and implemented TFA restrictions. Those strategies were effective to drive reformulation (Hyseni et al., 2017a; Downs et al., 2017). Reformulation was done by substituting the fats containing industrially-produced TFA with SFA, which impact on health is less harmful. The harmful effect of TFA on health may have contributed to making mandatory reformulation acceptable to industries and populations (Bloks, 2019).

Mandatory reformulation thresholds also exist for sodium. Some countries have only one food category targeted, mostly bread, after having been identified as a main carrier of sodium in the diet (e.g.in the Netherlands, Greece, Portugal) (Trieu et al., 2015). Other countries such as South Africa or Argentina have mandatory standards for salt content in most foods (Trieu et al., 2015).

1.5.3 Feedback loops between consumer demand and manufacturers' decision to reformulate

As seen in the previous section, the options for governments to incentivize reformulation lie along a continuum between market approaches where consumer demand drives reformulation, to mandatory limits imposed by governments (Kaldor, 2018). Changes in consumer demand have an important role in driving reformulation in all types of incentives (except for mandatory targets). When governments launch dietary guidelines, FOP labelling, or taxation they are aiming to steer consumer demand towards more nutritious products. The consequence of a change in consumer demand is a reaction from manufacturers, who would reformulate to match new consumer demand.

For example, the implementation of the 2005 US Dietary Guidelines for Americans, in which the consumption of whole grains was recommended for the first time in US dietary guidelines, is an example of a double incentive for reformulation. As consumers were asked to consume more whole grain products, the demand was steered to those products. Also, manufacturers could gain market shares by reformulating their products with whole grains. Mancino, Kuchler and Leibtag (2008) investigated the reasons behind the increase in whole grain sales that was observed. They found that manufacturers responded to the guidelines by changing the food offer (Mancino, Kuchler & Leibtag, 2008). Refined-grain products were reformulated with whole grains, and new products made of whole grains were introduced on the market.

The success of the new whole grain guideline was unexpected as other guidelines, such as the one about fruit and vegetable consumption that existed for a long time in the US dietary guidelines, were not so successful in changing population dietary habits. In the analysis of the effect of the whole grain guidelines, the role of manufacturers, rather than a shift in consumer demand, was shown to be the cause of the increase in whole grain products (Mancino, Kuchler & Leibtag, 2008). Indeed, the sales of raw whole grain products (such as whole grain flour, whole grain rice) did not increase as much as the sale of processed products containing whole grains as an ingredient. The response from manufacturers to the new guidelines provoked the increase in whole grains in consumers' baskets (Mancino, Kuchler & Leibtag, 2008). We can assume that the new whole grain guideline created an opportunity for manufacturers (for whom it was feasible to design products with whole grains). Conversely, guidelines on fruits and vegetables may not produce such an effect on manufacturers. One reason could be that consumer demand is not sufficient. Also, fruit and vegetable-based products are more expensive than other ingredients used by manufacturers, and reformulating products to add more fruits and vegetables may be too expensive. This example shows that changing consumer demand may depend on how manufacturers will respond to the incentive by developing new products.

Similarly to what happened in the US, the uptake of manufacturers developing new products had a crucial role in the Danish Whole Grain Partnership. The implementation of the logo was correlated with an increase in the number of products carrying the logo, and with an increase in whole grain intake (Greve & Neess, 2014). Whole grain products were developed to anticipate a shift in demand provoked by education campaigns on whole grains. The logo created a two-fold incentive for manufacturers: demand was created for whole grains, and it was possible to advertise the whole grain content of products (in the absence of this logo, claims are regulated with an EU regulation restricting the use of claims that are not on a list). Like in the US, the offer was changed before the demand could be modified: manufacturers reformulated their products to give consumers the choice to consume whole grain products.

However, it can be difficult to disentangle the role of changes in offer and changes in demand in the effect of reformulation initiatives. Such bidirectional effects were observed in the evaluation of the Healthy Weight Commitment Foundation pledge. This initiative was created in 2010 by major manufacturers of packaged foods and drinks in the US, with the aim to help reduce obesity, especially in children. Manufacturers taking part in this pledge committed to reducing the amount of energy they put on the US market. Crude results suggested that manufacturers went beyond the committed reduction in calories, with a 6.4 trillion calorie reduction by 2012, exceeding by far the initial objective of a 1.5 trillion calorie reduction by 2015 (Ng, Slining & Popkin, 2014). This reduction was achieved by a combination of reformulation (and the launch of less energy-dense products) and a loss of market shares by companies partaking in the pledge. The loss of market shares indicates a change in consumer demand. However, this calorie reduction may result only from the pledge. Another evaluation of the pledge found that the reduction in calories sold by partaking manufacturers was actually smaller than the reduction predicted from pre-existing trends (Ng & Popkin, 2014). The commitment has been denounced as a mockery to hide companies' loss of market shares (i.e., a change in demand). The pledge happened after the Great Recession of 2007-2009, during which the value of food purchased decreased. It is possible that during this period, consumers turned away from famous brands, being often more expensive than retailer brands. Around 2010, the economy started to recover from the Recession, and it is possible that consumers started to consume again branded products (under the influence of marketing, supposedly even part of the commitment). This shows how consumer demand and manufacturers response are closely intertwined, making causal inferences difficult to make.

1.6. Focus on food reformulation in the UK

Foods available in the UK have been reformulated in different settings. Salt and more recently sugar were targeted in government-led programmes. The removal of TA by reformulation was done in the context of industry pledges.

1.6.1 Government-led reformulation programmes

The UK reacted to the WHO call to limit salt intake of populations by launching a salt reformulation campaign in 2003 (Wyness, Butriss & Stanner, 2012). The strategy was first launched by the FSA and one of its key features was a set of voluntary reformulation targets defined by food category. Manufacturers were incentivised to reformulate their products through the threat of these targets becoming mandatory if not enough reformulation was done (He, Brinsden & MacGregor, 2014). In 2011, the FSA strategy was replaced by the Responsibility Deal, a public-private partnership in which manufacturers voluntarily agree to improve the foods they produce, including by reformulating foods (Laverty et al., 2019). The threat of making the targets mandatory became less clear and the monitoring was weaker, making the Responsibility Deal a weaker incentive for reformulation (Laverty et al., 2019; Knai et al., 2015).

A similar reformulation programme was launched as part of the Childhood Obesity plan to reduce the sugar content of foods (HM Government, 2016). A set of voluntary reformulation targets were set, similarly to the salt reduction targets. The initial objective was to reduce by 20% the average sugar content of each food category contributing the most to UK population sugar intake (HM Government, 2016). The sugar reformulation programme was launched together with the SDIL, that was an additional incentive to reformulate drinks (see section 1.5.2(5)). More recently, the UK government launched a strategy to reduce energy content of foods (Public Health England, 2020e).

1.6.2 Manufacturer-led reformulation strategies

In addition to government-led reformulation policies, food manufacturers are engaged to reformulate their foods. As introduced above in the context of salt reduction, the Responsibility Deal was set to encourage public-private partnerships in which manufacturers committed to improve their products (Knai et al., 2015). Another nutrient than salt often targeted in the Responsibility deal was TFA (Knai et al., 2017). However, an evaluation showed that the Responsibility Deal had limited impact on the TFA content of foods as manufacturers involved in pledges had already removed TFA from their foods, while the ones still using TFA were not involved in pledges (Knai et al., 2017).

In addition, some manufacturers committed to reformulate their foods. Soft drinks manufacturers started reformulating their foods before the SDIL was announced (Bandy et al., 2020).

1.7. Evaluation of the use and the effectiveness of different incentives to promote food reformulation

Many food reformulation initiatives were launched around the world in the past decades. These initiatives had different settings and used different designs. To map initiatives launched and understand their design, we conducted a systematic review of the literature. This review can also be used to identify what designs were effective to drive reformulation of food products.

1.7.1 Methods of the systematic review

This review was initially designed as a subpart of the review presented in Chapter 3. Here, we selected studies corresponding to a specific outcome (food composition), as described below. The methodology was adapted from the Cochrane methodology (Anon, 2011) and the GRADE guidelines (Anon, 2013).

(1) Research question

The research question for this review was the following: How the design of reformulation initiatives had an impact on the nutrient composition of foods?

(2) Criteria for considering studies for the review

Criteria to include studies in the review were designed following the PICO scheme.

- Participants: population representative of the general population of any country/region
- Intervention: intervention incentivizing the reformulation of food or drink products sold in supermarkets or chain restaurants. Strategies could include voluntary/mandatory reformulation guidelines, taxation based on nutrient content, or nutrition labelling.
- Control: studies should have a control condition (i.e., a similar group that was not subject to the intervention) or a comparator group (i.e., comparison of the same group before and after the implementation of the strategy studied).
- Outcomes: food composition. Only this outcome was considered in the scope of this review, as a measure of how manufacturers reacted to the reformulation-promoting initiatives. Outcomes as sales- or purchases- weighted food composition (i.e., mean composition of food purchases or sales) were also included.

Only empirical studies were included; studies modelling the possible food composition resulting from the implementation of a reformulation initiative were excluded.

(3) Search strategy

Three databases were searched: Medline, Embase, and the Health Management Information Consortium databases. The search was built using keywords and database-specific medical subject heading (MeSH) terms. The search was built on Medline and adapted to the two other databases. The search strategy was initially done together with the systematic review in chapter 3 about the impact of reformulation on consumers intake and health. The outcome included in this review (food composition) was later excluded from the review in chapter 3 as this outcome allows to respond to a different question than the impact on consumer health, namely the question of this review.

Grey literature was also explored, to include in the review reports of initiatives that were not published in journals. These reports were searched using the NOURISHING database of reformulation initiatives (World Cancer Research Fund International, 2018) and following recommendations from experts[1].

The search was updated in May 2021 in the scope of a targeted review on comparing the effectiveness of mandatory versus voluntary reformulation guidelines.

(4) Data collection and analysis

Results from the three databases were exported to Endnote, where duplicates were removed. Results were first screened based on title and abstract. Second, I read the full text of selected papers and assessed their content against the eligibility criteria.

Key characteristics of the intervention and the study were extracted in an Excel template. Extracted characteristics include:

- Nutrient(s) targeted
- Time frame and place of the strategy
- Type of strategy promoting reformulation
- Characteristics of the incentive
- Initiators of the strategy
- Type of outcome reported ((weighted) food composition)
- Outcome measured

The outcome reported was classified into three categories: succeeded in driving reformulation, failed to drive reformulation, or mixed results. The success of the policy to drive reformulation was when there was a statistical significant improvement in the nutrient composition of products available, after the implementation of the policy. The use of the statistical significance means that the change may not always be of biological significance. Failure to drive reformulation was when there was no change or change in the opposite direction than the one incentivized by the reformulation policy. The outcome was mixed when there was at the same time successes and failures (for example, between different food categories, or between different nutrients).

(5) Data synthesis

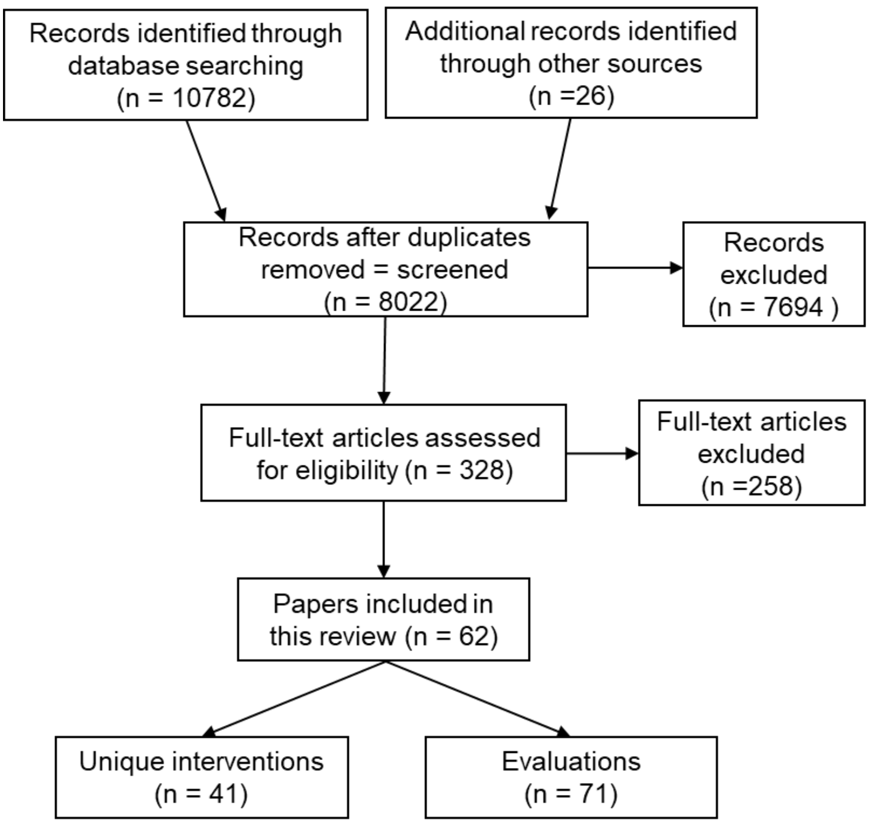
[1] Experts' views were collected during conversations with experts on reformulation. Experts included Boyd Swinburn (University of Auckland, New Zealand), Victoria Targett, Michelle Young and Alison Tedstone from Public Health England (now the Office for Health Improvement and Disparities)

We planned to perform a narrative review of the findings. This narrative review should include the nutrients most frequently targeted, the types of incentives preferred, and who initiated those reformulation strategies. The aim is not to measure the mean effect of reformulation strategies on the composition of food products across all strategies included. Hence, we did not plan to perform a meta-analysis of the results.

1.7.2 Preferred options used to incentive reformulation

The search strategy performed included the outcomes linked to consumer health that are included in the review from chapter 3. Hence, this wide search strategy led to 10 782 results, complemented with 26 from other sources (Figure 1-1). 8022 unique records were screened with their title and abstract, leading to 328 articles screened full-text. After the full-text screening, 62 papers were included in this review.

Figure 1-1: Flow chart of the selection of studies for the systematic review on the use and effectiveness of incentives on promoting food reformulation



(1) Places of included reformulation initiatives

These 62 publications evaluated 41 different reformulation initiatives (Table 1-2). Most studies were from developed countries. Eleven (27%) initiatives were from the US, four from

Australia, and three from the Netherlands. Latin America had some initiatives evaluated, with two in Argentina and Brazil, and one each in Costa Rica and Mexico. It is worth noting that this study only informs about strategies launched *and* evaluated. There are more reformulation initiatives launched around the world, however, if they were not evaluated and published, these initiatives were not included in this study.

Table 1-2: Mapping of initiatives included in the review on the effectiveness of different initiatives to drive food reformulation

Country	Description of the initiative	Type of reformulation	Study focus
Argentina	From 2014 TFA limits 2% of fats in oils and margarine, 5% in other foods	mandatory reformulation	TFA
	Mandatory salt limits, by category. Passed in Dec 2013, came into force in December 2014. Limit for three categories	mandatory reformulation	sodium
Australia	Health Star rating labelling: voluntary since 2014, supported by the Australian and New Zealand governments	information to consumers	energy
	Food and Health Dialogue in 2009 (Framework for governments, public-health groups and industry to work together, including voluntary targets on salt)	voluntary reformulation	sodium
	Calorie labelling in restaurants	information to consumers	energy
	Reformulation of salt in one brand of bread (large-scale experiment)	voluntary reformulation	sodium
Austria	Mandatory labelling of TFA contents	information to consumers	TFA
	Beverage checklist initiative' monitoring and disclosing the sugar content of drinks	information to consumers	sugar
Brazil	Voluntary agreement to gradually reduce salt in foods	voluntary reformulation	salt
	Mandatory labelling of TFA contents	information to consumers	TFA
Canada	Mandatory labelling of TFA contents	information to consumers	TFA
	Voluntary targets for salt reduction	voluntary reformulation	sodium
Costa-Rica	Mandatory labelling of TFA contents	information to consumers	TFA
Denmark	Ban on TFA from 2003, (passed 01/01/2014)	mandatory reformulation	TFA
	Whole Grain Partnership to increase whole grains in products	information to consumers	whole grains
	Supermarket-led reformulation	voluntary reformulation	several nutrients
France	Public-Private Partnership defining reformulation targets for various nutrients	voluntary reformulation	several nutrients
Ireland	Food and Drink Ireland (trade association) promotes reformulation in the Healthy Ireland initiative	voluntary reformulation	several nutrients
Mexico	Mandatory labelling of TFA contents	information to consumers	TFA
New Zealand	Health Star Rating (front-of-pack labelling using a nutrient profile model) since 2015	information to consumers	several nutrients
	Tick logo (FOP logo) introduced in 1991	information to consumers	several nutrients
The Netherlands	Choices front-of-pack labelling system: voluntary labelling since 2006	information to consumers	several nutrients
	Mandatory limits for salt in bread (gradual reduction from 2009, latest amendment in 2013), several industry engagements to reduce salt in their foods	mandatory reformulation	sodium
	Manufacturers' voluntary self-regulation	voluntary reformulation	TFA

Country	Description of the intervention	Type of reformulation	Study focus
Slovenia	Awareness campaigns on TFA	information to consumers	TFA
Spain	Salt reduction in breads (voluntary reformulation by a manufacturer)	voluntary reformulation	sodium
South Africa	mandatory targets on salt content. Signed in 2013. First deadline in 2016, second deadline in 2019	mandatory reformulation	sodium
United Kingdom	FSA salt reduction programme from 2003 to 2011 (agreements with the food industry to reformulate, public health campaigns and nutrition labelling)	voluntary reformulation	sodium
	PHE sugar reduction programme from 2017 (voluntary reformulation targets and soft-drink industry levy)	voluntary reformulation	sugars
	Voluntary reformulation of TFA	voluntary reformulation	TFA
	Soft drink industry levy	voluntary reformulation	sugar
US, California	Restriction on toy giveaways in restaurants	information to consumers	several nutrients
US, New York	TFA restriction in fast food restaurants from 2006 in New York City	mandatory reformulation	TFA
US, Massachusetts	Nutrition standards for competitive foods sold in schools from Massachusetts in 2012-13 (similar to the nationwide standards to be implemented in 2014-2015)	mandatory limit (standards for competitive foods sold in schools)	several nutrients
US	Mandatory labelling of TFA in packaged foods	information to consumers	TFA
	Healthy Weight Commitment Foundation pledge of selling 1.5 trillion fewer calories in 2015 than 2007	voluntary reformulation	energy
	Walmart initiative to improve the healthfulness of food purchases	information to consumers	several nutrients
	Calorie labelling in restaurants	information to consumers	energy
	National salt reduction initiative	voluntary reformulation	sodium
	Voluntary reformulation commitment from restaurants	voluntary reformulation	several nutrients
	Healthy, Hunger-Free Kids Act of 2010 2014: standards for competitive foods	mandatory reformulation	several nutrients
	New dietary guidelines on whole grain intake in 2005	information to consumers	whole grains

Notes: PHE: Public health England; TFA: trans-fatty acids; US: United States of America

(2) Type of incentive mostly used and evaluated

Only a small number of initiatives implemented (9/42) used mandatory reformulation as an incentive for manufacturers to reformulate their products. More interventions provided information to consumers (18/42) as a way to incentivize manufacturers to reformulate their products than voluntary reformulation itself (15/42). These two latter types of initiatives left the choice to manufacturers to reformulate or not their products.

Initiatives using information to consumers to incentivize reformulation used different information tools. Thirteen initiatives used nutrition labelling; five used interpretative FOP labelling while eight others implemented the mandatory labelling of the nutrition content of products (Table 1-3). Three initiatives used awareness campaigns to give consumers the knowledge to make better food choices. Of the fifteen initiatives using voluntary reformulation, seven were self-regulation from the private sector, with no specific guidelines. Seven used guidance on reformulation (i.e., targets). Taxation was only used by one intervention (for which we found evaluation matching our inclusion criteria).

Table 1-3: Details of instruments used to incentivize food reformulation

Instrument to incentivize food reformulation	N interventions
Information to consumers	**18**
Awareness campaign	3
Mandatory labelling	8
Self-regulation	1
Standards for marketing	1
Voluntary labelling (incl. front-of-pack)	5
Voluntary reformulation	**15**
Guidance on reformulation	7
Self-regulation	7
Taxation	1
Mandatory reformulation	**9**
Restricting standards	9

(3) Focus and incentive type

The most commonly targeted nutrient was TFA (Table 1-4). Initiatives targeting TFA used mandatory labelling or restricting standards to make manufacturers reformulate their products. Eleven initiatives targeted several nutrients together, often using voluntary FOP systems built on nutrient profiling systems using different nutrients in their algorithms. Sodium was targeted in ten initiatives, eight of those used targets to guide manufactures to reformulate (both mandatory and voluntary). Only three initiatives targeted sugars, two targeted whole grains.

Table 1-4: Mapping of initiatives implemented incentivizing food reformulation, by the nutrient targeted, and the type of incentive implemented

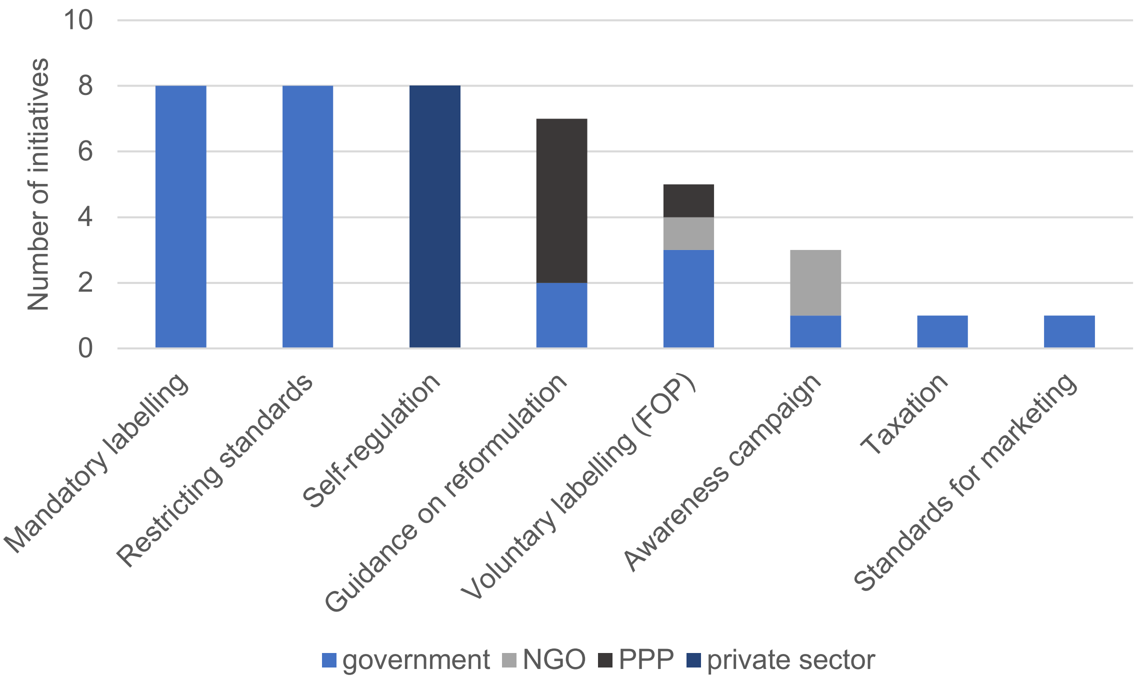
	TFA	several nutrients	sodium	energy	sugar	whole grains	Total
Restricting standards	3	2	3				8
Mandatory labelling	6			2			8
Self-regulation	1	3	2	1			8
Guidance on reformulation		1	5		1		7
Voluntary labelling (FOP)				1		1	5
Awareness campaign	1				1	1	3
Taxation					1		1
Standards for marketing		1					1
Total	11	11	10	4	3	2	41

Notes: FOP: Front-of-Pack; TFA: *trans*-fatty acids. Cells show the number of initiatives

(4) Initiator of the reformulation initiatives

Reformulation initiatives were most often implemented by governments (59%) (Figure 1-2). Governments implemented mostly restricting standards and mandatory labelling. Restricting standards targeted all foods (i.e. mandatory reformulation targets), foods that can be advertised (Otten et al., 2012, 2014), or foods sold in schools (Jahn et al., 2018). The private sector was behind eight self-regulated initiatives. These initiatives were carried either by a unique player taking part in an experimental study (McMahon, Webster & Brimblecombe, 2017), by a retailer (Taillie, Ng & Popkin, 2015; Jensen & Sommer, 2017), but more often by trade organizations, or other associations of manufacturers (Pigat et al., 2018; Ng, Slining & Popkin, 2014). Guidance on reformulation was either created with PPPs or by the government alone. Three initiatives were initiated by NGOs, either information campaigns to make consumers change their diet (Luger et al., 2018; Zupanič et al., 2018) or by the launch of a voluntary FOP labelling, such as the Tick Logo in Australia, launched by the Australian Heart Foundation (Young & Swinburn, 2002).

Figure 1-2: Initiators of reformulation initiatives, by type of incentive implemented



Notes: NGO: Non-governmental organisation; PPP: Public-Private Partnership

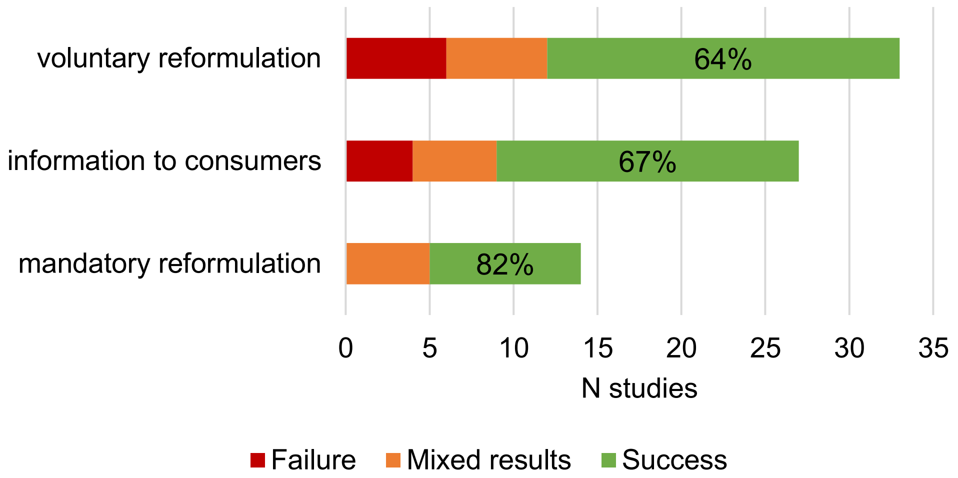
1.7.3 Effectiveness of different strategies to drive reformulation

(1) Mandatory versus voluntary

Mandatory standards were more effective in driving food reformulation than strategies relying on voluntary reformulation. 82% of mandatory strategies led to a significant reformulation of food products (Figure 1-3). For example, nationwide strategies limiting the quantity of TFA in food products were effective to decrease this nutrient in Argentina, Denmark, and the USA (Angell et al., 2009; Monge-Rojas et al., 2017; Bysted, Mikkelsen & Leth, 2009). Two studies found that mandatory reformulation policies were not effective to drive the reformulation of foods. In the study of the evaluation of the mandatory standards for branded foods sold in one US State's schools, only 17% of foods were reformulated (Jahn et al., 2018). Other foods were repacked with smaller package sizes, as the standards were defined per portion. Although not all foods were reformulated, the nutrient composition across all competitive foods sold improved, with decreased mean energy, sodium, saturated fat, and sugars. In Argentina, the implementation of the mandatory standards on salt was assessed not effective enough. Indeed, the standards were not very strict, such as the salt content of Argentinian foods did not comply with the voluntary Pan American Health Organisation (Allemandi et al., 2019).

Compared to mandatory standards, strategies that did not use such strict standards were less effective to drive reformulation. Only 67% and 64% for strategies relying on giving information to consumers, and voluntary reformulation, respectively, succeeded in making manufacturers reformulate their products (Figure 1-3). The effect of these policies on reformulation was often mixed. Some strategies were effective to drive some product reformulation, but only a small number of products were reformulated, creating only a marginal change. For example, the introduction of a law enforcing the mandatory calorie labelling of restaurant foods in the US led to a reduction in energy content of main dishes sold in fast foods and of side dishes in restaurants but not of side dishes in fast foods, or main dishes in restaurants (Deierlein, Peat & Claudio, 2015). In the UK, the launch of the sugar reduction reformulation guidelines led only to a 2% reduction during the first year, a smaller reduction than the 5% target for the first year (Tedstone et al., 2018).

Figure 1-3: Effectiveness of reformulation initiative to drive reformulation, by type of initiative



Notes: The percentages indicate the proportion of studies showing successful results. Strategies were rated as a success, failure or having mixed results in driving reformulation. Success was defined as a significant change in average nutrient density of targeted products going in the direction of an improvement for public health (e.g., reduction for sodium, TFA, energy or sugars, increase in fibre). Failure was defined as an absence of change, or a change in the unexpected direction. Mixed results mean both success and failure (e.g., for different categories).

(2) Importance of the type of incentive used

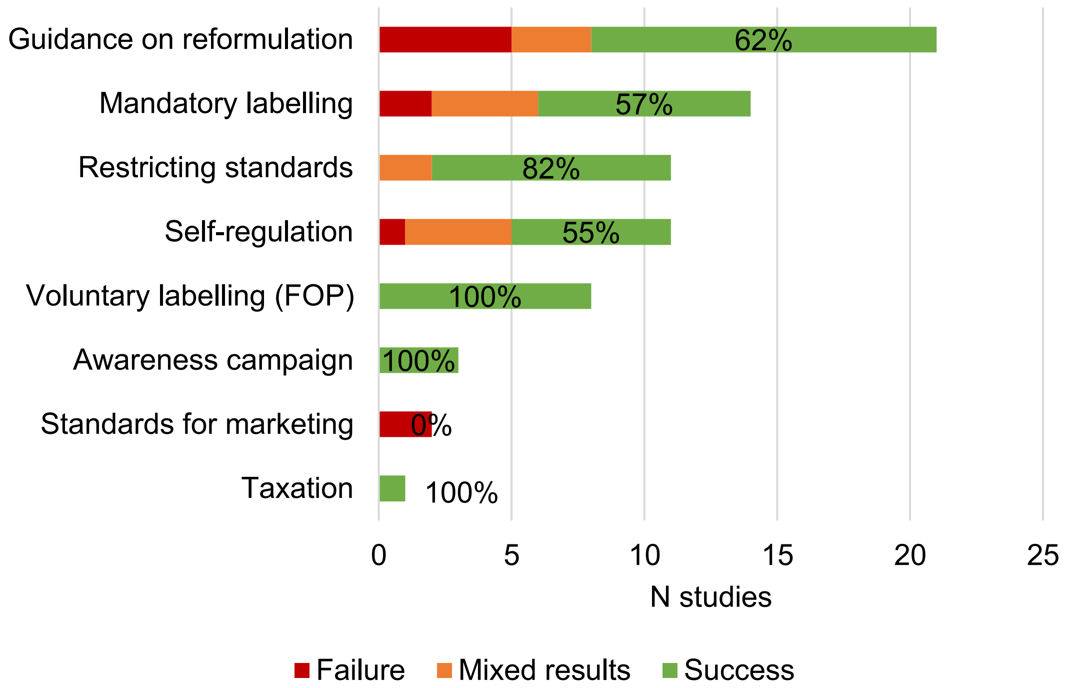
The type of incentive used to promote reformulation had an impact on the success of the strategy. We have shown in the previous section that mandatory standards had a high success rate of 82%. In comparison, only 62% of studies found that reformulation occurred after the implementation of reformulation guidelines (Figure 1-4). Although 13 studies found that giving manufacturers targets was effective to incentivize reformulation, eight studies found mixed effects or failure, with a different response between manufacturers. This resulted in a low number of categories that had their nutrient density changed. While strategies implemented in the UK with a strong push from the government were effective to drive some reformulation of salt and sugar, other initiatives setting guidelines in PPPs were less effective. For example, the effectiveness of the Australian Food and health dialogue has been discussed, with no change in sodium content observed between 2008 and 2011 (Christoforou, Dunford & Neal, 2013). The salt reduction strategy in the US launched as the National Salt Reduction Initiative had a positive effect on only a part of the food categories the initiative created targets (Ahuja et al., 2015; Poti, Dunford & Popkin, 2017).

All eight included studies on FOP labelling found that its implementation led to the reformulation of food products (Figure 1-4). The implementation of the Tick logo in Australia led to the reformulation of products and was estimated to have contributed to the decrease in the quantity of energy, SFA, and sodium sold in New Zealand (Ning et al., 2017; Thomson et al., 2016; Young & Swinburn, 2002). Another study in New Zealand found that 83% of products that carried the Health Star Rating FOP label in 2016 have been reformulated since the announcement of this logo in 2014 (Ni Mhurchu, Eyles & Choi, 2017).

Mandatory labelling of nutrient content (such as TFA on foods, or energy in restaurants) was less effective to promote reformulation, with only 57% of evaluations showing that the initiatives were linked to a reformulation of food products (Figure 1-4). Two studies in Australia and the US found no effect of calorie labelling in restaurants (Wellard-Cole 2018, Wu and Sturn, 2014). Other studies on calorie labelling in the US found mixed results, with a partial reformulation of the food offer (Bleich, Wolfson & Jarlenski, 2017), or disparities between restaurants (Namba et al., 2013).

Self-regulation, despite being implemented by the manufacturers or retailers setting them, showed limited efficiency (55%). Some interventions showed mixed results, with debate about the role of the pledges in improving the nutrient profile of products sold by the companies. Such debates exist for the Healthy Weight Commitment Pledge (see more details in section 1.5.3) and a strategy launched by Walmart (Taillie, Ng & Popkin, 2015). After Walmart launched their initiative, there was an improvement in the nutrient profile of purchases done in the intervention stores. However, researchers question whether Walmart improved their products (or the placement of healthier products), or if they changed their consumer target (in which case the diet of these new consumers is not automatically improved) (Taillie, Ng & Popkin, 2015).

Figure 1-4: Success rate of reformulation strategies (in %), by type of incentive implemented

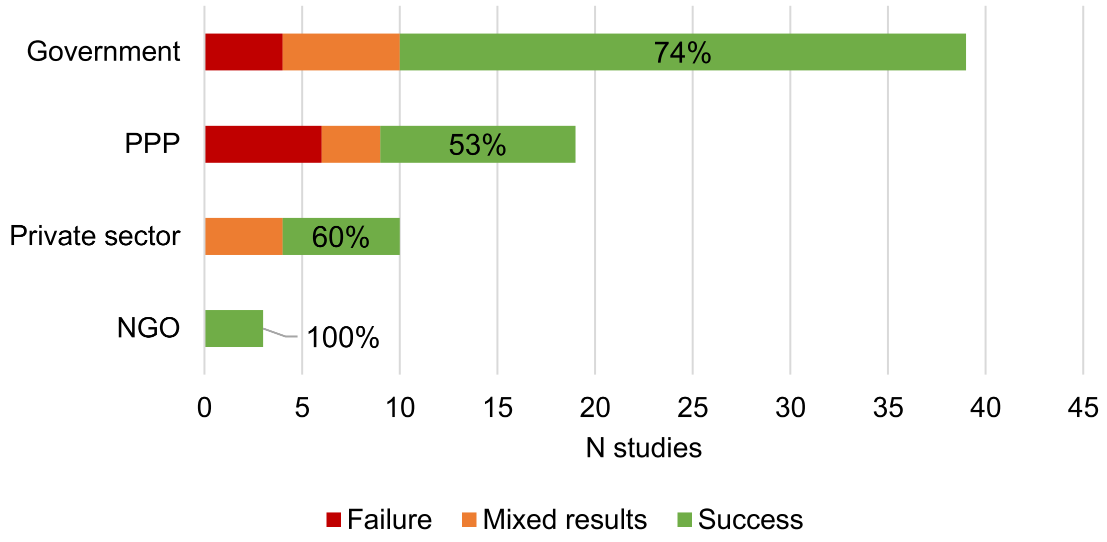


Notes: The percentages indicate the proportion of studies showing successful results (see definition in the note of Figure 1-3).

(3) Importance of who implements the strategy

The rate of success of interventions varies with who implemented the strategy (Figure 1-5). Strategies launched by the government had the highest rate of success (74%), compared to strategies implemented in partnership with the private sector (53%) or by the private sector alone (60%). As such, it appears that the implication of manufacturers in the setting of the reformulation targets does not guarantee that the targets will be applied. However, the frontier between these two types of strategies is difficult to draw, as sometimes strategies led by the government include a consultative phase with manufacturers. Labelling laws are often discussed with the industry, who has the knowledge on how long the implementation phase should be, or what margin of error should be allowed. Strategies initiated by NGOs had a high success rate (100%), but this result relies on a small number of studies (three).

Figure 1-5: Success rate of reformulation strategies, by who implemented the strategy



Notes: The percentages indicate the proportion of studies showing successful results (see definition in the note of Figure 1-3).

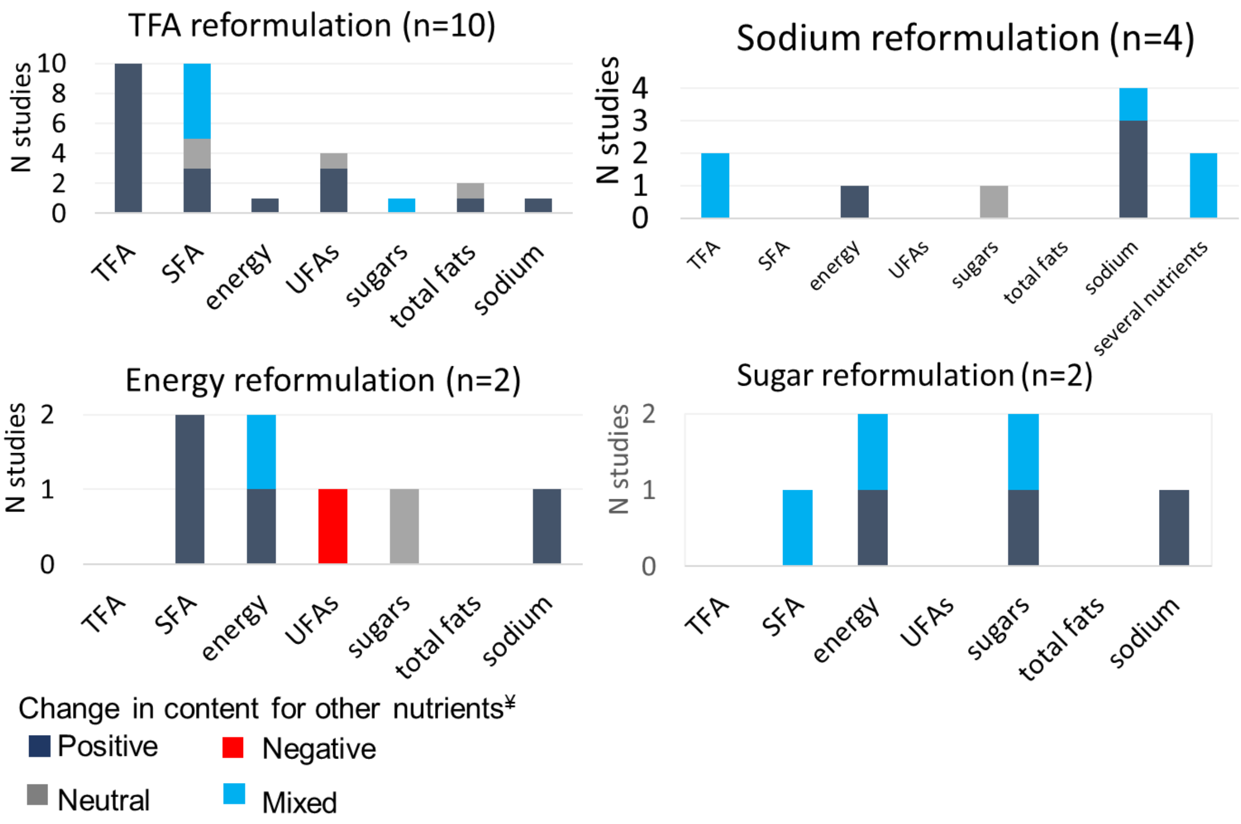
1.7.4 Concerns raised by this analysis

(1) The full picture is missing

Overall, 68% of strategies included in this study were successful in driving food reformulation. However, most studies focused only on the nutrient targeted by the reformulation policy. Only 18 included papers evaluated the impact of the reformulation policy on other nutrients than the one targeted by the intervention. This is of particular concern as most of the interventions included in this review (28/37) targeted only one nutrient. The effect of reformulation on the nutrition properties of food products can only be fully assessed if the whole nutrient profile of products is studied.

Results on the effect of single nutrient strategies on other nutrients were heterogeneous. Nine studies found overall a positive effect of reformulation on other nutrients, in which the reformulation focusing on one nutrient also improved the nutrient content of other nutrients of concern. Nine studies (50%) reported both positive and negative effects of reformulation on nutrients not targeted by the policy (Figure 1-6). For example, an analysis of reformulation following the National Salt Reduction Initiative in the US found that other nutrients such as total fat, SFA, sugar, or fibre changed together as sodium (Ahuja et al., 2015). However, those changes sometimes degraded the nutrient profile of food products (e.g., increase in sugars, decrease in fibre). Ten studies evaluated the change in the nutrient profile of products following TFA reformulation. Overall, the nutrient profile of reformulated foods was always improved, given the detrimental effect of TFA on health. Even if some foods had no change (or increased) TFA+SFA content, the possible increase in SFA did not outbalance the positive changes given by the decrease in TFA. Only one study evidenced a potentially detrimental effect of reformulation on a related nutrient. The reformulation of restaurant foods following the introduction of mandatory labelling led to a decrease in unsaturated fatty acids in one study from the US (Jarlenski, Wolfson & Bleich, 2016).

Figure 1-6: Impact of single-nutrient reformulation policies on related nutrients



Horizontal axis: nutrients not targeted by the intervention for which a change in content was reported

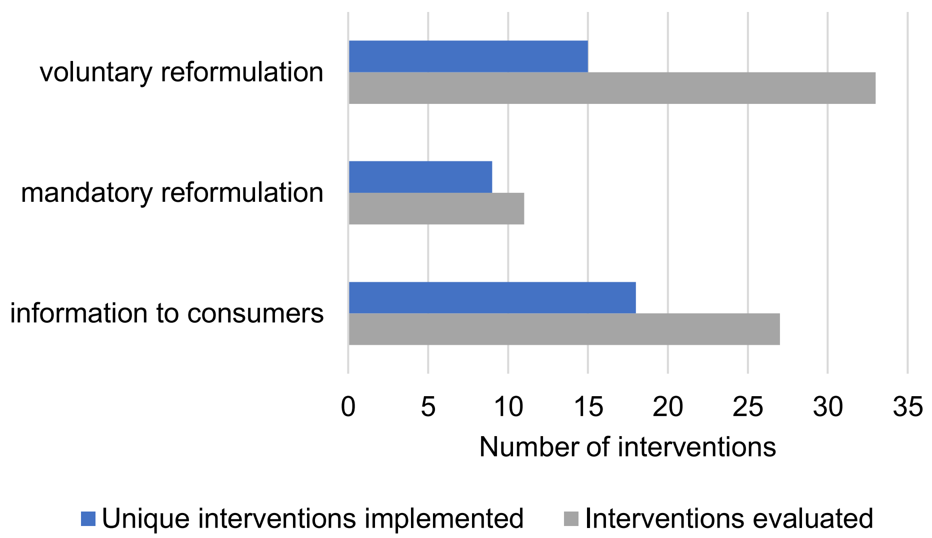
¥: Positive/negative result: change in a related nutrient going in the direction of an improvement/degradation of the nutrient profile

Mixed result: presence at the same time of positive and negative changes; Neutral result: no change in the related nutrient

(2) Potential bias in published studies

The evaluation of reformulation strategies implemented relies on evaluations that are published. This study included the maximum number of studies, screening both the published and grey literature. The risk of bias in published results exist. Because of the diversity of outcomes reported, it was not possible to do a funnel plot, a method recommended to study publication bias. However, we noticed a different proportion of the type of studies between published studies and single interventions included in the study (Figure 1-7). Mandatory reformulation strategies were evaluated in 15% of studies, while they represented 21% of interventions implemented. Voluntary reformulation tended to be over-represented in studies, representing 46% of studies while representing 36% of implemented strategies. This over-representation of voluntary reformulation studies could be the reflect of an intense communication on voluntary reformulation strategies that worked. Conversely, the reporting of strategies that failed to incentivize reformulation may be missing. For example, Magnusson and Reeve noted that the Australian Health Dialogue lacked monitoring (Magnusson & Reeve, 2015). The consequence could be an overestimation of the success rate of reformulation policies, an especially for manufacturer- than for government-driven ones.

Figure 1-7: Type of interventions implemented (and included in this study) and the number of studies by type of reformulation strategy



The World Cancer Research Fund International is constructing the Nourishing database recording all initiatives promoting healthy diets (World Cancer Research Fund International, 2018). One focus of this database is strategies promoting reformulation. In November 2020, 62 initiatives directly focusing on reformulation were listed (i.e., mandatory or voluntary reformulation, excluding the provision of information to consumers). In this study, we found published evaluation for 19 of these initiatives. In addition, there were 116 initiatives listed regarding labelling. Most interventions implemented were not evaluated for their impact on the quality of the food supply.

1.8. Conclusions

To respond to the growing burden of NCDs, improving the populations' dietary intake seems necessary. One way to respond to this challenge is to improve the environment people live in. This can be done by reformulating foods, the process by which manufacturers improve the nutrient profile of the foods they are making.

Reformulation strategies are increasingly used by both manufacturers to improve their portfolio and avoid stronger regulations by governments. Governments encourage reformulation by various policies with different levels of stringency. Governments can incentivize reformulation in many ways, and the review conducted showed that more stringent policies are more likely to promote reformulation. Populations and the civil society also have ways to incentivise manufacturers to reformulate.

Reformulation is aimed at improving the dietary intake and health status of populations. The next chapter will describe how reformulation is expected to impact consumer choices, dietary intake, and health.

2. CHAPTER 2: CONCEPTUAL MODEL OF FOOD REFORMULATION

In this chapter, I explain the pathway through which food reformulation can have an impact on the food environment, consumer purchases, dietary intake, and population health. First, I present the theoretical logic model currently used to model the effect of food reformulation on dietary intake and health. This model assumes that consumer behaviour does not change as a result of reformulation. I challenge this assumption in the second part using consumer behaviour theories. Lastly, I take into consideration these theories of consumer possible reactions to reformulation and include them in a more complex logic model of the action of food reformulation on consumer health.

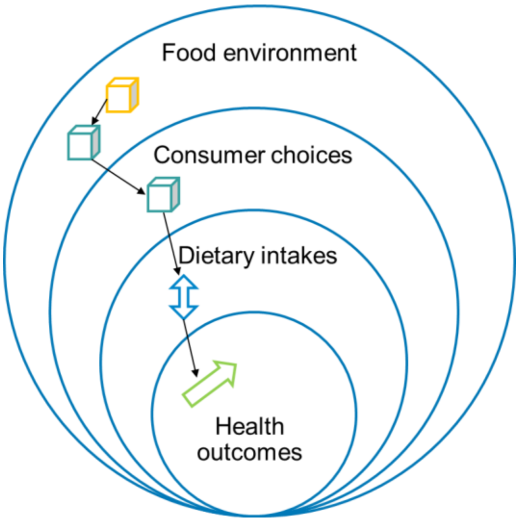
An earlier version of the logic model was published in a peer-reviewed commentary (link to full text in Appendix II):

Gressier, M., Sassi, F. & Frost, G. (2020) Healthy Foods and Healthy Diets. How Government Policies Can Steer Food Reformulation. *Nutrients*. 12 (7), 1992. doi:10.3390/nu12071992.

2.1. Current theoretical logic model of the action of food reformulation on health

A logic model of the action of food reformulation on health is used in models evaluating the health impact of reformulation, to quantify the effect of different food reformulation scenarios on health (Hendriksen et al., 2017). Current models use a logic model following the principles of the one pictured in Figure 2-1. This logic model also shows that the effect of reformulation can be estimated from different measures (e.g., consumer choices, dietary intake).

Figure 2-1: Logic model of the effect of food reformulation on consumer health currently used in modelling studies (such as in Hendriksen et al., 2017).



Note: This model does not include the effect of changes in behaviours

2.1.1 From the reformulation of a food product to changes in the food environment

The reformulation of a food product in the context of public health policies is likely to change its balance of nutrients. Therefore, the nutrient profile of foods available to consumers is changed by reformulation. As such, monitoring the nutrition composition of the food offer is one way to evaluate the reformulation of food products (Swinburn et al., 2013).

The logic model of reformulation currently used in modelling studies assumes that the reformulation of foods leads to a change in the nutrient profile of targeted categories, proportional to the reformulation of products. For example, a study modelling the impact of a 5% energy reduction in soft drink products modelled that the energy content of all drinks would be reduced by 5% (Crino et al., 2017).

Many models evaluating the impact of reformulation on health skip this part, and model directly the effect of a change in the nutrient purchases or intake of populations on risk factors or health-related measures (Hendriksen et al., 2017).

2.1.2 From a change in the food environment to a change in products purchased

The effect of food reformulation on dietary intake can be approximated by the effect on consumer purchases. In practice, reformulation changes the food offer, which in turn, is expected to change the composition of consumers' food baskets. Hence, the impact of reformulation can be estimated using the change in the nutrient profile of consumer purchases. Measuring the quality of purchases is a key measure to evaluate the effect of reformulation interventions. Data on food purchases have been increasingly used in public health research (Bandy et al., 2019). For example, the health impact of a sugar reduction in soft drinks was estimated using data of consumer purchases (Briggs et al., 2017).

The nutrition quality of food purchases can be obtained with different measures. First, the sales-weighted average nutrition composition of a category can be used to track reformulation. For example, this measure is used both by Public Health England to track the impact of the sugar reduction programme (Public Health England, 2020e), and by the French Observatory of the quality of foods (Oqali) to monitor voluntary reformulation commitments (Combris et al., 2011). Compared to the crude average nutrient content of a food category, the sales-weighted measure informs also about consumer choices. Indeed, the reformulation of a product would have an impact that relates to its market share. The reformulation of a popular product is expected to have a higher impact than the reformulation of a niche product. For example, an Oqali study found that, between 2009-2010 and 2011, six (out of 19) categories of non-alcoholic beverages had a decrease in their (non-sales weighted) sugar content. However, only two of these categories showed a significant decrease in their sales-weighted average sugar content (with a magnitude of change smaller than the one observed at the product level) (Oqali, 2016). The market shares of the non-reformulated products were higher than the ones of the reformulated products.

Second, several studies used household purchases to evaluate if a policy was effective in changing the typical basket of products purchased (Bandy et al., 2019). Modelling studies can also use household purchases, and model what would a reformulation of products means for total household purchases. For example, Briggs and colleagues (2017) modelled that a 5% sugar reduction in soft drinks would be equivalent to the sugar reduction obtained if purchases of soft drinks had reduced by 10mL per person and per day, while a 15% and 30% reformulation (for drinks with more than 5g/100mL and 8g/100mL, respectively) would lead to a sugar reduction equivalent to a 58.5mL reduction in purchases (Briggs et al., 2017).

2.1.3 From a change in purchases to a change in dietary intakes

The logic model of food reformulation assumes that reformulation will translate into a change in dietary intakes, that will in turn have an impact on health. Using dietary data from surveys, researchers translate a change in food composition to a change in nutrient intake. For example, this approach was used to estimate the health impact of soft drinks energy reduction in Australia (Crino et al., 2017). Modelling an energy reduction of all drinks by 5%, energy intake from drinks was estimated to be reduced by the same proportion (Crino et al., 2017).

This method can also be used to check the validity of a set of reformulation targets. For example, the Nestlé Nutrient Profiling System was tested using this approach (Gressier et al., 2017). Dietary intake in France and the US were estimated using national food consumption surveys. Two scenarios were tested: one where foods had their original composition, and another where foods had a theoretical composition complying with the Nestlé Nutrient Profiling System. This method allowed to test how dietary intake would be changed in a theoretical food environment where all foods complied with the nutrient profiling system. The study found that compliance with this profiling system would improve population compliance to SFA, added sugars or sodium recommendations, but would have no effect on the compliance to fibre intake recommendations (Gressier et al., 2017).

2.1.4 From a change in intake to a change in health

The final step of the logic model is to translate changes in nutrient intake to change in diet-related risk factors. This step often uses results from meta-analyses that estimate the dose-response relationship between dietary intake and a risk factor. In the example of the salt reduction campaigns, a reduction in the quantity of salt consumed is expected to result in a reduction in the prevalence of hypertension, as salt is a risk factor for hypertension (Hendriksen et al., 2017).

2.2. Theories of consumer behaviour towards food

The theoretical logic model of reformulation presented in Figure 2-1 assumes that consumer food choices are not changed by reformulation. It does not include possible reactions from consumers when a food reformulation initiative is implemented, for example, a change in market shares of different products. Most models assume that a change in food composition will translate to a change in purchases, leading to changes in dietary intake and health. In this section, we discuss theories of consumer behaviour, and how they could explain consumer reactions when foods are reformulated.

2.2.1 The theories of consumer food choices: between rationality and intuition

(1) Consumers make rational choices

Understanding how people choose what they buy and consume is a complex task. A theory of consumer behaviour assumes that consumers make rational choices. Consumers are called “rational” because their actions are done to satisfy their goals and values (Stone, 2007). Individuals' goals and values are measured with individuals' utility. The utility is defined differently for each individual based on his preferences and is considered fixed for each individual at a certain time. Individuals choose a combination of products in order to maximize their utility. When consumers are facing several options (hence, they have a choice to make given a certain income), they evaluate each choice option before making the decision that will maximize their utility (Stone, 2007). This theory supposes that individuals are aware of their goals and values and that they have complete information about how products can satisfy their utility. It is used by many researchers to model food choices (Cobiac et al., 2019).

(2) Factors influencing consumer choices

Many factors influence consumers while choosing between different options. Some are linked to information about the product, such as its price, its brand, or the information contained on the pack. For example, health-conscious consumers may use the detailed back-of-pack nutrition information available or use a simplified version such as FOP labelling.

Other factors are not linked to the product directly but to the context of the decision making. For example, it is estimated that two-thirds of decisions about food purchases are made in stores (Cohen & Babey, 2012). Hence, in-store advertisement has a prominent role in purchases. Likewise, the placement of products has an important role in the decision-making process (Cohen & Babey, 2012). In addition, previous exposure to advertisements is known to affect food choices (Zimmerman & Shimoga, 2014). Peers are also influencing one's food choices (Janssen et al., 2017).

2.2.2 Habits vs. loyalty to brands/products

(1) Definition of habits and loyalty

Food choices are low involvement decisions, relying on heuristics. As some heuristics rely on habits, habits play an important role in the diet (Cohen & Babey, 2012). Habits are the process by which individuals tend to keep the same consumption patterns over time, with limited changes or innovation in their consumption patterns. The formation of a habit is characterised by the influence of past expenditures on the current utility: utility will increase if products already purchased are purchased again (Cleeren et al., 2016).

Habits are different from loyalty to a product. Loyalty to a product or a brand involves an active process whereby consumers prefer a certain brand they trust or like (Stone, 2007). In the context of food choices characterised by frequent purchases, the notion of loyalty to a product or a brand vs. habits may be difficult to distinguish from one another. In both cases, we observe the consumer buying the same product repeatedly. In the case of a decision with low involvement, habitual repeated purchases are called inertia, whereas when the involvement is high, it is called loyalty (Stone, 2007).

Brand loyalty may interact with the will to make health-oriented choices. In a study where participants were asked to choose between two products, one being a nutrient-improved version of the original version, preference was given for the healthier product. However, this preference for the healthier version was attenuated when the two products belonged to the leading brands of the market (Ares et al., 2018a).

(2) Are consumers loyal to food products?

The theory of food choices implies that consumers are loyal to the food brands they consume (Stone, 2007). However, food is characterised by a large offer, discouraging strict loyalty. For example, a study on loyalty to crips found that households purchased on average 2.1 brands of crisps in a year (and 2.2 variants of crisps) (Cleeren et al., 2016). Loyalty is different across categories. A study found that only 3% of consumers were 100% loyal to a variant of breakfast cereal (i.e. only buying this variant), while soups, yoghurt and tea bags had 6%, 9% and 10% of loyal consumers, respectively (Singh, Ehrenberg & Goodhardt, 2008). The study of a panel of consumers showed that some consumers are loyal to brands, while others would react to marketing cues and easily switch between products (Guadagni & Little, 2008).

(3) The influence of habits and loyalty on the impact of reformulation

The notions of loyalty and inertia are important to consider when studying the impact of reformulation. Reformulation, by changing the nutrition composition of products, could have different consequences in consumers loyal to a product, versus consumers who have the habit of consuming it (i.e., inertia).

We can hypothesize two different reactions from loyal consumers. Loyal consumers are characterised by the trust they give to a product, where this trust is used as a heuristic to choose this product. This trust can produce two opposite reactions after a product is reformulated. First, the reformulation is noticed and perceived as a breach of their trust. In that case, we expect loyal consumers to stop consuming this brand, and products linked to this brand. Conversely, it is possible that the reformulation is not perceived, or that the trust in the product prevails, and loyal consumers would continue consuming the reformulated product, with the same frequency and quantity as before (Ares et al., 2018a).

On the other hand, individuals consuming that product from habit have a lower involvement in the decision-making process. Hence, it may be more likely that they don't perceive reformulation and continue consuming the product.

2.3. Integrating consumer behaviour into the logic model of reformulation

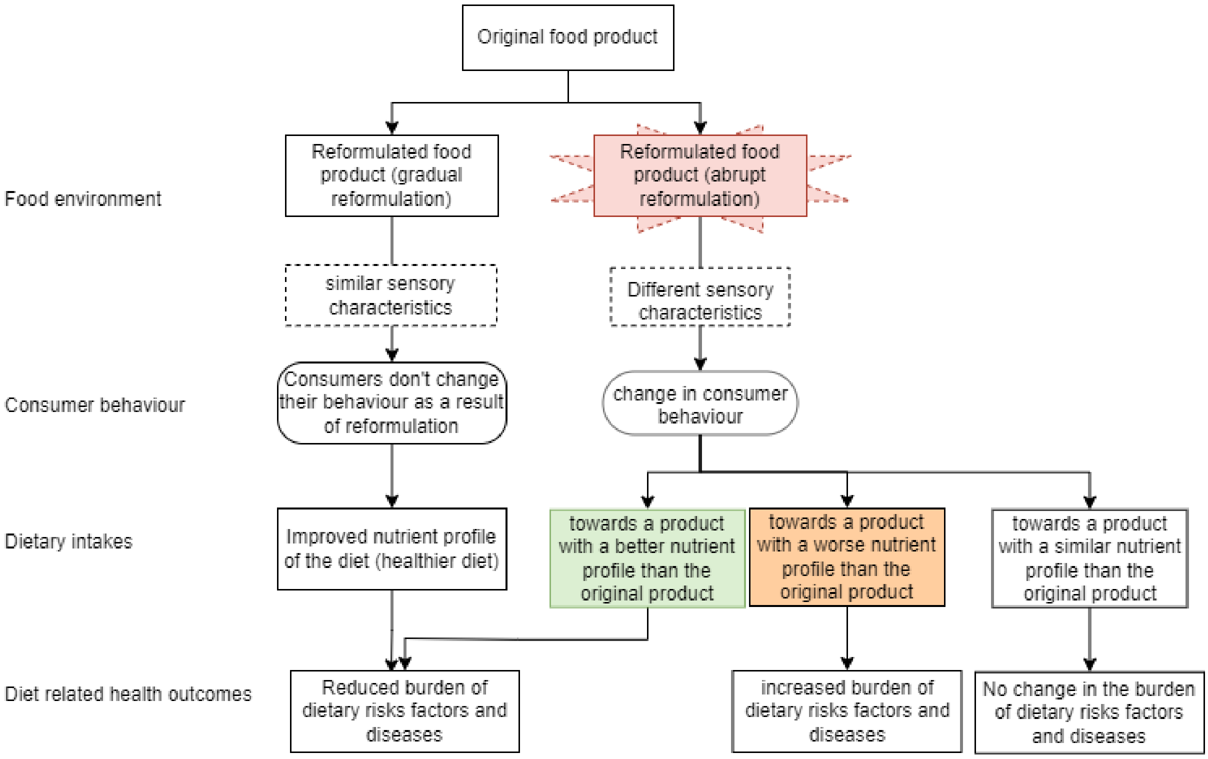
The logic model presented in section 2.1 is based on the hypothesis that reformulation provokes no change in consumer choice. However, we have seen in section 2.2 that food choice is a complex process that can be influenced by many factors such as advertisement or loyalty. The behaviour of consumers can modulate the logic model of reformulation at multiple steps. In addition, the reformulation process itself can trigger a change in consumer behaviour. In this section, we describe the feedback loops between the logic model of reformulation and consumer behaviour.

2.3.1 Effect of a change in sensory characteristics of the product

Reformulation is done while minimizing the changes to the sensory profile of the products. Ideally, manufacturers want consumers not to notice the change to avoid losing consumers (Popkin & Kenan, 2016). The left pathway in Figure 2-2 shows that, with a reformulation that does not change the sensory profile of products, consumers may conserve their food choices. As a result, the reformulation of products will translate into an improvement in dietary intakes, and potentially health.

However, reformulation can change the sensory characteristics of products, as when reformulation is abrupt. In an experiment that tested an abrupt vs. gradual reformulation, the liking for the product decreased for participants in the abrupt reformulation group (Bobowski, Rendahl & Vickers, 2015). That means that consumers facing products with a different sensory profile would be more likely to switch to other products. The liking in the gradual reformulation group did not change, meaning that consumers facing gradual reformulation were more likely to adapt to the change in the recipe (Bobowski, Rendahl & Vickers, 2015). The liking after 16-weeks was similar between the two groups (Bobowski, Rendahl & Vickers, 2015). However, in real conditions, consumers disliking a product will turn away from it, and won't likely continue to consume it for 16 weeks. A change in eating habits could go against the expected aim of reformulation if consumers consume a bigger quantity of the product, or if they switch to a product with a nutrient composition similar to the one of the initial product (Figure 2-2, right pathway).

Figure 2-2: Logic model of the effect of a change in sensory characteristics of the reformulated product on consumer choices, intake, and health.



2.3.2 Effect of disclosing or advertising reformulation

Manufacturers can choose to disclose the reformulation performed on their products. The decision to disclose reformulation is a marketing choice based on the balance between being transparent to consumers (Marotta, Simeone & Nazzaro, 2014) and limiting the risks that consumers would notice the change and turn away from the product (Popkin & Kenan, 2016).

Reformulation can be disclosed by advertising campaigns (with messages such as “new recipe”) or claims on packs. For example, reformulation may allow the use of claims such as “reduced salt” or “source of fibre”. In some instances, advertising about reformulation can become a competitive advantage (Marotta, Simeone & Nazzaro, 2014). This is the case when consumers are actively looking for healthier products, or in some categories where products are expected to be “healthy”.

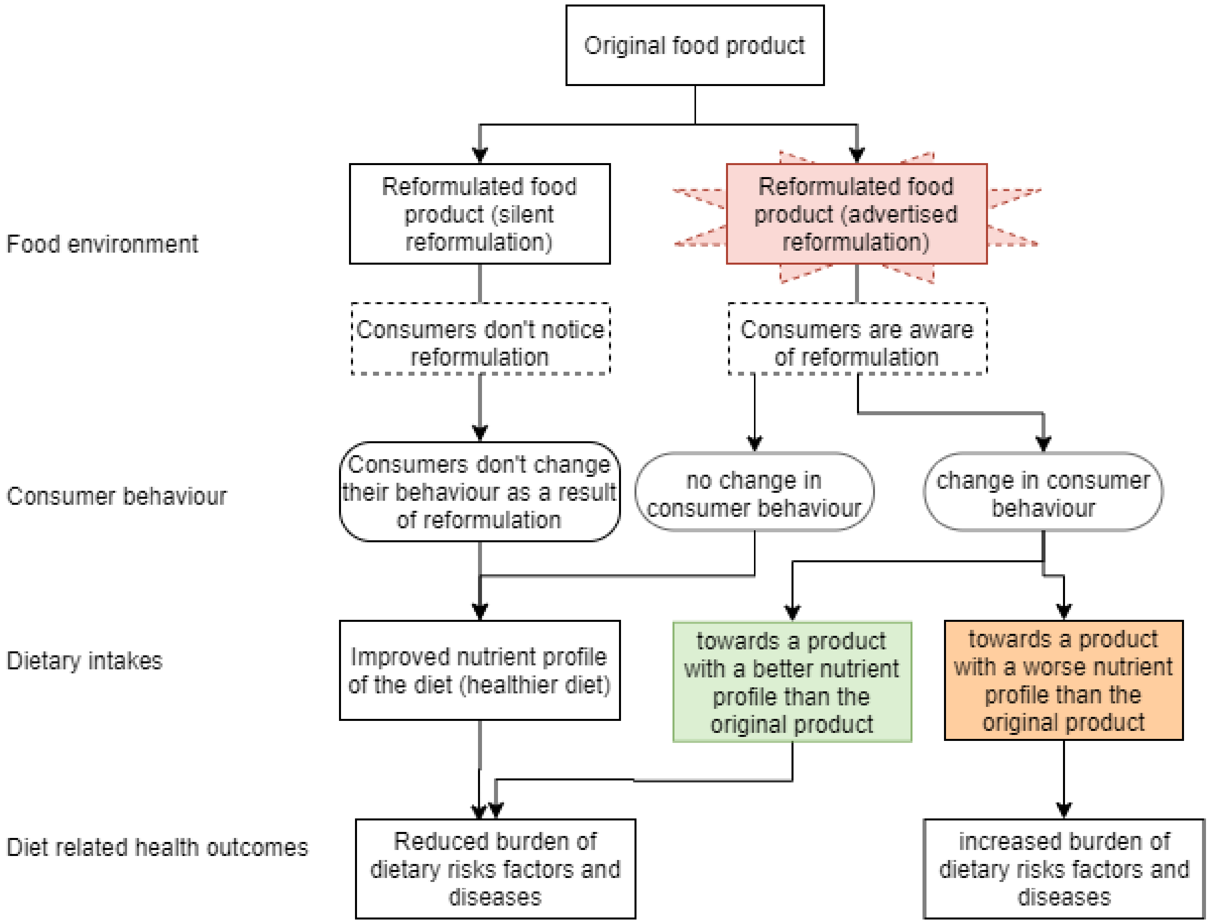
The decision to do a covert or an advertised reformulation is linked to the category, and specifically to the category-specific drivers of purchases. Advertising the reformulation of indulgent products can have an adverse effect on sales, as health cues are perceived negatively on indulgence products (Cohen & Babey, 2012). Staudigel and Anders (2018) studied this “unhealthy=tasty” dilemma in the potato chips market (an example of an indulgent category, for which most consumers are aware they are not consuming healthy products). They found that the reduced-fat products formed a category different from regular potato chips products: substitutions between these two groups were not frequent (Staudigel & Anders, 2018). They also found that products having a reduced-fat claim were less valued by consumers. In this category, we can expect that advertising reformulation would not be valued by consumers, and even be perceived as lower quality. As such, manufacturers may want not to advertise reformulation, and even do it covertly (Popkin & Kenan, 2016). A change in product taste can be a threat to lose consumers, as consumers would not hesitate to switch to another product if they are dissatisfied with the product they used to consume. Silently reformulating a product is a way to limit the risk that consumers would notice the change done (Popkin & Kenan, 2016).

The choice of advertising the reformulation of a product depends also on the context. For example, the UK childhood obesity plan had several elements focusing on sugar (details in Chapter 6). There were also awareness campaigns about the quantity of sugar in a typical diet, and how to decrease one’s sugar intake. This context of increased awareness may increase consumer will to purchase reduced-sugar products, and favour products advertising a lower sugar content.

Manufacturers could also claim that they reformulate their products to benefit from an improved image. In a context where consumers are looking for nutritionally better products, they may prefer to choose a brand they have heard was reformulated its products. The creation of competitive advantage was a selling point of the UK salt reduction strategy to manufacturers: the names of companies voluntarily reformulating their products were mentioned in press statements as well as in speeches from government representatives (Addison, 2010). Expectedly, consumers would value companies’ engagement in public health, and buy products from these praised companies (Van Camp, De Souza Monteiro & Hooker, 2012).

In summary, advertising reformulation can have both positive and negative consequences on consumer purchases (Figure 2-3).

Figure 2-3: Logic model of the effect of reformulation on consumer behaviour, dietary intake and health outcomes, for silent or advertised reformulation.



2.3.3 Effect of diversifying the offer

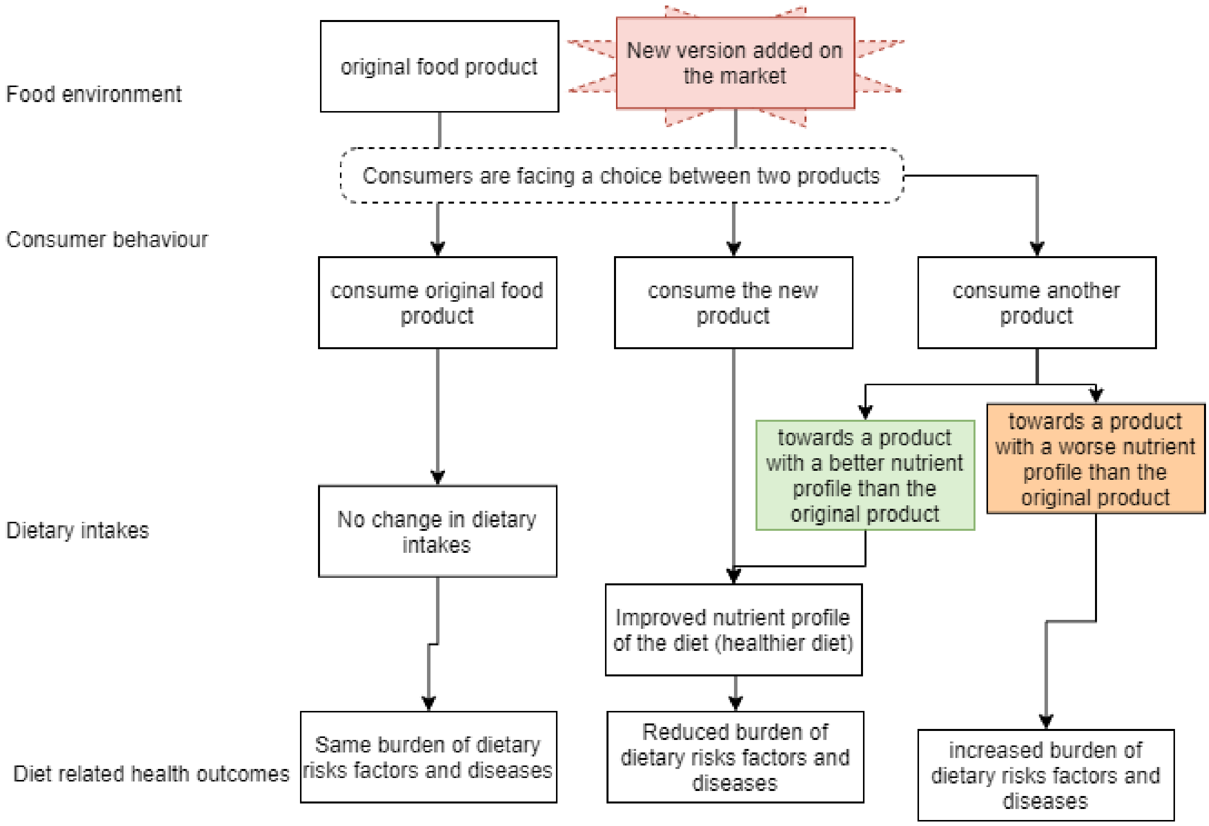
The first step of the logic model stipulates that reformulating a product creates a change in the food environment. It supposes that the reformulated product will replace the original product, such as individuals are likely to choose the reformulated version as their default choice (i.e. continuing their food habit).

However, manufacturers sometimes answer reformulation policies by adding new products (in addition to the existing ones) (Tedstone et al., 2018; Mancino, Kuchler & Leibtag, 2008; Magnusson & Reeve, 2015). Often, products are added as new variants when reformulation changes the sensory profile of the product, or when a substantial modification allows the use of a claim. Manufacturers may prefer to add the reformulated product as a new variant if they want to target new consumers. When the reformulation allows the usage of a claim, manufacturers may want to attract health-concerned consumers, and at the same time keep the original variant for consumers who could perceive “unhealthy” products as “tasty”

(Staudigel & Anders, 2020). That way, introducing a new product in addition to the original one ensures the manufacturer to not lose consumers, but instead win more consumers with the new version.

The effect of reformulation on the food environment would be different if the reformulated version is added as a new product. Adding the reformulated product as a new variant on the market increases the number of products consumers can choose from (as the new variant is introduced in addition to the original product). The success of adding a new variant on improving purchases relies on the willingness of individual consumers to switch to the healthier option (Figure 2-4). While when reformulation replaces the original product with an improved version (as discussed in section 2.1), consumers are nudged to consume the reformulated product as if it was the same as the original product. That is why reformulation is often called a “health by stealth” approach.

Figure 2-4: Logic model of the effect of introducing a new product with an improved composition instead of reformulating the original food product, on consumer choices and health outcomes.



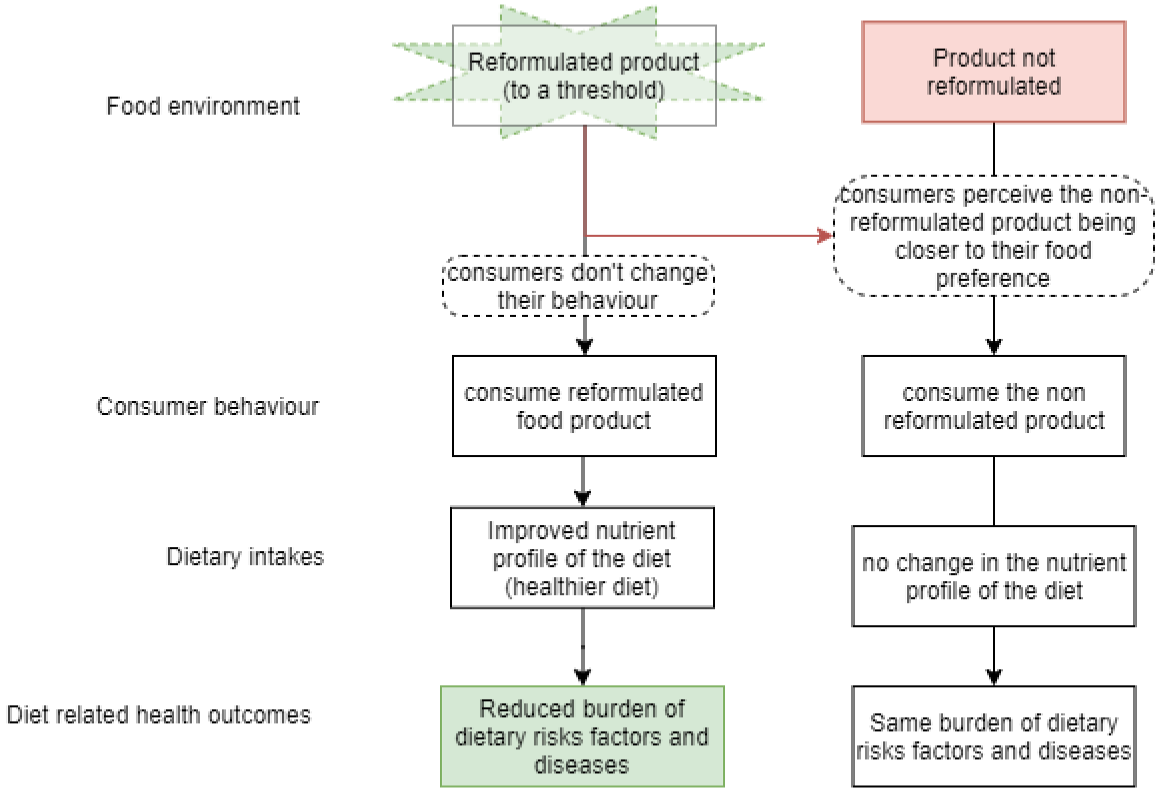
2.3.4 Isolated versus mass reformulation

(1) The pitfalls of isolated reformulation

We define isolated reformulation as a non-coordinated reformulation, where some manufacturers would reformulate their products, but not others. Isolated reformulation could prevent consumers from gradually getting used to a lower sweet/salty taste, as they would still have the possibility to switch to products that are not reformulated (Bobowski, Rendahl & Vickers, 2015). We saw in section 2.3.1 that gradual reformulation was necessary to get consumers used to reduced saltiness, or sweetness of foods. If some products with high salt/sugar remain in the market, the progressive habituation to less sweet/salty taste will be disrupted by switches between products. Isolated reformulation can threaten the effectiveness of any reformulation, in which the reformulated products will not be consumed (Figure 2-5, right pathway).

The first step of the current logic model (Figure 2-1) relies on the fact that a change in the composition of individual products will change the food environment, and hence the choices available for consumers. It supposes that if enough products are reformulated, the nutrient profile of a category changes. It means that consumers, when choosing a product from this category, will be facing reformulated products with an improved nutrient profile. If all products from a category are reformulated consumers will be left with no other choice than to consume a reformulated product (Figure 2-5, left pathway).

Figure 2-5: Logic model of the effect of reformulation of isolated products only, while non-reformulated products remain on the market, on consumer behaviour and health.



Notes: Here, reformulation is assumed to be done to a certain threshold, where reformulated products reach this threshold while non-reformulated products are above (resp. below) the threshold (for nutrients for which consumption should be reduced; resp. for nutrients which consumption should be increased)

(2) Mass reformulation vs. reformulation of the leading products

Some argue that not all products of a category must be reformulated, but that reformulating the market leader is sufficient to improve the food environment. Market leaders are particularly targeted in the salt reduction call from the US Food and Drug Administration (Staudigel & Anders, 2020). The rationale behind this strategy is that if the products with the highest market share are reformulated, more consumers would benefit from reformulation. This may be true in monopolistic (or quasi-monopolistic) markets, where the market leader gathers most of the market shares, or when the market leader has a worse nutrient profile than other products. However, the reformulation of one product has side effects on the consumption of other products that should be carefully considered to estimate the impact of reformulation. Indeed, similar products are often substitution products, for which consumers may switch between. Using a demand model, Staudigel and Anders. (2018) showed that if only the US market leader in the crisps category reformulate their products, the reduction of salt purchased by US consumers would be higher than the reduction obtained if *all* manufacturers were to reformulate their products (Staudigel & Anders, 2018). These counterintuitive findings result from an analysis of the switches between products that consumers would do if the market leader was reformulated, compared to switches that would occur if all products were reformulated. When all products are reformulated (as a percentage reduction of their original content), some products with a high baseline sodium content gain consumers who were initially consuming products with lower salt, limiting the effect of sodium reduction overall. This phenomenon does not happen when only the market leader is reformulated (Staudigel & Anders, 2020).

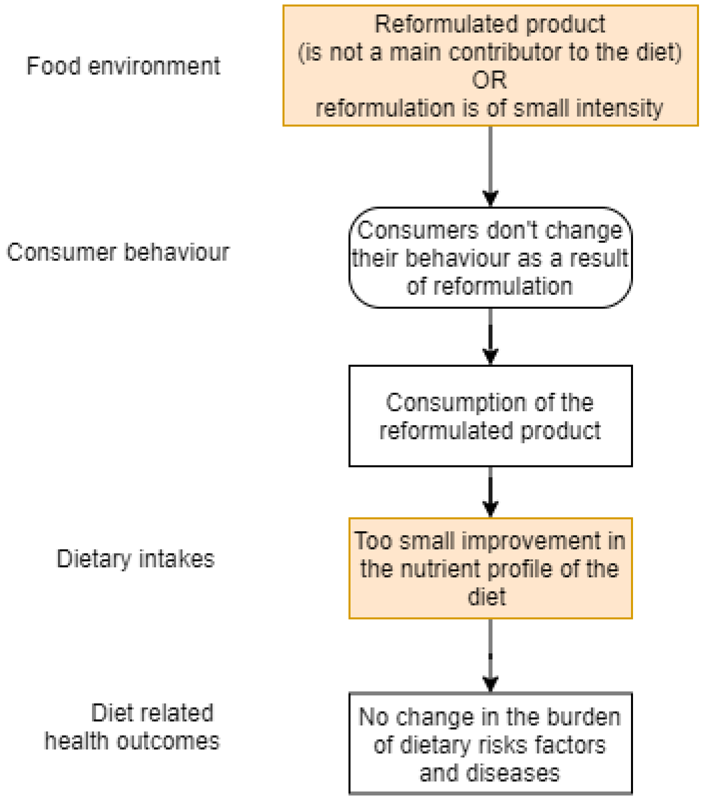
To sum up, reformulating only some products may intuitively leave the option for consumers to choose non-reformulated products (as in Figure 2-5). However, at baseline, the different products have different nutrient compositions, and reformulation does not mean getting all products to the same composition. The effect of reformulation on other products (substitutions) is complex and can have different effects on consumers choices and health.

2.3.5 Reformulation of relevant foods and change in intake

Similarly to the fact that many products of a category should be reformulated to see a meaningful change in the environment, different food categories should be reformulated to see a visible effect on dietary intake. More importantly, the sources of the nutrients that are consumed in excess should be reformulated. In the Netherlands, multiple initiatives targeted a reduction in the sodium content of foods (Temme et al., 2017). Sodium content in bread was regulated (with thresholds that progressively decreased to facilitate reformulation by bakers and to give time to consumers to get used to the reduced salt taste of bread). Other categories were targeted by voluntary programmes, including soups or cheese. These initiatives were effective to change the food environment. The monitoring of the salt content in foods showed a decreased sodium content. However, these changes did not lead to a reduction in sodium intake (Temme et al., 2017). The changes observed in the food environment were not big enough to be detected in participants' salt intake. This can either be because too few categories were reformulated (most sources of sodium in the diet were unchanged), or because the changes in products composition were too small. Similarly, an experimental study testing replacing bread with reduced-salt bread found no significant improvement in dietary salt intake (Riis et al., 2021). Reformulating, even intensively, only one category was not enough to observe a significant reduction in intake.

These two examples showed that if the reformulation is not big enough or does not cover the main sources of the nutrient, there won't be improvements in dietary intake. As a consequence, the reformulation won't result in health improvement (Figure 2-6)

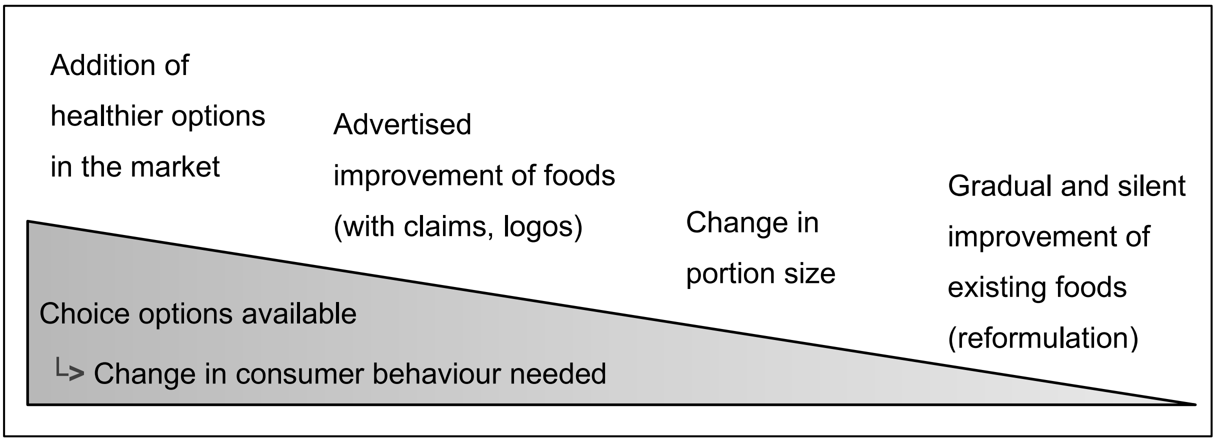
Figure 2-6: Logic model of the effect of irrelevant/small reformulation on health outcomes. Irrelevant reformulation means that the reformulated product is not a main contributor to the diet.



2.3.6 Changes in the food environment and their effect on consumer behaviour

In the previous sections, we showed that the characteristics of manufacturers' answers to reformulation strategies could have different effects on consumer behaviour. We classified the different options that manufacturers have to reformulate their products along a gradient showing the change in consumer behaviour needed so that he benefits from the reformulated product (Figure 2-7). Advertising the reformulation could prevent the "health by stealth" objective of reformulation, as it could discourage loyal consumers to continue consuming these products, while at the same time maybe attracting new health-oriented consumers. Silent reformulation is the strategy requiring the least change in consumer behaviour (it is expected not to provoke any behaviour change), while a diversification of the offer by adding healthier products relies on consumers' participation. This classification is aligned with the superficial to radical (or agentic to structural) continuum proposed initially by Rose to define preventive measures (Rose, 1992). Agentic strategies are based on behaviour changes by the population (the agent), while structural strategies rely on the context of the behaviour (McLaren, McIntyre & Kirkpatrick, 2010). Reformulation is therefore more of a radical (or structural) change than the launch of a new product that has an agentic nature.

Figure 2-7: Classifications of strategies changing the characteristics of food available for a population along a gradient of change in consumer behaviour needed to get a benefit from the new food products

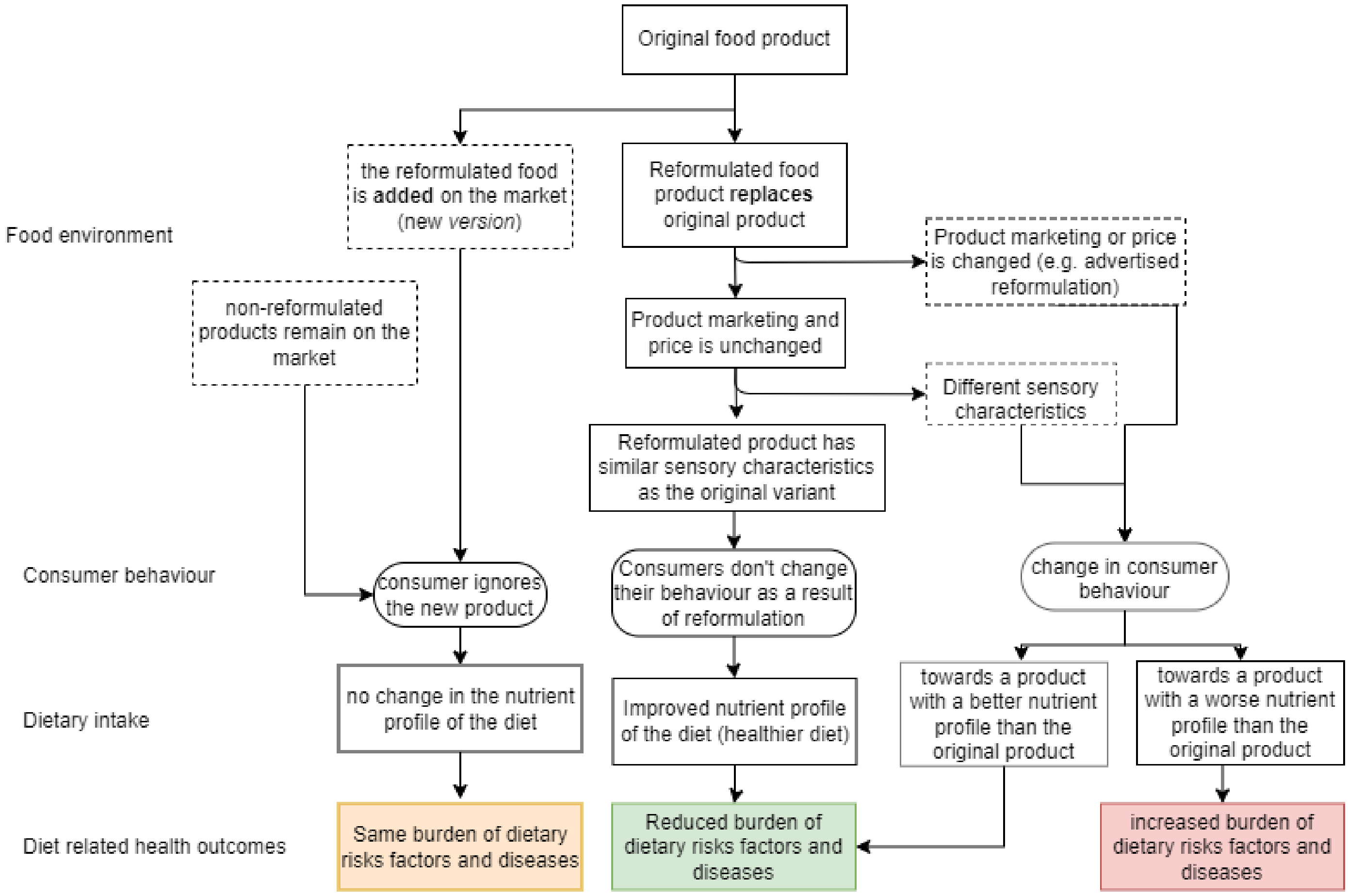


2.3.7 Expanded logic model of reformulation

The theoretical logic model of reformulation presented in section 2.1. shows the different steps from a reformulated product to change in consumer health outcomes in the absence of change in behaviour (Figure 2-1). However, many reasons would make consumers change their habits because of reformulation, as discussed previously. In addition, food purchases are characterised by a balance between recurrent purchases, and a desire for innovations, provoking changes in behaviour even in the absence of change in the food environment. The logic model of reformulation has been re-drawn taking into consideration the theories of consumer choice described in this section. Figure 2-8 takes into consideration changes in marketing that are linked to reformulation, and potential changes in consumer behaviour resulting from these changes.

We see that the current theoretical logic model is only likely to apply for some examples of “silent reformulation” where the new product would have the same sensory characteristics as the original version, would be sold at the same price and will not be advertised differently. However, given the costs associated with reformulation, and the potential appraisal-seeking from the manufacturers, it is unlikely that reformulation is done silently. The more complex model shown in Figure 2-8 warns about the different challenges for a reformulation strategy to lead to an improvement in health. It also shows that a careful reformulation, minimizing consumer advert choices, is possible.

Figure 2-8: Expanded logic model of the effect of food reformulation including possible changes in consumer choices resulting from a change in the food environment different than reformulation.



2.4. Summary

In this chapter, we started from the existing logic model of reformulation to build a more complex one including possible consumer reactions to the reformulation of foods. Indeed, we have seen that different characteristics of food reformulation (change in sensory profile, advertising, new product launches) can disrupt usual consumer behaviour, and could limit the impact of food reformulation on the health of consumers.

A change in the sensory characteristics of a food product is likely to result in lower sales. Even if the change in the sensory profile is minimum, consumers are often opposed to changes in the taste of products they are used to consuming. One way to limit these changes in behaviour is to gradually reformulate the products, such that consumers are gradually used to the changing sensory characteristics. In addition, the risk of consumers switching to products with a worse nutrient profile is lowered if a large proportion of the food offer is reformulated. In this case, the choice of consumers to switch to a non-reformulated product is limited.

Making consumers aware of the reformulation of a product can divert them from continuing to consume it but could as well attract health-oriented consumers. The fact of diversifying the food offer (by adding new products instead of replacing older versions with reformulated ones) can result in various outcomes. Some consumers may not change their behaviour, and no improvement in dietary intake will be observed. Or they can choose to switch to the newer product, which could result in an improvement of dietary intake. But there is also the risk that consumers would choose the new version in addition to the existing one, resulting in overconsumption, and a worsening of the diet.

To sum up, changes in consumer behaviour could have as well adverse and beneficial effects. Minimising these changes in behaviour can warrant reformulation strategies to have the expected improvement in population health.

In the next chapters, we will first review the existing evidence on the expanded logic model (i.e., evidence on the impact of reformulation strategies on consumer behaviour, intake and health). Then, we will investigate the role of consumer behaviour in reformulation policies.

Hypothesis, Aim and objectives

Hypothesis:

We hypothesise that reformulating food products lead to improvements in populations' diet, assuming that there are no changes in food choices offsetting the benefits of reformulation.

Aims

The overall aim of this thesis is to evaluate how, and to what extent reformulation policies could contribute to improving population health status.

Specifically, this thesis aims at:

- ➔ Reviewing the evidence on the empirical effect of reformulation on populations food choices, dietary intakes, and health
- ➔ Filling the gaps on the empirical evidence of reformulation on consumer health
    - o To test if reformulation contributes to improving population diets

The logic model shows that reformulation policies could lead in improvement, no change, or a worsening of the diet quality of populations. The UK is an interesting setting to study how reformulation had an impact on the diet of the UK population as different reformulation policies were implemented since the early 2000s.

- o To test if reformulation is linked to changes in dietary choices

The logic model shows that manufacturers' responses to reformulation policies could trigger changes in consumer food choices. The UK offers a unique context to study such changes with the Childhood Obesity Plan. This plan consisted in both a voluntary reformulation programme (not expected to trigger changes in food choice) and a tax on sugary drinks (expected to trigger a change in food choice).

Objectives and plan of the thesis:

The first objective is to systematically review the literature on the effect of food reformulation on food choices, dietary intake, and health.

The second objective is to analyse time trends in the fibre and sodium content of foods and the mean fibre and sodium intake of the population, and by age and income groups.

The third objective is to evaluate the contribution of changes in the demand for foods and changes coming from manufacturers (i.e., reformulation and product renewal) to the change in the sodium density of the UK diet, in the context of the salt reduction programme.

The fourth objective is to evaluate the role of reformulation, product renewal and changes in consumer choices in changing the sugar density of food and drink purchased in the UK, both for at-home and for out-of-home consumption, in the context of the childhood obesity plan.

The fifth objective is to analyse the reactions of consumers facing reformulated food products, and to assess if these reactions are distributed evenly in the population.

3. CHAPTER 3: SYSTEMATIC REVIEW ON THE EFFECT OF FOOD REFORMULATION ON DIETARY HABITS, INTAKES AND HEALTH STATUS

This chapter aims to answer the first objective of this thesis: to systematically review the literature on the effect of food reformulation on food choices, dietary intake, and health. The findings of this review will allow us to validate or invalidate the logic model drawn in Chapter 2. The research presented in this chapter was published (in a different form) in a peer-reviewed journal, in the following article (full text in Appendix II):

> Gressier, M., Swinburn, B., Frost, G., Segal, A.B. & Sassi, F. (2021) What is the impact of food reformulation on individuals' behaviour, nutrient intakes and health status? A systematic review of empirical evidence. *Obesity Reviews*. 22 (2), obr.13139. doi:10.1111/obr.13139.

3.1. Introduction

3.1.1 Existing reviews

Reformulation has been increasingly used by policy makers in the last decades (Federici et al., 2019). With the increasing popularity of reformulation policies, several reviews were undertaken to assess the effectiveness of reformulation policies on the quality of the food supply and population dietary intake (Hyseni et al., 2017a; Hashem, He & MacGregor, 2016; McLaren et al., 2016; Trieu et al., 2015).

Some reviews had as an outcome the nutrition quality of foods in a country. Assessing the effect of a reformulation policy on the nutrition quality of foods sold to consumers informs about how the policy was adopted by food manufacturers. These reviews give information about what type of foods were reformulated, and to what extent (i.e., the size of the reformulation). In the case of TFA reformulation, categories that were mostly targeted by the reformulation strategies were restaurant foods, bakery products and spreads (Downs et al., 2017). The extent to which TFA were removed in these foods varied by region, showing that reformulating foods to remove TFA is possible (Downs et al., 2017). The reformulation of foods to decrease salt contents depended upon the food categories targeted by the incentives. Incentives were either focusing on all foods (such as taxation on high salt foods) or specific food categories, most often bread (Trieu et al., 2015).

Reviews assessing the impact of reformulation on dietary intakes inform about how successful reformulation can be in changing population dietary intakes. A systematic review on different strategies to decrease sodium intakes found that strategies that included reformulation were more effective in doing so than other types of strategies relying on education (McLaren et al., 2016). Another systematic review recorded that sodium intakes reduced after the implementation of a reformulation strategy in twelve countries (Trieu et al., 2015). The reformulation of foods to decrease TFA contents was also shown to be successful at reducing dietary intakes of TFA (Hyseni et al., 2017a; Downs, Thow & Leeder, 2013; Downs et al., 2017). The systematic reviews by Downs et al. (2017) found that all the nine studies evaluating TFA intakes following various strategies that can incentivize reformulation (such as labelling, self-regulation or limits) showed decreases in intakes (Downs et al., 2017). Meta-analyses of randomised controlled trials (RCTs) testing sugar reduction in drinks concluded that reformulation of such products should result in decreased sugar intakes (Hashem, He & MacGregor, 2019). Conversely, the Cochrane systematic review on environmental interventions to reduce the consumption of sugar-sweetened beverages found no study evaluating the effect of reformulation on beverage consumption or health (von Philipsborn et al., 2019). A systematic review on the characteristics of studies that lead to increased fibre intakes found that reformulation had such an effect (Suthers, Broom & Beck, 2018).

A smaller number of systematic reviews investigated the effect of reformulation on health outcomes. A systematic review of empirical evidence from clinical trials found that reformulation to reduce TFA in foods results in reduced risk of coronary heart diseases (Hyseni et al., 2017a). The RCTs included in the systematic review evaluating the effect of the reformulation of SSB found that such intervention should result in an average reduction in body weight of about 1kg (Hashem, He & MacGregor, 2019).

In addition, some reviews focused on the findings from modelling studies. Those modelling studies found that reformulation could be effective to reduce sodium intakes (Hyseni et al., 2017b; Grieger et al., 2017), sugar intakes (Grieger et al., 2017; Hashem, He & MacGregor, 2019), or to improve multiple nutrients simultaneously (Federici et al., 2019).

Some reviews aimed at comparing different policies to help policy makers decide what is best to implement to improve population dietary intake or health status. Systematic reviews compared the effect of mandatory and voluntary reformulation strategies, finding that mandatory policies were more effective to reach the wanted goal (Hyseni et al., 2017b; Downs, Thow & Leeder, 2013; Downs et al., 2017; Hyseni et al., 2017a). Also, some reviews included the effect of other strategies than reformulation, such as labelling or education campaigns. They found that changes in the structure of the food environment (such as reformulation) was more effective than strategies based on education such as labelling (Hyseni et al., 2017b; Downs et al., 2017; McLaren et al., 2016).

3.1.2 Gap in existing systematic reviews, and aim of this review

Published reviews focused on the reformulation of one specific nutrient at the time, mostly sodium or TFA. However, to evaluate the relevance of reformulation itself it is valuable to gather evidence about reformulation as such, regardless of the focus of the strategy. Indeed, the logic model presented in Chapter 2 assumed that the mechanism through which reformulation has an effect on consumer behaviour, dietary intake and health status, is the same regardless of the type of reformulation.

In addition, the logic model informed us that the effect of reformulation strategies is determined by how consumers react to the reformulation of foods they are used to consuming. Hence, we chose to focus our review on outcomes that reflect consumer behaviour. To do so, we included all outcomes ensuing from consumer behaviour: consumer choice itself, dietary intakes, and health outcomes.

Furthermore, we were interested in understanding the effect of reformulation on consumers in a real-life setting. RCTs can miss compensation behaviours happening during a long time scale. Then, we chose to include only evidence coming from conditions as close as possible to real conditions. As a result, this systematic review should inform us about the evidence on the different steps of the logic model, to validate or invalidate the different hypotheses drawn in the logic model (Figure 2-8).

The aim of the review was phrased: “To assess the empirical evidence of the impact of food reformulation on food choices, nutrient intakes and health status, with no restriction on the type of reformulation strategy employed, nor the nutrient targeted.”

3.1.3 Novelty of this review

To make sure the planned systematic review would not overlap with systematic reviews in preparation, databases listing ongoing systematic reviews were screened. Both the Cochrane website listing protocols of Cochrane reviews (https://www.cochranelibrary.com/central), and the International prospective register of systematic reviews (PROSPERO, https://www.crd.york.ac.uk/prospero/) database were searched in September 2018 for reviews on reformulation. Authors of protocols that could overlap with the planned one were contacted to ask if their studies had a clear overlap with the one we planned. No overlap in the research question was found.

3.2. Methods

We designed the methodology of this systematic review to be as close as possible to the Cochrane methodology, using the Cochrane handbook version 5 (the 6th version was not yet released when we started this study) (Anon, 2011). We chose not to comply completely with the Cochrane guidelines for several reasons. First, Cochrane reviews are extensive reviews in which different structures are involved, especially a Cochrane Centre specialized in the field of research. This is done to ensure the review is of the best quality. However, the drawback of this rigour is the long time needed to perform a Cochrane review: between two and three years. This long process was not compatible with one of the aims of this review: to get insights about what question about the effect of reformulation on health remained unanswered. These insights were necessary to design the following studies in my PhD, incompatible with the length of the Cochrane reviews. In addition, to ensure the independence of research, a Cochrane review cannot have any commercial sponsor. This was incompatible with one funder of my PhD. Nonetheless, Cochrane standards were followed as much as possible to ensure the validity of the systematic review, as defined in this section. The protocol of the systematic review was published on the PROSPERO database (Gressier et al., 2019).

3.2.1 Criteria for considering studies for the review

The first step of a Cochrane systematic review is to identify the inclusion criteria of the studies. This is done using the PICO framework:

- Participants/Populations that should be studied
- Interventions studied
- Control condition or Comparison used
- Outcome studied.

The building of the PICO criteria is justified with the aim of the systematic review and is described below (summarized in Table 3-1).

Table 3-1: PICO (Population, Intervention, Comparator, Outcome) table for the selection of studies in the systematic review

PICO feature	Criteria
Population	The general population (subgroup analysis for children if possible). *Studies focusing on the effect in specific subgroups with medical conditions were excluded.*
Intervention	Reformulation interventions include those targeting packaged foods and/or beverages, or food sold in restaurant chains. Reformulation at a population scale can be driven by mandatory or voluntary targets, labelling, self-regulation or public-private partnerships. *Studies evaluating consumer reaction to reformulated products in lab experiments will be included though will be analysed separately from policies implemented at a population level.*
Comparison	Comparators may include no intervention or a comparison of the same group before the implementation of the intervention.
Outcomes	Studies must focus on food product choices, nutrient intakes or health outcomes linked to non-communicable diseases. Primary outcomes include choice behaviour (food purchases or sales), dietary intakes and patterns, risk factors for non-communicable diseases (BMI, blood pressure, biological markers of dietary intakes) or health outcomes (mortality). *Excluded outcomes: changes in awareness, knowledge or beliefs, measures of liking, studies with non-quantitative outcomes, and studies evaluating only the change in food composition but not the change in consumer behaviour.*

Participants / Populations

As the aim of reformulation is to reach the entire population, all studies evaluating the entire or a sample representative of a population or community were included. Studies focusing on populations with specific medical conditions were excluded as these populations are likely to receive a specific diet or be under medications.

Intervention

Interventions should be strategies directly or indirectly promoting reformulation. For example, the implementation of mandatory labelling of TFA content would be included if and only if reformulation of foods was observed. Strategies could be voluntary/mandatory reformulation guidelines, taxation based on the content of a nutrient, or nutrition labelling (including front-of-pack). The introduction of a new product deriving from an existing one (such as the introduction of a diet variant of a soft drink, or a range of reduced-fat dairy products) that did not replace existing products is not strictly considered as reformulation. Indeed, such an addition to the market requires consumers to make an informed choice to choose between the different products. However, it is impossible in many studies to distinguish between reformulation that replaces products vs. addition to the market. Hence, strategies that provoked additions to the market were included in this review.

To match the population targeted (the general population), intervention should target foods available in supermarkets, fast-foods, chain restaurants, or other stores and restaurants selling processed foods to the general population.

Comparators/Control

Control condition could be the same group before the intervention started (single group pre-post-test), or a comparable group not facing the intervention (e.g., from a place where the strategy was not implemented).

Outcomes

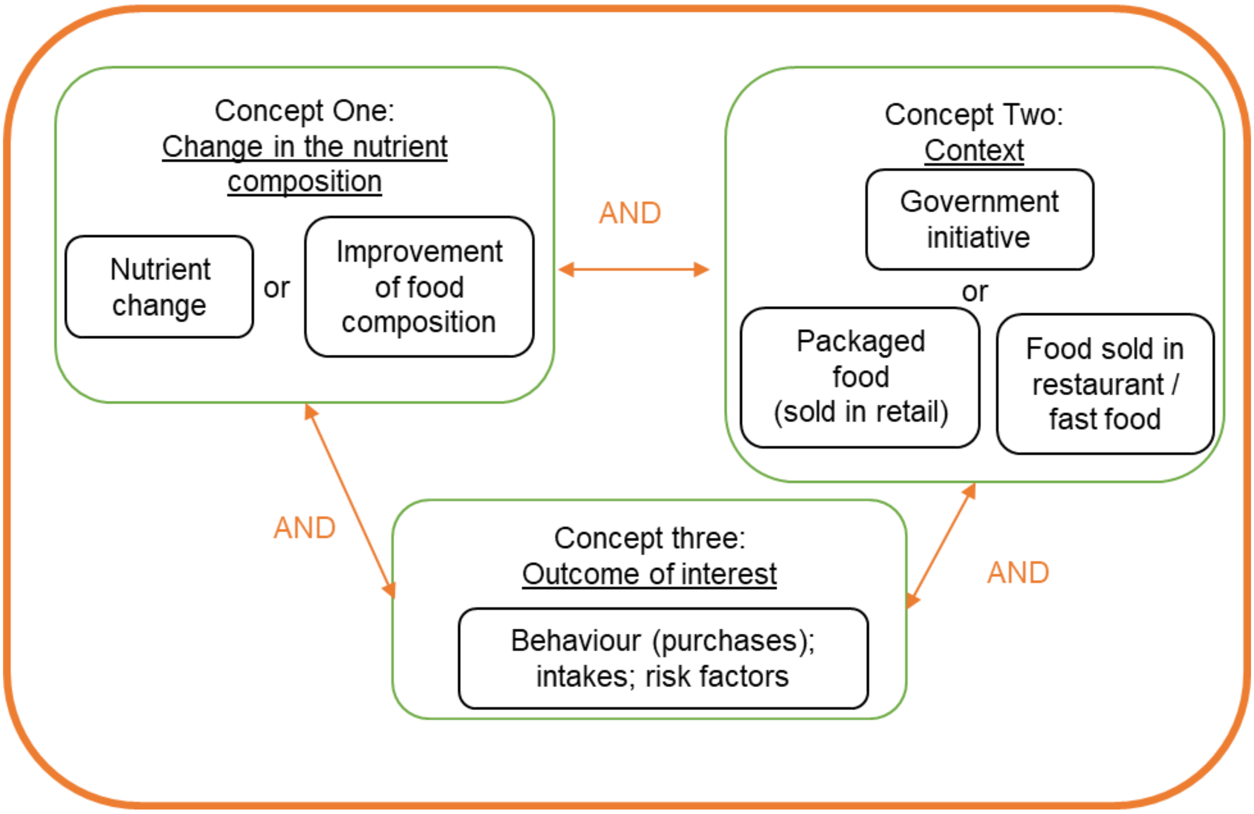
Outcomes reported should encompass consumers' responses to reformulation. As such, qualifying outcomes were consumer purchases, measures of food consumption (including dietary intakes surveys), or evaluation of health outcomes. Studies describing solely the composition of the food environment but no outcome relating to individuals' choices were excluded. This latter type of outcome informs about the characteristics reformulation policies should have to successfully incentivize manufacturers to reformulate their products. But studies focusing only on outcomes at the food level (e.g., non-weighted nutrient content of a category) are not fully informative on what would be the impact of reformulation on consumers health, given that this depends on how consumers react to reformulated products. All papers discussing reformulation without presenting quantified outcomes were excluded. Only empirical analyses of reformulation in the setting of a natural experiment were included. Included study designs could be controlled or uncontrolled pre-post studies, or interrupted time series. As such, simulation studies modelling the impact of a strategy (either not implemented, or without measuring the results) were excluded. Studies estimating the health impact of a policy using econometric models based on data from measured metrics (synthetic control method, counterfactuals) were included.

3.2.2 Search strategy

The search strategy is the translation of the PICO criteria to a search on the relevant literature databases. The search strategy needs to be broad enough to ensure all relevant studies are included. However, there is a trade-off between relevance and exhaustivity, as having a too broad search strategy leads to a high number of records that need to be screened afterwards.

The search strategy was designed in collaboration with the co-authors of the systematic review, and subject librarians from Imperial College Library. The search strategy was articulated around three concepts: a change in nutrient composition (strategy), the context of the strategy (in foods), and the outcomes of interest (Figure 3-1). Compared to the PICO criteria, the population was not included in the search strategy as the general population was targeted.

Figure 3-1: Schematic view of the search strategy for the systematic review of the literature, implemented in EMBASE, MEDLINE and Global Health databases.



To ensure that the search strategy was able to retrieve all relevant papers (i.e., exhaustivity of the search), we checked the presence of 15 key papers in the results of the search. These key papers were examples of relevant papers to be considered in the screening process, and hence are expected to be retrieved from the search strategy. These papers were linked to the themes studied in the systematic review but were not all fit to be included in the review. We adjusted the search strategy until 85% (13/15 papers) of the key papers were retrieved in Embase. We sought the reason why two papers were not found. In one, the term 'food' was not included as such. Concept one in Figure 3-1 was missing. The second paper was not found because it was a systematic review that does not focus primarily on reformulation. Hence, the concept linked to the context (concept 2 in Figure 3-1) was missing.

Papers from previous systematic reviews of the literature (cited in section 3.1.1) were also included for screening. Grey literature was explored, especially for reports of initiatives that were not published in journals. These reports were searched using the NOURISHING database of reformulation initiatives and following recommendations from experts.

The search strategy was built for Medline (via OvidSP) and was adapted for Embase and Global Health (via OvidSP). Relevant keywords and Mesh terms were used. The final search was performed in January 2019 and included all records published until December 2018. The exact search strategy for Medline is given in Appendix Table i.

3.2.3 Data collection and analysis

(1) Selection of studies

All records from the three databases, plus the ones identified on the grey literature or from other sources were imported in an online reference management software (Endnote), where duplicates were removed. Records were then screened using the online reference manager tool Rayyan (Ouzzani et al., 2016). This tool was chosen for its option to perform a blind review by several reviewers. At this stage, I screened all results by title and abstract, selecting the papers that need to be read full-text to assess them against the selection criteria. A co-author of the review (Alexa B. Segal) screened a randomly selected sample of 10% of records. At the second stage, I screened the full text of all the selected papers. The full text of papers selected after this stage were doubly screened by the second reviewer.

(2) Data extraction and management

Data from selected studies were extracted in an Excel template including the following characteristics:

- Type of strategy promoting reformulation
- Nutrient(s) targeted
- Initiators of the strategy
- Time frame and place of the strategy
- Type of outcome reported (food composition, purchases, dietary patterns,...)
- Outcome measured
- If any: analysis by subgroups of the population

(3) Assessment of risk of bias in included studies

The risk of bias of each study was assessed using an adapted Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies (Wells et al., 2009). This tool was the most appropriate given that most studies were designed as natural experiments. Studies were rated on seven criteria gathered in four domains: selection (representativeness of the sample, ascertainment of exposure), comparability of the two groups, outcome (ascertainment of outcome, duration of follow-up) and adjustment (control for confounders, evaluation of reformulation independent of other mechanisms).

The selection domain had two criteria. The first one was about the representativeness of the sample, for which a point was given if the sample was representative of the population studied (here, the general population). For outcomes linked to nutrient purchased, a point is given if the sampling of food purchases is representative of all foods purchased by a consumer, and if the consumers sampled are representative of the general population. The second criterion was about the ascertainment of exposure. One point was given if the study showed that reformulation happened during the study period. The comparability domain had one criterion: the comparability between the groups. For repeated cross-sectional, one point was given if the two groups had similar characteristics. For case-control studies, a point was given if the intervention group and the control group had similar characteristics and a similar outcome level at baseline. The outcome domain had two criteria. First, the ascertainment of the outcome was assessed: a point was given if we were confident the method was appropriate to measure the outcome. The second criterion was about the study period, for which a point was given if the follow-up period was long enough to detect the effect of reformulation (defined as per the literature on reformulation would suggest as one year for outcomes linked to behaviour, three years for outcomes linked to intakes or health). The last domain, adjustment, contained two criteria. The first evaluated the control of the confounders; one point was given if the possible confounders were controlled for. The second criterion assessed if the evaluation of reformulation was isolated from other interventions; one point was given if the effect measured was coming from reformulation, while zero points were given if other interventions were simultaneous to reformulation, or if the effect could come from a change in behaviour independent of reformulation.

An overall score was then calculated (out of seven), reflecting decreasing levels of risk of bias. To calibrate the risk-of-bias tool, 10% of the included studies were doubly assessed by the two co-reviewers, and conflicts were resolved by a discussion.

(4) Data synthesis

A narrative synthesis of the findings was written, evaluating the evidence for the different outcomes included and the different strategy focus.

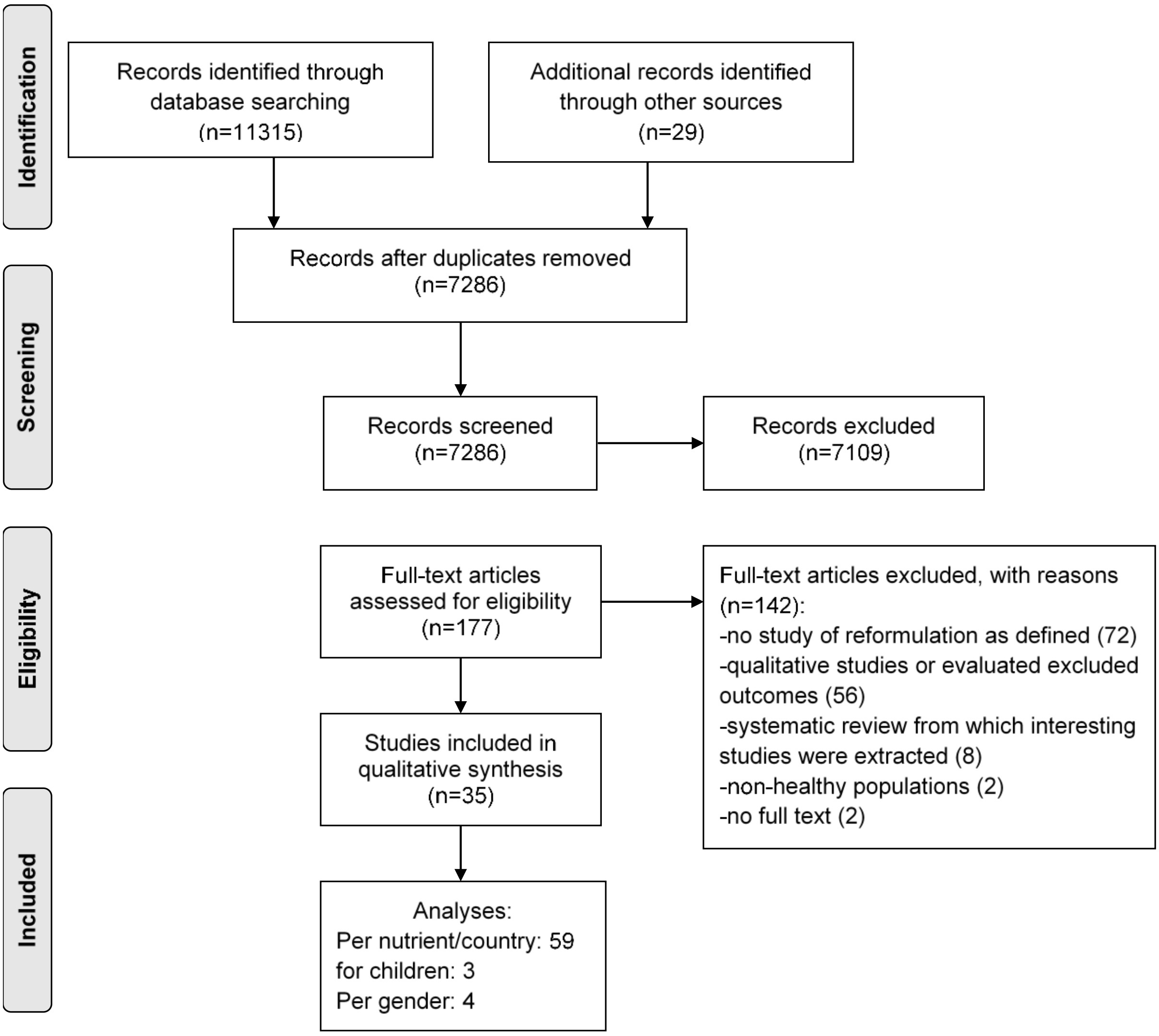
For studies similar enough to be pooled, we performed a meta-analysis using inverse-variance weighting with random effects. The meta-analysis allowed to evaluate the overall effect of reformulation. However, it could only be done for studies that evaluated similar outcomes, on similar populations. We selected the measure to use according to the Cochrane Handbook (Anon, 2011). When the outcome was reported in the same unit, or when it was possible to convert an outcome to the same unit (e.g., sodium intakes can be easily converted to salt intakes), we pooled the studies using their mean differences. Standardized mean differences (*Hedge's g*) were used otherwise, as a measure of the effect size. The between-study variance was estimated using restricted maximum likelihood as recommended for continuous outcomes (Veroniki et al., 2016). Heterogeneity was assessed with the I^2 statistics, and meta-regressions were performed to explain heterogeneity for each analysis. Sensitivity analyses were conducted by restricting the sample to studies with the least risk of bias, defined as having more than two points from the NOS. We drew funnel plots to assess publication bias. These plots show the effect estimate of a study against the precision (standard error) of this study. If there is an asymmetry in the plot, there may be a risk of publication bias. Publication bias occurs when studies showing non-significant results are not published. Hence, these studies are missing from meta-analyses. The results from a truncated meta-analysis may be over-estimated, as only studies showing significant results are included.

3.3. Results

3.3.1 Screening of the results

11315 studies were retrieved from the three databases. Searches of grey literature, from the reference list of included studies, and expert recommendations led to the addition of 29 papers (PRISMA flow chart (Moher et al., 2009) in Figure 3-2). 7286 unique records were screened using their titles and abstracts after the removal of duplicates. 177 papers were selected based on their abstracts to have their full-text assessed against the eligibility criteria. After screening, 35 papers were included in the review. 142 papers did not fill the inclusion criteria so were excluded. Most often, the intervention was not fitting the inclusion criteria (for 72 papers), or the outcome was not one of the ones we included (for 56 papers). The 35 papers reported on 29 different reformulation initiatives. Some papers included more than one outcome, others reported on several initiatives, making the number of studies included in the qualitative analysis 59.

Figure 3-2: PRISMA flow chart of the selection of studies



3.3.2 Characteristics of included papers

The reporting of the three types of outcomes included (on consumer choices, dietary intake, and health outcomes) were not evenly found (Table 3-2). Most studies reported on consumer acceptability of reformulated foods (n=27) (Ahuja et al., 2015; Angell et al., 2012; Clapp et al., 2018; Curtis et al., 2016; Eyles et al., 2013; Henninger & Ulberth, 1996; Jensen & Sommer, 2017; Mancino, Kuchler & Leibtag, 2008; McMahon, Webster & Brimblecombe, 2017; Ni Mhurchu, Eyles & Choi, 2017; Oqali, 2016; Poti, Dunford & Popkin, 2017; Quilez & Salas-Salvado, 2016; Spiteri & Soler, 2018; Tedstone et al., 2018; Zupanič et al., 2018) or nutrient intakes (n=26) (Curtis et al., 2016; Greve & Neess, 2014; Eyles et al., 2013; Griffith, O'Connell & Smith, 2017; He, Brinsden & MacGregor, 2014; Hutchinson et al., 2018; McLaren et al., 2016; McMahon, Webster & Brimblecombe, 2017; Millett et al., 2012; Monge-Rojas et al., 2013; Poti et al., 2017; Poti, Dunford & Popkin, 2017; Ratnayake et al., 2014; Shankar et al., 2013; Temme et al., 2017; Vesper et al., 2017; Friesen & Innis, 2006). Only six studies reported on the effect of reformulation on health outcomes such as changes in diet-related risk factors or disease prevalence (Grabovac et al., 2018; Colón-Ramos, Baylin & Campos, 2006; He, Pombo-Rodrigues & MacGregor, 2014; Restrepo & Rieger, 2016a, 2016b; Brandt et al., 2017).

Table 3-2: Table of reformulation initiatives included in the review, and summary of findings per study evaluating them

Country	Description of the intervention	Type of reformulation (Incentive)	Study focus	Effect of reformulation isolated[a]	Outcome[b]			Reference[d]
					Acceptability	Intakes	Morbidity/ Mortality	
Australia	Salt reduction in a bread (large-scale experiment)	Research study	sodium	yes	+[c]	-		McMahon, 2017
Austria	Multicomponent initiative on salt since 2011 (public health campaign, reformulation, food procurement policies in some institutions)	voluntary reformulation (raised awareness)	sodium	no		-		McLaren, 2016
	TFA restriction (<2% total fat) for processed foods since 2009	mandatory limit (standards)	TFA	no			-	Grabovac, 2018
	voluntary reformulation of TFA	voluntary reformulation (raised awareness)	TFA	no	+			Henninger, 1996
Canada	labelling of TFA and voluntary reformulation	voluntary reformulation (raised awareness)	TFA	no		+		Friesen, 2006
			TFA	no		+		Ratnayake, 2014
Costa Rica	Public-Private Partnership and Health campaigns to reduce TFA intakes	voluntary reformulation (PPP)	TFA	no			+	Colón-Ramos, 2006
			TFA	no		+		Monge-Rojas, 2013
Denmark	Ban on TFA from 2003	mandatory limit (standards)	TFA	yes			+	Restrepo, 2016 (Am J Prev Med)
	Danish Whole Grain Partnership: public-private partnership	voluntary reformulation (PPP)	whole grains	no		+		Greve, 2014
	Energy reduction in 8 products (retailer brand)	voluntary reformulation (manufacturer led)	energy	yes	+			Jensen, 2017
	Multicomponent initiative on salt since 2008 (Public health campaign, nutrition labelling, reformulation, food procurement policy in some institutions)	voluntary reformulation (raised awareness)	sodium	no		+		McLaren, 2016
Finland	Multicomponent initiative on since 1979 (public health campaign, nutrition labelling, reformulation, food procurement policy in some institutions)	voluntary reformulation (raised awareness)	sodium	no		+		McLaren, 2016

Country	Description of the intervention	Type of reformulation (Incentive)	Study focus	Effect of reformulation isolated[a]	Outcome[b]			Reference[d]
					Acceptability	Intakes	Morbidity/ Mortality	
France	Multicomponent initiative on salt since 2001 (public health campaign, reformulation, food procurement policies in some institutions)	voluntary reformulation (raised awareness)	sodium	no		+		McLaren, 2016
	Public-Private Partnership defining reformulation targets for various nutrients	voluntary reformulation (PPP)	sodium	yes	+/-			Oqali, 2016
			sugar	yes	+/-			
			several nutrients	yes	+/-			
			fibre	yes	-			Spiteri, 2018
			several nutrients	yes	+			
			sodium	yes	+			
			sugar	yes	-			
Ireland	Multicomponent initiative on salt since 2003 (public health campaign, reformulation, nutrition labelling)	voluntary reformulation (raised awareness)	sodium	no		+		McLaren, 2016
New Zealand	Health Star Rating (Front-of-pack labelling using a nutrient profile model) since 2015	voluntary reformulation (raised awareness)	several nutrients	no	+			Ni Mhurchu, 2017
			sodium	no	+			
			energy	no	+			
			fibre	no	+			
Slovenia	Public health campaign in 2015-2016	voluntary reformulation (raised awareness)	TFA	no	+			Zupanič, 2018
Spain	Salt reduction in bread (voluntary reformulation by a manufacturer)	voluntary reformulation (raised awareness)	sodium	no	+			Quilez, 2016
Switzerland	Multicomponent initiative on salt since 2008 (public health campaign, reformulation, food procurement policies in some institutions)	voluntary reformulation (raised awareness)	sodium	no		-		McLaren, 2016
The Netherlands	Mandatory limits for salt in bread (gradual reduction from 2009, latest amendment in 2013), several industry engagements to reduce salt in their foods	voluntary reformulation (standards + voluntary)	sodium	no		-		Temme, 2017

	Description of the intervention	Type of reformulation (Incentive)	Study focus	Effect of reformulation isolated [a]	Outcome[b] Acceptability	Intakes	Morbidity/ Mortality	Reference[d]
The Netherlands	Multicomponent initiative on since 2007 (public health campaign, nutrition labelling, reformulation, food procurement policy in some institutions)	voluntary reformulation (raised awareness)	sodium	no		-		McLaren, 2016
Turkey	Multicomponent initiative on salt since 2011 (public health campaign, reformulation, food procurement policies in some institutions)	voluntary reformulation (raised awareness)	sodium	no		+		McLaren, 2016
UK	FSA salt reduction programme from 2003 to 2011 (agreements with the food industry to reformulate, public health campaigns and nutrition labelling)	voluntary reformulation (PPP)	sodium	no	+	+		Eyles, 2013
			sodium	yes		+		Griffith, 2017
			sodium	no		+		He, 2014 (*J Hum Hypertens.*)
			sodium	no			+	He, 2014 (BMJ Open)
			sodium	no		+		McLaren, 2016
			sodium	no		+		Millett, 2012
			sodium	no		+		Shankar, 2013
	PHE sugar reduction programme from 2017 (voluntary reformulation targets and soft-drink industry levy)	voluntary reformulation (raised awareness)	several nutrients	no	+			Tedstone, 2018
			sugar	no	+			
	voluntary reformulation of TFA	voluntary reformulation (raised awareness)	TFA	yes		+		Hutchinson, 2018
US, New York States	TFA restriction in fast food restaurants	mandatory limit (standards)	TFA	yes	+			Angell, 2012
			TFA	yes			+	Brandt, 2012
		mandatory limit (standards)	TFA	yes			+	Restrepo, 2016 (J Health Econ.)
US	Multicomponent initiative on salt since the late 1980's (public health campaign, reformulation, nutrition labelling)	voluntary reformulation (raised awareness)	sodium	no		-		McLaren, 2016
	National Salt Reduction Initiative: voluntary targets	voluntary reformulation (PPP)	sodium	no	+			Ahuja, 2015
			sodium	no	+			Clapp, 2018

		several nutrients	no	+		
		energy	no	+		
		sodium	no	+	+	Curtis, 2016
		sodium	yes	+	+	Poti, 2017 (JAMA Intern Med. And FASEB J)
		sodium	no		-	
New dietary guidelines on whole grain intakes in 2005	voluntary reformulation (raised awareness)	whole grains	no	+		Mancino, 2008
restriction in fast-food restaurants, labelling for packaged foods	voluntary reformulation (raised awareness)	TFA	no		+	Vesper, 2017

[a]: The effect of reformulation was estimated to be estimated on its own when the effect of the reformulation initiative was isolated from potential confounders (such as educational campaigns aiming at changing behaviours).

[b]: Positive results were defined as a significant change in the outcome measured, going in the direction of an improvement in public health (i.e. reduction of intakes for sodium, TFA, energy or sugar, increase for fibre or whole grains), or a reduction in disease risk or mortality.

[c]: Positive ("+") results were defined as a significant change in average nutrient density of purchased products or a change in nutrient intake going in the direction of an improvement for public health (i.e. reduction for sodium, TFA, energy or sugar, increase in fibre or whole grains and improvement of the nutrient profile of foods), or a reduction in disease risk or mortality. Negative or the absence of impact are denoted with "-".

[d]: The number of the reference is specified when the short citation is ambiguous.

PPP: Public-Private Partnership

TFA: *Trans*-fatty acids

PHE: Public Health England

FSA: Food Standard Agency

Most studies were conducted in high-income countries: ten studies focused on the US, nine on the UK. Only three studies (5%) were conducted in upper-middle-income countries (in Costa Rica and Turkey) (Table 3-2). Twenty-nine distinct initiatives were analysed, three of them were mandatory (bans on the use of TFA). Nineteen strategies to promote voluntary reformulation used consumer awareness methods such as public health campaigns, or nutrition labelling, six were public-private partnerships (with targets to incentivize manufacturers to reformulate their products), two were initiatives led by manufacturers, and one was a real-condition experiment led by a research group (Table 3-2).

3.3.3 Risk of bias

The adapted NOS risk of bias tool was effective in differentiating the risk of bias between studies (Table 3-3). The average risk of bias score was 4.2. Four studies received the highest score (seven), while two studies received zero points, showing a very high risk of bias. Studies modelling the effect of reformulation on health tended to have better scores, as their study designs allowed them to isolate the effect of reformulation from other interventions (Restrepo & Rieger, 2016a, 2016b; Brandt et al., 2017). It was more difficult to isolate the effect of reformulation in studies evaluating changes in dietary intakes.

Table 3-3: Risk of bias of included studies (according to the adapted Newcastle-Ottawa Scale)

Reference	Selection: representativeness of the sample	Selection: ascertainment of exposure	SELECTION	COMPARABILITY of groups	Outcome: ascertainment of outcome	Outcome: follow-up long enough	OUTCOME	Adjustment: control for confounders	Adjustment: reformulation isolated	ADJUSTMENT	Sum of points
Brandt, 2017	1	1	2	1	1	1	2	1	1	2	7
Restrepo, 2016	1	1	2	1	1	1	2	1	1	2	7
Restrepo, 2016	1	1	2	1	1	1	2	1	1	2	7
Poti, 2017	1	1	2	1	1	1	2	1	1	2	7
Grabovac, 2018	1	1	2	1	1	1	2	1	0	1	6
Angell, 2012	1	1	2	1	0	1	1	1	1	2	6
Colón-Ramos, 2006	1	1	2	1	1	1	2	1	0	1	6
Hutchinson, 2018	1	1	2	1	0	1	1	1	1	2	6
Vesper, 2017	1	1	2	1	1	1	2	1	0	1	6
Eyles, 2013	1	1	2	1	0	1	1	1	1	2	6
Griffith, 2017	1	1	2	1	1	1	2	0	1	1	6
Spiteri, 2018	1	1	2	1	1	1	2	0	1	1	6
He, 2014	1	1	2	1	1	1	2	0	0	0	5
He, 2014	1	0	1	1	1	1	2	1	0	1	5
McLaren, 2016 (Finland)	1	0	1	1	1	1	2	1	0	1	5
McLaren, 2016 (UK)	1	1	2	1	1	1	2	0	0	0	5
McMahon, 2017	1	1	2	0	1	1	2	0	1	1	5
Poti, 2017	1	1	2	1	1	1	2	0	0	0	5
Shankar, 2013	0	1	1	1	1	1	2	1	0	1	5
McLaren, 2016 (France)	1	1	2	1	1	1	2	0	0	0	5
Greve, 2014	1	1	2	1	1	1	2	0	0	0	5
Jensen, 2017	1	1	2	0	1	0	1	0	1	1	4
Millett, 2012	0	1	1	0	1	1	2	1	0	1	4
McLaren, 2016 (Netherlands)	1	1	2	0	1	1	2	0	0	0	4
McLaren, 2016 (US)	0	1	1	1	1	1	2	0	0	0	4
Ni Mhurchu, 2017	1	1	2	1	1	0	1	0	0	0	4
Temme, 2017	0	1	1	0	1	1	2	1	0	1	4
Clapp, 2018	0	1	1	1	1	1	2	0	0	0	4
Mancino, 2008	1	1	2	1	1	0	1	0	0	0	4
Curtis, 2016	0	1	1	1	0	1	1	0	0	0	3
Quilez, 2016	1	1	2	0	0	1	1	0	0	0	3
Ratnayake, 2014	0	1	1	0	1	1	2	0	0	0	3
Ahuja, 2015	0	0	0	1	1	1	2	0	0	0	3
McLaren, 2016	1	0	1	1	1	0	1	0	0	0	3
Tedstone, 2018	1	1	2	0	1	0	1	0	0	0	3
Oqali, 2016	1	0	1	0	1	0	1	0	1	1	3
Friesen, 2006	0	1	1	0	1	0	1	0	0	0	2
McLaren, 2016 (Ireland)	1	0	1	0	0	1	1	0	0	0	2
McLaren, 2016 (Switzerland)	0	0	0	0	1	1	2	0	0	0	2
Monge-Rojas, 2013	0	1	1	0	0	1	1	0	0	0	2
Zupanič, 2018	0	1	1	1	0	0	0	0	0	0	2
Henninger, 1996	0	1	1	0	0	1	1	0	0	0	2
McLaren, 2016 (Austria)	0	0	0	0	0	0	0	0	0	0	0
McLaren, 2016 (Turkey)	0	0	0	0	0	0	0	0	0	0	0

The domain representing the higher risk of bias was the adjustment domain, with only seven papers (16%) having a point in the two criteria of the domain (adequate control for confounders: 34%, and evaluation of reformulation prevented from other input 27%). This meant that for many studies we could not rule out that the effect measured is the one from confounders or other interventions. Other domains from the risk of bias scale had better compliance. Two-thirds of included papers used a sample that was representative of the population, and for 80% of papers, the population faced reformulation. The comparability of the control and intervention groups was satisfying for 64% of the papers. Regarding the assessment of the outcome, 75% and 77% of papers had a satisfying ascertainment of the outcome and a follow-up long enough, respectively.

3.3.4 Effect on consumer behaviour and food choices

Included studies showed that the implementation of a reformulation strategy was followed by changes in the nutrition quality of purchases. An improvement in the sales-weighted average nutrition content of a category or households purchases after the implementation of a reformulation strategy was observed in 22 studies (amongst 27 evaluating this outcome, Table 3-4). This meant that the reformulation of food products was accepted and did not provoke a behaviour change. A change in the sales-weighted or purchase-weighted nutrient density meant that the reformulation of foods was accepted by consumers and there was no compensation (or at least it did not offset the effect of reformulation).

Table 3-4: Number of studies and proportion showing positive results for acceptability of reformulated products, daily intakes, and morbidity or mortality reduction resulting from the implementation of a reformulation strategy (table from (Gressier et al., 2021))

		Acceptability [a]		Intake [b]		Morbidity / Mortality	
Characteristics	All outcomes (n)	Studies (n)	Positive results (%)	Studies (n)	Positive results (%)	Studies (n)	Positive results (%)
Total	59	27	81%	26	73%	6	83%
Effect of reformulation isolated							
no	41	16	100%	22	73%	3	67%
yes	18	11	55%	4	75%	3	100%
Nutrient studied							
sodium	31	10	90%	20	65%	1	100%
TFA	13	3	100%	5	100%	5	80%
several nutrients [c]	5	5	80%				
energy	3	3	100%				
sugar	3	3	33%				
fibre	2	2	50%				
whole grains	2	1	100%	1	100%		
Type of reformulation							
Mandatory limit	5	1	100%			4	75%
voluntary reformulation [d]	54	26	81%	26	73%	2	100%

Positive results were defined as a significant change in average nutrient density of purchased products or a change in nutrient intake going in the direction of an improvement for public health (i.e. reduction for sodium, TFA, energy or sugar, increase in fibre or whole grains and improvement of the nutrient profile of foods), or a reduction in disease risk or mortality.
[a] Acceptability of reformulated products was either measured using:
Sales/purchases of the reformulated product before and after reformulation
The evolution of market-share weighted averages of a nutrient content before and after reformulation
[b] Intakes were measured through traditional methods (dietary survey, biomedical measures) or by evaluating the nutrient content of all purchased items by households representative of the population.
[c] 'Several nutrients' is used either for measures of nutrient profile (e.g. score) or when several nutrients were evaluated jointly
[d] Voluntary reformulation can be triggered via commitment or the implementation of labelling.

The acceptability of reformulated products was studied in the case of sodium (n=10), TFA (n=3), or energy reductions (n=3), in the case of fibre (n=2) or whole-grain (n=2) increases, or in the case of reformulation to improve several nutrients at the same time (n=5) (Table 3-4).

Reformulated foods were accepted despite varying reformulation rates. These reformulation rates depended upon the nutrient that was targeted. For example, the TFA reduction in reformulated foods was between 80% to almost 100% (Angell et al., 2012; Grabovac et al., 2018), while energy or sugar reductions were much smaller (energy reductions between 0.4-

3% (Jensen & Sommer, 2017; Ni Mhurchu, Eyles & Choi, 2017), sugar reductions of 2-3% (Tedstone et al., 2018; Oqali, 2016)).

In addition, the size of the reformulation was linked to the effect on the quality of purchases. Large TFA decrease in foods led to large TFA reduction in purchases (e.g. TFA ban in New York City restaurants led to an 85% reduction in TFA purchases (Angell et al., 2012)); while modest reductions in food energy density led to smaller changes in the energy of food purchased (e.g. the energy reformulation of restaurant foods by 0.1 to 4.4% led to an average reduction in energy purchased by 1.1% (Clapp et al., 2018)).

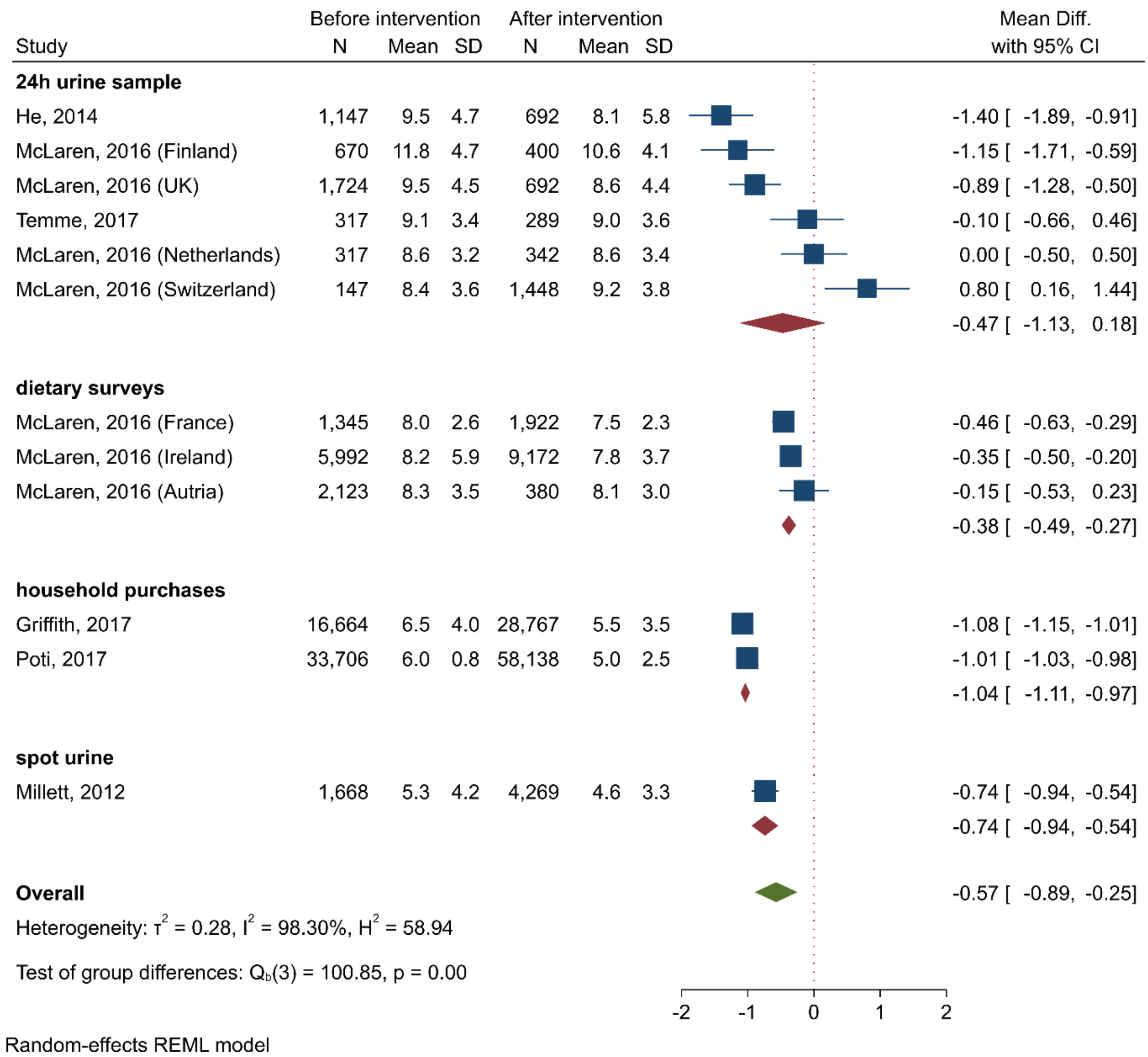
3.3.5 Effect of reformulation on dietary intakes

The reformulation of foods led to improvement in the intake of the nutrient targeted in 20/26 studies (Table 3-4). The success rate of reformulation was similar between studies that measured sodium intakes using biomarkers (n=13, success rate=77%) and studies that used reported food intake to estimate nutrient intake (n=13, success rate=69%) (Appendix Table ii). Studies reporting on changes in dietary intake focused on sodium or TFA reformulation. None reported results of sugar, fibre, or energy reformulation.

(1) Effect on salt intakes

The effect of reformulation on dietary intake was mostly investigated for sodium reduction. In these studies, intakes decreased by between 4% and 15% (in 20 studies). The meta-analysis showed that the pooled effect was 0.57g/day (CI -0.89; -0.25 g/day) (Figure 3-3).

Figure 3-3: Pooled estimate of the effect of initiatives including salt reformulation on populations' salt intake (in g/day), by measurement method used to measure a change in dietary sodium.



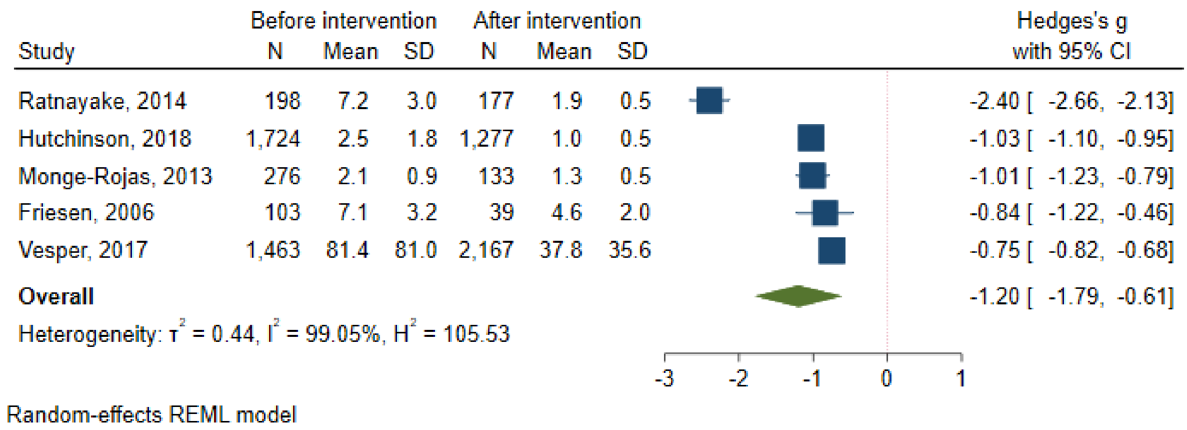
The effect of salt reformulation to reduce salt intake was higher in studies that used household purchases to estimate salt intake than in studies that used dietary surveys or measured salt excretion (Figure 3-3). Nonetheless, the sensitivity analyses showed that the method used to estimate salt intake could not explain these differences (Appendix Table iii). The stratification by method or duration of study showed no significant difference (Appendix Table iv). The results were robust to the quality of included studies; and removing the studies with the highest risk of bias (NOS score ≤ 2) led to a stronger effect (-0.78g/day (CI -1.06; -0.49g/day), Appendix Figure i)

No publication bias was detected as studies were symmetrically distributed around the pooled estimate (Appendix Figure iii), Egger's test showed no evidence for small study effect.

(2) Effect on TFA intakes

All five studies reporting on TFA reformulation reported a reduction in TFA intakes (Table 3-4). The meta-analysis performed showed that TFA reformulation had an estimated standardized mean difference of -1.20 (CI: -0.79; -0.61) (Figure 3-4). As for sodium reformulation, the effect was stronger when the studies with the least risk of bias were selected. In that case, the effect size was -1.4 (CI: -2.37; -0.39).

Figure 3-4: Pooled estimate of the effect of initiatives including TFA reformulation on populations' TFA intake (the effect size is the standardized mean difference given by the Hedge's g statistic).



3.3.6 Effect of reformulation on health outcomes

The effect of reformulation on health status was reported in only six studies. Five studies reported improvements in health outcomes (Table 3-5). Similarly to results on dietary intake, the focus of these studies was only on TFA (n=5) and salt (n=1) reformulations. TFA reformulation led to a decrease in cardiovascular disease in 4/5 studies. Mortality decreased by between 4.3% and 6.2% (Table 3-5). The only study on the effect of salt reformulation on health found that salt reduction in the UK was linked to improvement in population blood pressure (Table 3-5).

Table 3-5: Effect sizes reported for the impact of food reformulation on health outcomes (mortality) (from (Gressier et al., 2021))

1st author	Country	Nutrient targeted	Method used	Outcome measured	Effect on health outcomes[a]	Reported results
He, 2014	UK	sodium	Multiple linear regression	Changes in population blood pressure	+	blood pressure decreased by 2.7/1.1mm Hg in individuals who were not on antihypertensive medication
Grabovac, 2018	Austria	TFA	Synthetic control method	% reduction in CVD-related mortality	null	No significant change in mortality in Austria compared to the control cohort
Colón-Ramos, 2016	Costa-Rica	TFA	Case-control study	Myocardial infarction occurrence	+	Blood TFA was no longer a risk factor for Myocardial infarction after the intervention, while it was before
Restrepo, 2016	Denmark	TFA	Synthetic control method	% reduction in CVD mortality rates (heart diseases and strokes)	+	Reduction in CVD mortality rates by 4.3% (equivalent to 14.2 deaths avoided/100 000). Reduction in coronary heart disease mortality by 10.3% (26.5 deaths avoided /100 000)
Brandt, 2017	US, New York States	TFA	Difference-in-differences	% reduction in hospital admissions for CVD (myocardial infarctions and strokes)	+	Reduction in hospital admissions for CVD by 6.2% (-7.8% for myocardial infarction and -3.6% for strokes, NS). Is equivalent to 43 admissions avoided for 100 000 people
Restrepo, 2016		TFA	Panel regression	% reduction in CVD mortality rates (heart diseases and strokes)	+	Reduction in CVD mortality rates by 4.5% (equivalent to 13 deaths avoided/100 000). Reduction in coronary heart disease mortality by 4.1%, and strokes by 7.4%

[a]: the effect on health outcome is positive if there was a significant reduction of mortality or risk factor reported.

CVD: cardiovascular diseases; NS: not significant; TFA: *trans*-fatty acids

3.3.7 Equity impact of reformulation

Only a few studies evaluated equity in the impact of reformulation policies. Most studies evaluated the effect of reformulation in samples representative of the general population, with no stratification by age, gender, or socioeconomic status.

Three studies evaluated the effect of reformulation in children or adolescents (Monge-Rojas et al., 2013; Poti et al., 2017; Greve & Neess, 2014). The study by Monge-Rojas et al. (2013) evaluated the effect of TFA reformulation in adolescents' TFA intake. They found a reduction of similar size to studies done on adults (Figure 3-4). In the study by Poti et al. (2017b), the salt intake of both adults and children showed no change despite a pledge from manufacturers to reduce the sodium in their foods. The study by Greve & Neess (2014) showed that the proportion of adults and children reaching the recommended whole grain daily intake followed similar trends between 2000-2004 and 2011-2013 (Greve & Neess, 2014). In summary, reformulation initiatives had the same effect across age groups.

Some studies evaluated the changes in intakes for both genders. Most studies found that the effect of reformulation was similar across genders (McLaren et al., 2016; Hutchinson et al., 2018; Millett et al., 2012; He, Brinsden & MacGregor, 2014).

Three studies evaluated the impact of reformulation strategies in different groups of the population defined with their socioeconomic status (Hutchinson et al., 2018; Millett et al., 2012; Vesper et al., 2017). All studies reported similar patterns: the effect of reformulation was similar across groups. It was often reported that this similar effect of reformulation across socioeconomic status groups resulted in the maintenance of socio-economic disparities observed at baseline (Millett et al., 2012; Vesper et al., 2017). In the case of the TFA reduction in the UK, the reformulation of foods may have contributed to erasing socio-economic differences in the population: while at baseline a high TFA consumption was associated with socioeconomic disadvantage, this was not the case post-reformulation anymore (Hutchinson et al., 2018).

3.3.8 Isolated effect of reformulation

The reformulation strategies evaluated in the included studies often had multiple components. As such, only 18/59 studies evaluated the isolated effect of reformulation. To do so, either reformulation was implemented alone, or the effect of reformulation was isolated from confounders using adequate methods. Studies on the acceptability of reformulated products were less likely to report positive results (i.e., reformulated products are accepted by consumers) when they isolated the effect of reformulation (Table 3-4).

Studies that isolated the effect of reformulation ignored the effect of other policies, that is why they were less likely to report that reformulated foods were accepted by populations. The acceptability of reformulated products could have been improved by awareness campaigns implemented together with the reformulation policy. Conversely, studies on the isolated effect of reformulation were more likely to report improvement in health outcomes. This result highlights that reformulation can improve diets but may be limited by other concurrent trends in consumer purchases. For example, in Austria, the removal of TFA from foods did not result in health improvements because smoking rates increased (and the study could not control for smoking rates) (Grabovac et al., 2018).

3.4. Discussion

Overall, this systematic review of the literature suggests that reformulation strategies are useful to improve the nutritional quality of purchases, dietary intake, and health outcomes. Evidence was convincing for reformulation policies aiming at reducing salt or TFA intake, but there was missing evidence about the impact of reformulation policies targeting other nutrients, or the full nutrient profile of foods.

3.4.1 Effect of reformulation on health outcomes

Reformulation can lead to health benefits, according to five of the six studies looking at health outcomes. However, the link between reformulation and health outcomes was only studied in the case of TFA reduction (or removal), so this link cannot be generalised to other nutrients. The magnitude of the reformulation had an impact on health outcomes as well. The combination of the total elimination of TFA from several nations' food supplies, as well as the significant link between TFA intake and health (Mozaffarian et al., 2006), produced the conditions for a measurable impact on health. This direct link between reformulation and health improvement may be more difficult to get for other nutrient focuses of reformulation. First, in the case of TFA reformulation, it was possible to maintain the total fat content while guaranteeing a better nutrient profile of foods (Ratnayake, L'Abbé & Mozaffarian, 2009). Contrarily to TFA removal, reformulating foods focusing on other nutrients may be challenging. Because most nutrients (sugar, fats, fibre, and salt) play a role in texture, stability, and flavour, reformulating the entire nutrient profile of foods is difficult (Buttriss, 2013). Reformulating a food product to change one nutrient has implications for the food's entire nutrient profile, as the quantity of other nutrients typically needs to be modified (Savio et al., 2013). The difficulty in observing any health impact of single nutrient reformulation may be due to the fact that the health impact of diets is not mediated by only one nutrient. Secondly, whereas artificial TFA-containing foods are easy to recognize, determining which foods should be included in other reformulation initiatives is more complex because nutrients like sugars and salt are naturally found in foods. The use of salt replacements and gradual reductions in salt intensity were used for sodium reformulation. In contrast to TFA reformulation, sodium reformulation was gradual, which may explain why evaluating the health impact of sodium reformulation is more challenging.

3.4.2 Likely impact on reformulation to reduce energy in foods

Reformulation strategies mostly target nutrients that are consumed in excess, such as TFA, sodium, and more recently sugars or energy. One arm of the UK government's plan to curb childhood obesity is to reduce the energy content of foods using reformulation (Public Health England, 2020a). The strategy is targeting foods sold in supermarkets and takeaway outlets, with targets for calorie reduction of 5% to 20% depending on the type of food. In this review, only three studies evaluated the effect of energy reformulation strategies and found those strategies were helpful to reduce the energy sold to, or purchased by consumers (Clapp et al., 2018; Jensen & Sommer, 2017; Ni Mhurchu, Eyles & Choi, 2017). However, no study evaluated the impact of those strategies on dietary intake. Some experimental studies suggest that reducing the energy density of foods, for example by increasing the vegetable part of a mixed dish, or substituting sugar with non-caloric sweeteners in beverages, led to a decrease in energy intakes (Leahy, Birch & Rolls, 2008; Blatt et al., 2012). However, the decrease in energy intake was smaller than the decrease expected based on the reduction in foods, and some compensation occurred (Leahy, Birch & Rolls, 2008; Blatt et al., 2012; Markey, Le Jeune & Lovegrove, 2016). In the study by Markey et al. (2016), participants replaced some of the foods and beverages they consumed with similar sugar-free foods and beverages. Whereas participants had lower sugar intakes after the intervention than before, the energy intake was not changed; in that study, participants compensated the energy from a nutrient (sugar) to another nutrient (fat), resulting in no change of energy intakes (Markey, Le Jeune & Lovegrove, 2016). The study by Leahy et al. (2008) tested giving children an energy-reduced entrée as part of their lunch. A 30% reduction in energy of the entrée resulted in a 25% reduction in energy intake from the entrée and an 18% reduction over the whole lunch (Leahy, Birch & Rolls, 2008). This means there was a partial compensation, whereby children consumed a higher quantity of the energy-reduced entrée. These studies in experimental settings could mean that reformulation to reduce the energy content of foods may have a limited impact on energy intake.

In addition, manufacturers may struggle to reduce the energy density of certain foods. Reducing the calorie content of foods depends on the type of matrix the food is made of. One aim of the SDIL is to incentivise manufacturers of soft drinks to reformulate to decrease the sugar content of drinks. As the calorie content of soft drinks is mostly determined by their sugar content, reducing sugar in drinks automatically induces a calorie reduction. Between 2015 and 2018, soft drinks in the UK had their sugar content reduced by 28.8%, while their energy content per portion was reduced by 20.5% (Niblett et al., 2019). At the same time, sugar in other foods consumed at home was reduced by 2.9%, while their calorie content was only reduced by 0.4%. In addition, sugar in foods consumed out-of-home was reduced by 4.9%, while the energy content of a portion of those foods increased by 1.8% (Niblett et al., 2019). The first learning is that, as expected, it is possible to decrease the energy content of soft drinks by reducing their sugar content, and that the UK SDIL was effective to drive reformulation. However, such reduction was not obtained in solid foods. Reformulating solid foods to reduce their energy density is more challenging than reformulating soft drinks, where replacing sugar with artificial sweeteners automatically lead to a reduction in energy content. Sugar has a role in the texture, stability, and sensory profile of foods. While in liquids it can be easily replaced by artificial sweeteners, in solid foods this substitution is not as easy as artificial sweeteners are introduced in a much smaller quantity than sugar and can't reproduce the technical characteristics of sucrose (Buttriss, 2013). To reproduce the characteristics of sugar lost with reformulation, manufacturers could use additives, but those are negatively perceived by consumers. One common solution is to replace sugar with modified fibre. However, in the case of a 1 to 1 substitution of sugar with fibre, the resulting calorie reduction is only 2 kcal per gram. This substitution will not greatly change the energy density of a food. Also, often a full revision of the recipe is needed, which could lead to an increase in other nutrients such as fat or energy. The analysis of the effect of the UK sugar reduction programme showed that amongst the top-selling brands that had a sugar reduction of more than 2%, only 14% had also reduced energy and SFA, while half of them had either an increase in energy or SFA (Niblett et al., 2019).

The fact that reformulating may not lead to a reduced energy density of products is not only guessed from observations about sugar reformulation. For example, the reformulation to reduce TFA in foods was done by substituting other fats. The replacement was done with fats made of unsaturated fatty acids, or SFA (Mozaffarian, Jacobson & Greenstein, 2010; Ratnayake, L'Abbé & Mozaffarian, 2009). Overall, TFA reformulation did not change the fat content of products, hence did not impact its energy content.

3.4.3 Food reformulation policies should consider foods consumed out-of-home

The majority of reformulation policies found in this review targeted foods sold in supermarkets, while only four out of thirty-five papers included restaurant meals (Angell et al., 2012; Restrepo & Rieger, 2016b; Tedstone et al., 2018; Ahuja et al., 2015). Some policies included food sold in schools or state-owned facilities such as hospitals or administrations (Jahn et al., 2018). For example, these settings were often included in salt-reduction policies.

In 2005-06, US working-age adults consumed on average a third of their daily calories away from home, with 11% of calories from fast-foods (Todd, 2017). In Australia, fast-foods represent between a third and one-half of daily calorie intakes (Dunford et al., 2017). The lowest share of calories from food consumed away-from-home was found in elderly from Mediterranean Europe, who derived between 6 and 20% of their calorie intake from foods consumed away from home (Lachat et al., 2012). And this share has been increasing in recent years. In 2005-06, 34% of daily calories of US people born 1980-1990 were coming from food away from home. In 2013-14, the share of the same population was 40% (Todd, 2017). This effect does not seem to be an age effect (but a cohort effect) as older cohorts did not experience such an increase in calories from food consumed away from home (Todd, 2017). From the 1990s, US children consumed more energy from fast foods and restaurants than from schools (Lachat et al., 2012).

Eating outside has been associated with diets of lesser quality by many studies. Most of these studies evaluate correlations between diet quality and eating away from home (Lachat et al., 2012). This difference in diet quality may be due to the quantity of food eaten away from home compared to at home, or the choice of less healthy foods while not at home. In Australia, foods from categories available both as packaged foods or in restaurants received similar Health Star Ratings, despite some variability across different groups (Dunford et al., 2017). Many studies found an association between energy consumed and total energy (see Lachat et al., 2012 for a review). Using a causal inference method, Mancino and colleagues estimated that in the US, each meal consumed away from home added 130 calories to the daily intake, and lowered the Healthy Eating Index by two points (Mancino, Todd & Lin, 2009).

Despite this increasing role of foods consumed away-from-home, few reformulation strategies tackled them. Restaurant food could be manufactured in big quantities, distributed and advertised following similar processes to packaged foods. Foods sold in fast-food chains follow a uniformized production, and advertisement focuses on the food sold in chains, intending to attract customers in all chains. Some foods from fast-food chains are now consumed on a very frequent occasion. The UK charity Action on Sugar noted very high levels in hot drinks sold in coffee shops, visited on average by a fifth of the UK population every day (Action on Sugar, 2016). As such foods are manufactured, distributed, and advertised using similar methods to packaged foods sold in supermarkets, they could easily be the target of reformulation policies. Following this approach, the UK plan to curb obesity includes foods taken away from home as well as packaged foods (see section 3.4.2). Early results showed that sugar reformulation led to a 5% reduction in the sugar content of foods sold for takeaway consumption (Niblett et al., 2019). This measure is not weighted by sales but suggest that manufacturers of those foods reformulated their products. However, at the same time, the energy contained in one portion slightly increased. A first explanation could be an increase in the portion size of those foods. Foods consumed out-of-home are perceived as discretionary treats, for which the portion size is an indicator of value-for-money (Ledikwe, Ello-Martin & Rolls, 2005). Also, the increase in calories observed may be a side-effect of sugar reduction, by which manufacturers of out of home foods increased their fat content to maintain a satisfactory sensory profile. Foods consumed away-from-home have long been consumed only on special occasions. However, while the consumption of such products is now wide and not restricted to special occasions, they are still perceived as a treat that should be hedonic.

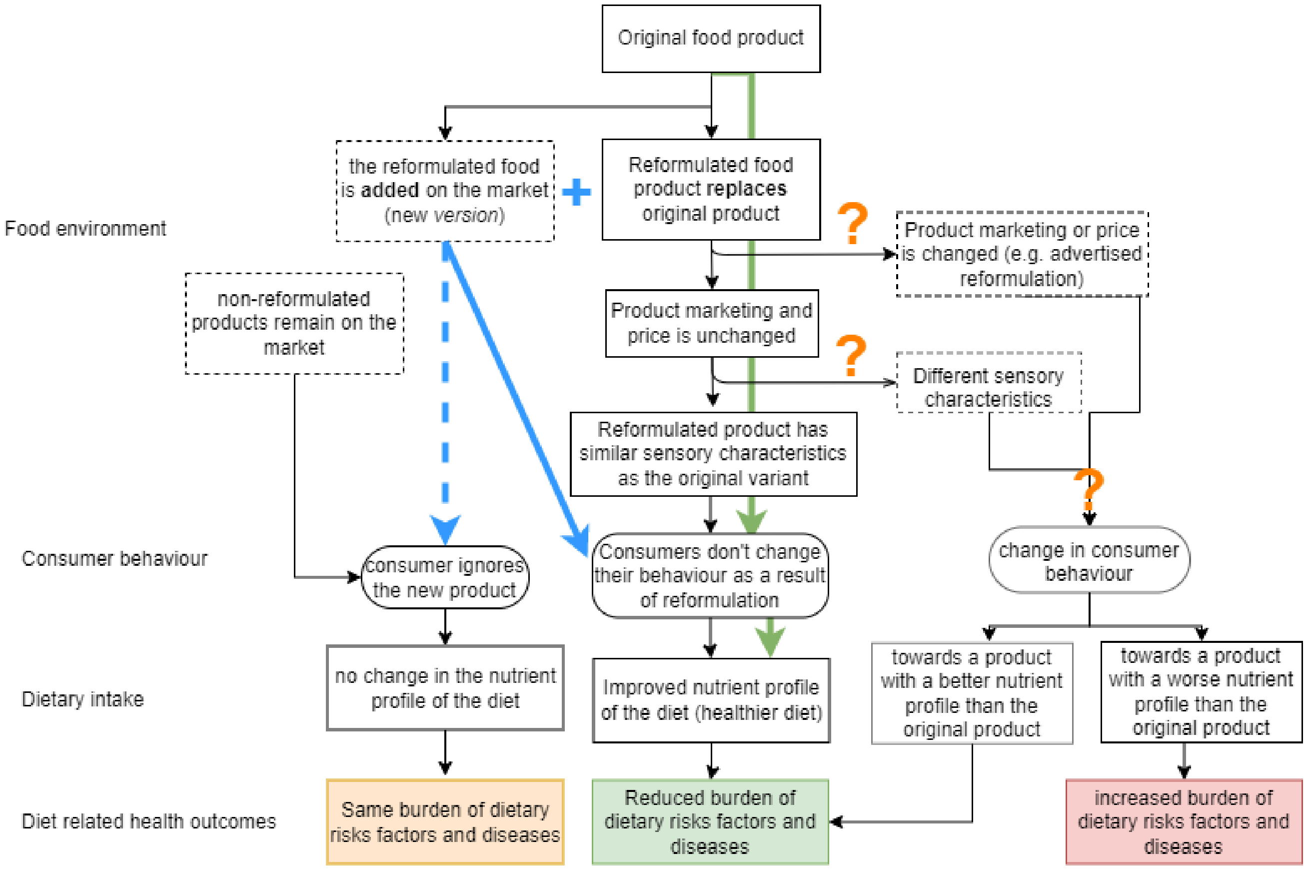
Given their high consumption, improving the composition of foods consumed away from home could have an important impact on the diet of populations. For example, the reformulation of New York restaurant foods to reduce their TFA content was shown to improve the health outcomes of populations subject to these reformulated foods (Restrepo & Rieger, 2016b).

3.4.4 Validation and modification of the logic model of reformulation

The aim of this systematic review was to check the validity of the logic model drawn in Chapter 2 (Figure 2-8). Several learnings can be added to the figure. First, the studies included in this review did not always focus on reformulation that replaces original products: some initiatives also led to the addition of new products in the market. From the evidence included in this review; we can conclude that adding new products (as well as reformulating some products) led to an improvement in purchases, and/or dietary intakes. The logic model of the action of reformulation has been updated with this finding that product diversification does not seem to be a risk of levelling of the effect of reformulation (blue arrows on Figure 3-5).

In addition, the fact that reformulated products were accepted in many instances of reformulation suggests that, at a population level, reformulation led to improved purchases with limited compensation (green arrows in Figure 3-5). Evidence on the reformulation of different nutrients also showed that reformulation had a visible impact on improving dietary intake. Nonetheless, population dynamics can hide different behaviours at an individual level (question marks in Figure 3-5).

Figure 3-5: Updated logic model of the effect of reformulation, with learnings from the systematic review



Notes: Dotted boxes are deviations from "silent" reformulation policies. Blue arrows and 'plus' signs are learnings from the systematic review of the literature, where reformulation policies that included product diversification led to improved dietary intakes (and thereby acceptance of reformulated products). Green arrows show the pathway that was found in the literature review. Questions marks highlight pathways for which no information was gained from the systematic review.

3.4.5 Strengths and limitations

This review is the first to look at the empirical evidence on the effect of reformulation, regardless of the nutrient targeted. The originality is that the review does not partition research according to the nutrient (or group of nutrients) that was targeted with the reformulation policy. We chose this original approach to be able to make conclusions regarding the consequences of the *mechanism* of reformulation, more than of specific strategies to reformulate foods. Also, we included outcomes linked to three measures (change in purchases, dietary intake and health) to ensure broad coverage of empirical evidence published till now, and to be able to gather all evidence informing policymakers and researchers about the likely impact of reformulation on health.

Our review is also subject to some limitations. First, and in high dependence on the research published, the different targets of reformulation initiatives (i.e., nutrients) are not equally represented. There is an overrepresentation of studies focusing on salt or TFA reduction, and the evidence about the impact of reformulation on intakes or health is almost solely coming from interventions focusing on salt or TFA.

Second, studies evaluating the effect of reformulation on the nutritional quality of purchases, or some of the ones evaluating the effect on dietary intake rely on the nutrition content of packaged foods from labels. Using nutrition labels can create a bias as labelling laws allow for a margin of error between the labelled content, and what could be measured in a product (Albuquerque et al., 2020). Although the margins of error are small, a systematic bias in the content of one nutrient could lead to a significant bias in the estimation of dietary intakes from these labels.

Third, in the majority of included studies, reformulation was not done in isolation, and it was not possible to isolate the effect of reformulation. The effect of reformulation was isolated in 18 studies, of which only seven appropriately controlled for confounders. We cannot rule out that the effect measured in some studies is linked to other policies than reformulation, and that reformulation alone would have the same effect.

3.4.6 Gaps in the research and needs for future research

This review highlighted several gaps in the evaluation of the impact of reformulation on consumer behaviour, intake, and health. The impact of reformulation policies targeting sugar and/or fibre has not been studied in many studies.

Another major gap found in the literature is that most studies only focused on the specific nutrient that was targeted by the reformulation initiative. Studies evaluating the effect of salt reformulation only evaluated changes in salt intakes. Hence, such studies are not informative of possible side-effects of reformulation. Conversely, studies evaluating the effect of reformulation on health, by design, take into consideration all changes in food composition resulting from reformulation. The whole nutrient profile of products, purchases and diets should be investigated to evaluate the impact of reformulation on health.

Also, there is a research gap in terms of methodologies used to evaluate the effect of reformulation policies. First, reformulation can lead to small improvements in dietary intake, that are difficult to measure in populations (such as in Temme et al. (2017)). Nonetheless, even a small improvement in individual dietary intake can have a significant health effect at the population scale. Second, because reformulation policies are often implemented together with other policies such as education campaigns, specific methods need to be used to adequately isolate the effect of reformulation. That way, the effect of reformulation policies on health outcomes could be correctly assessed. On the other hand, it is also relevant to evaluate the combined effect of different policies implemented, including reformulation. Indeed, a main finding of this and previous research is that reformulation works best when implemented together with other policies (McLaren et al., 2016; Hyseni et al., 2017b). When reformulation is implemented with other strategies, we need to understand the interactions between the different strategies.

None of the studies included in the review focused on the way consumers react to reformulated foods (questions marks in Figure 3-5). Included studies evaluated the overall population effect, but this effect can be the result of different individual behaviours. For example, we included in the logic model that if the product marketing mix was changed, this could result in a shift in consumer demand towards other products. The consequence on intakes can be favourable or unfavourable depending on the characteristics of the substitution product. To examine this effect, data at an individual level are needed, as the overall effect could be neutral, despite people shifting towards a better diet, and others to a worse diet.

Lastly, only a few studies reported on the equity impact of reformulation. Given that there are important disparities in food intake and diet-related health conditions, it is important to evaluate if reformulation participates in widening or erasing these disparities.

3.5. Conclusion

In this study, we found a substantial body of evidence suggesting that reformulated products were accepted (i.e., purchased) by consumers. This resulted in a change in dietary intakes in the same direction as the change in nutrient composition induced by the reformulation of foods. However, studies mostly analysed reformulation strategies in which sodium or TFA were reformulated. We found no studies evaluating this effect for other nutrients. Also, studies included in this review showed that reformulation to reduce foods TFA content led to an improvement in health measures. Evidence on the effect of other reformulation initiatives on health is lacking. To gain knowledge on the likely impact of reformulation on health, we will investigate the unknown links in the logic model. Namely, we will investigate domains of reformulation that have not been thoroughly studied: the reformulation of fibre and sugar (Chapters 4 & 6). Then, we will investigate the effect of reformulation and other policies implemented together (Chapter 5& 6), and reformulation in foods sold in retail vs. takeaways (Chapter 6). In addition, we will seek to understand how consumers react to reformulated foods (Chapter 7).

4. CHAPTER 4: REFORMULATION OF CEREAL-BASED PRODUCTS, AND THE ABSENCE OF AN INCREASE IN FIBRE INTAKE IN THE UK

In this chapter, I analyse trends in fibre content and intake in the UK, during the past decade. This chapter aims at answering (in part) the second objective of the thesis. The research presented in this chapter was published as a peer-reviewed article (link to full text in Appendix II):

Gressier, M. & Frost, G. (2021) Minor changes in fibre intake in the UK population between 2008/2009 and 2016/2017. *European Journal of Clinical Nutrition*. 1–6. doi:10.1038/s41430-021-00933-2.

4.1. Background: A low fibre intake in the UK, and initiatives launched to promote fibre consumption

4.1.1 Dietary fibre and their role in health

Dietary fibre is needed in the human diet to maintain health. Dietary fibre is a component of plant-based foods, making the structure of plant cell walls. It is present in all plant-based foods but absent from animal-based foods. Sources of dietary fibre in the diet include grain products (especially whole grains), vegetables, potatoes and fruits (Stephen et al., 2017).

Because of its molecular structure, fibre is not digested or absorbed in the small intestine but fermented by micro-organisms in the gut (Scientific Advisory Committee on Nutrition, 2015). The digestion of fibre by the gut microbiota helps absorbing nutrients that are not available as such (such as calcium) and produces metabolites that have a role in healthy digestion. In addition, dietary fibre provides bulk in foods: as it is not completely digested, it has a low caloric value compared to other nutrients. As a result, the consumption of dietary fibre is linked to various health benefits, including reducing the risk of cardiovascular diseases, type 2 diabetes and bowel cancer (Stephen et al., 2017).

4.1.2 Intake of dietary fibre and its determinants

Despite its known benefits, intake of dietary fibre is consistently lower than recommended in all regions of the world (Afshin et al., 2019). Amongst the Global Burden of Disease study regions, intakes are the lowest in Asia (8-10g/day) and the highest in Oceania and western & eastern sub-Saharan Africa (16-20g/day) (Afshin et al., 2019). The inadequate consumption of fibre was estimated to be responsible for about 100 000 deaths in 2017 globally (Afshin et al., 2019).

And some countries document no increase in fibre intake recently. For example, in the US, the intake of dietary fibre only slightly changed in the first decade of the 2000s (McGill, Fulgoni & Devareddy, 2015). Intakes did not change significantly for US adults and stayed stable around 16g/day. There was however a significant increase in fibre intakes for children and adolescents and adults over 51 years. This trend was not attributable to an increase in the intake of whole grains (McGill, Fulgoni & Devareddy, 2015).

Fibre intake and trends in fibre intake vary with socio-economic status. Another study done for the US population between 2005 and 2012 found an increase in the intake of whole grains for adolescents aged 13 to 18 years (Tester et al., 2017). However, when stratified by income, this change was only visible for high-income adolescents.

4.1.3 Fibre intake in the UK, and sources of fibre

The role of the UK Scientific Advisory Committee on Nutrition (SACN) is to inform UK public authorities about the nutrition status of the UK population and give recommendations about how to improve the health status of the population. In 2015, they published a report on dietary carbohydrates (Scientific Advisory Committee on Nutrition, 2015). The main results from this report were that the UK population was consuming too much sugar and not enough fibre. Fibre intake was estimated at around 14g/day in adults, and 11-12g/day in children (Scientific Advisory Committee on Nutrition, 2015). In comparison, the dietary reference value for the average population intake was defined at 30g/day for adults aged more than 16 years. Recommendations for children goes from 15g/day for children aged 5 to 11 years to 25g/day for children aged 11 to 16 years. These recommendations were based on the state-of-the-art published literature. The report highlighted that, in the UK, average daily intake is, like in most parts of the world, well below recommended daily intake. UK adults are on average consuming only half of the recommended intake.

The main sources of fibre in UK adults in 2009-2011 were grain products, vegetables and potatoes (Stephen et al., 2017). The sources of fibre for children were similar, but children derived a greater proportion of fibre from grain products and a lower from vegetables (Stephen et al., 2017). Fibre from grain products in the UK diet appears to come mainly from non-whole grain products. A study estimated that only 12% of fibre intake came from whole grain products, against 40% from non-whole grain products (Gibson et al., 2019).

4.1.4 Strategies to increase population fibre intake

Following the publication of the SACN report showing the large gap between observed and recommended intakes of dietary fibre, different initiatives were launched to promote a higher fibre consumption in the UK population. The message was promoted by various health-promotion organizations such as the NHS, the British Heart Foundation or the British Nutrition Foundation (NHS, 2019; British Heart Foundation, 2019; British Nutrition Foundation, 2020). These organisations designed new messages and campaigns to raise population awareness about the benefit of adequate fibre intake. These messages put emphasis on swapping refined grains to whole grains, as fibre and other healthful minerals are lost during the refinement of grains. The message to eat five fruits and vegetables a day was also reinforced.

Nonetheless, these initiatives were not enforced by the government. Contrarily to salt or sugar (see chapters 5 and 6), there was no intervention coming from the government to promote the consumption of fibre, or the reformulation of foods to add more fibre. The initiatives mentioned above had hence limited funding and more limited scope.

4.1.5 Food reformulation to increase the content of fibre

Even in the absence of a government incentive to reformulate foods to increase their fibre content, some manufacturers claim to increase the fibre content of their products. Manufacturers can choose to increase fibre contents to attract consumers as some consumers are sensitive to claims such as “rich in fibre”. In addition, increasing the fibre content of a food can be a way to improve a food nutrient profile (Foschia et al., 2013). Different changes in the recipe of food products can be made to increase the fibre content. For starchy products such as bread or pasta, refined flour can be replaced with whole grain flour. The substitution can be done entirely or only partially, depending on the technical barriers to add whole grain and consumer acceptability of those. Otherwise, ingredients such as inulin, wheat or oat bran, or resistant starches can be added to the products to increase their fibre content (Foschia et al., 2013). It seems that manufacturers started to reformulate their products with increasing fibre content since the early 2000s. One impulse could have been given by the launch in the US of the Dietary Guidelines for Americans in 2005, in which the recommendation to eat whole grain was introduced (Mancino, Kuchler & Leibtag, 2008). As some products are sold by multinational food companies, it is possible that they updated their portfolio for the UK at the same time as for the US.

4.1.6 Research question and aim of the chapter

Different actions were made in the UK to improve the fibre consumption of the population. Some actions aimed at changing behaviours, others at changing the food offer.

We hypothesized that:

1. The awareness campaigns were associated with increased fibre intake resulting from better food choices
2. The content of fibre in products increased as a result of voluntary reformulation by manufacturers

This chapter aimed at testing these hypotheses by analysing the trends in the fibre intake of the UK population and fibre content of foods at the beginning of the 21st century.

4.2. Methods

4.2.1 The National Diet and Nutrition Survey

(1) Choice of the National Diet and Nutrition Survey for this study

The National Diet and Nutrition Survey (NDNS) was chosen to study the changes in fibre content of foods and in the fibre intake of the UK population as the most reliable source of data for population intake. Indeed, the NDNS Rolling Programme has been conducted on 9 years (at the time this study was performed, in 2020) and hence provides a series of cross-sectional data of similar methodology. This stable methodology is needed to study changes in population food choice and intake. The strong methodology of the NDNS includes the representativeness of the UK population, essential to correctly evaluate the consequence of reformulation or fibre promotion campaigns on the population.

Furthermore, the NDNS is linked to a food composition database (see below section (4)4.2.1(4)) that is updated regularly to take into consideration dynamics in the food offer (reformulation, turnover of products).

(2) Sampling of participants

Estimates of the UK population food intakes were derived from the National Diet and Nutrition Survey (NDNS) Rolling Programme, from the years 2008/2009 (Year 1) to 2016/2017 (Year 9) (NatCen Social Research & MRC Elsie Widdowson Laboratory, 2019). The NDNS is a cross-sectional annual national survey, carried over approximately 1000 participants each year. Participants are sampled across the four regions of the UK to get a sample representative of the UK population. The sample is made representative of the UK population characteristics (age distribution, ethnicity, gender, education, income...) using survey weights.

(3) Information collected

Participants filled a four-day food diary, with all foods and beverages consumed either at home or away from home (e.g., in restaurants, school or work canteens). To have a sufficient number of participants with good quality data, participants who filled at least three days of the diary were kept in the survey. The validity of the food diary technique was checked against plausible values of energy expenditure using doubly labelled water.

Participants were also weighed and measured so that their body mass index (BMI) can be calculated. Participants also filled a questionnaire about their health habits. They are also asked to answer questions about their demography (e.g., income, education...)

(4) Link to the composition of foods

Year-specific nutrient information was taken from the UK Nutrient Databank, and foods' nutrition composition was linked to food codes reported by participants. The UK Nutrient Databank gathers the nutrition composition of food products commonly consumed in the UK. Nutrition composition is derived from chemical analyses or extracted from the nutrition declaration on products' packaging. Similar branded products matching the same definition of foods consumed by the survey's participants are aggregated into the same NDNS food code. The use of aggregated foods has been evaluated as reliable as using the composition of branded foods to study population intake (Perrin et al., 2018).

Each food has its non-starch polysaccharide (NSP) fibre content measured by the Englyst method or calculated. The Nutrient Databank did not include the total fibre content of foods before year 8 (2015/2016). In year 8, total fibre content was added retrospectively in all previous years. As one focus of this study is to evaluate the impact of the reformulation of food products, the measure of total fibre cannot be used. We used NSP fibre contents instead.

(5) Data cleaning

From the food categories defined in the McCance and Widdowson table, we derived 13 food categories adequate to analyse trends in fibre content. The food categories from the McCance and Widdowson tables are quite broad to analyse fibre intake. One category, 'Cereal and cereal-based products' gathered all products made of cereals. For this analysis, we split this category between bread, and pasta, rice, and other cereals. Similarly, we split the "Vegetable" category between Potato-based products and Vegetables. Potato based products include fries, roast, boiled potatoes, potato salad or dishes, but exclude potato crisps (classified in snacks).

Age groups were created from the age of participants:

- young children: from 1.5y to 3y
- children: from 4y to 10y

- adolescents: from 11y to 18y
- adults: from 19y to 64y
- older adults: from 65y

4.2.2 Analyses of time trends

Different time trends were investigated to explain changes in fibre in foods and diets.

(1) Trends in the fibre content of foods

To understand if there was reformulation, and if the fibre content of foods changed between 2008/2009 and 2016/2017, we compared the mean fibre content between these two years. We used Mann-Whitney U-tests to compare the mean fibre content of all foods and for each food category. To evaluate if the reformulation led to significant changes in the fibre content of foods, we selected products present in the database for the two years and paired their two fibre contents (for the same products in the two years). Then, we compared the paired fibre contents between the two years for all foods and then per food category using Wilcoxon signed-rank tests. We used such non-parametric tests as the distribution of the fibre content of foods does not follow a normal distribution.

(2) Trends in fibre intake

The primary outcome of this study is the dietary intake of fibre. Indeed, we want to understand if there were any changes in the dietary fibre intake of the UK population. Then, we were interested in explaining this change (or the absence of change). Mean fibre intake was estimated from the food surveys for each year of the survey. Trends in the mean fibre intake of the population were tested using linear regressions. The survey year was the independent variable of interest (coded as 1 for Year 1, ...). The regressions were adjusted for demographic characteristics (age group, gender, BMI, ethnicity and equivalised income) and total energy intake.

Time trends were also stratified by age group and gender to gain understanding of the different trends by age group or gender. As total energy intake is a strong predictor of fibre intakes, we also evaluated time trends in fibre for 1000 kcal and stratified this analysis by gender.

(3) Contribution of food groups to fibre intake

We calculated the contribution of each food group to the mean population fibre intake: we estimated the average percentage of fibre coming from each food group for the population. We did this calculation for each year of the survey, and for each age group. Non-consumers of food categories were attributed a zero to have a complete-case design. Time trends in the contribution of the different food groups to fibre intake were calculated using linear regressions, adjusted for the same variables as described above.

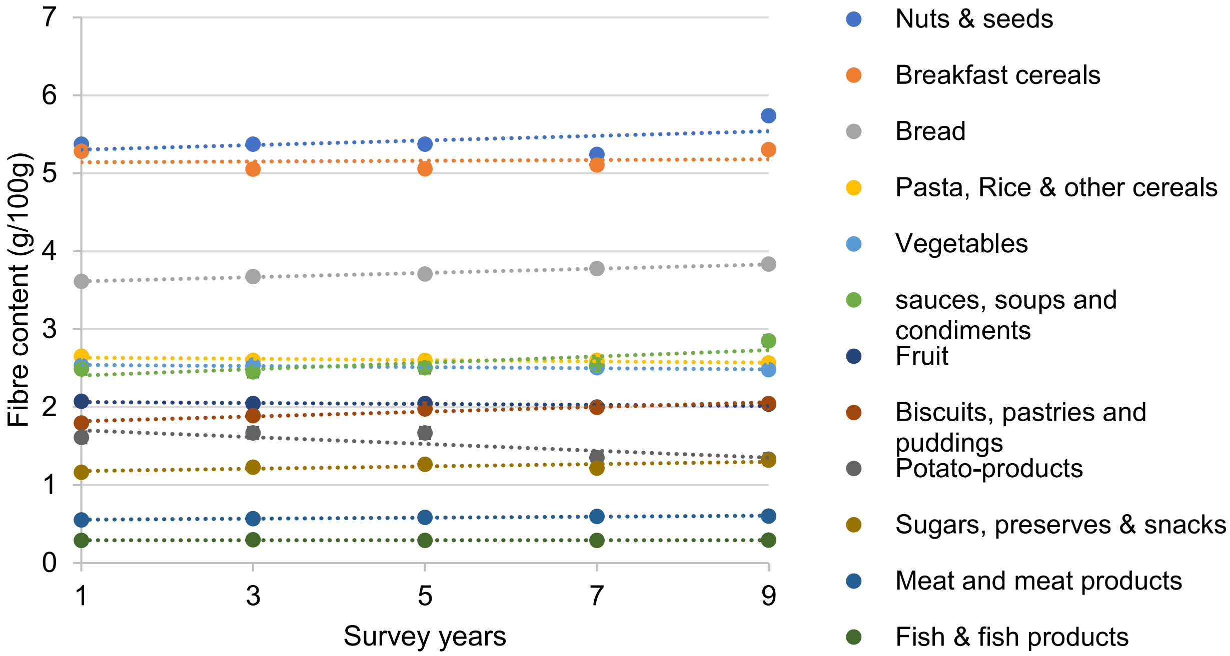
4.3. Results

4.3.1 Changes in the fibre content of foods

The mean fibre content of food categories varied between 0.0g per 100g of food of that category and 5.5g/100g in 2008/2009 (Figure 4-1). Nuts and seeds is the category with the highest mean fibre content, with more than 5 g of fibre per 100g of foods. Breakfast cereals and bread have more than 3g of fibre per 100g. The fibre content of products in the NDNS is estimated for products as consumed, as the aim of the NDNS is to estimate food and dietary intakes. As a result, contents of fibre may appear low for products that are cooked in water (such as rice or pasta). For example, the mean fibre content of cereals was 2,5g/100g, as this content is measured after cooking.

Overall, while some products were reformulated (showed by the significant Wilcoxon paired test for all products in Table 4-1), the fibre content of all foods consumed in 2008-09 and 2016-17 remained stable (non-significant Mann-Whitney U-test). The fibre content of some food categories changed between year 1 and year 9. For example, the mean fibre content of bread and breakfast cereals showed an upward trend, while the mean fibre content of potato products showed a downward trend (Figure 4-1). The mean fibre content of bread increased from 3.6 (SD 1.8) g/100g in year 1 to 3.8 (SD 1.9) g/100g in year 9 (Table 4-1). This increase is significant for paired products, but not for all products. It suggests that bread consumed both in year 1 and year 9 had their fibre content increased, signalling some reformulation. But overall, the distribution of the fibre content of all bread products has not significantly changed between year 1 and year 9. The median fibre content of potato products was significantly lower in year 9 (1.2g/100g) than in year 1 (1.5g/100g). Both tests, for all potato products and for paired products were significant, showing a decrease in the fibre content of the products belonging to that category.

Figure 4-1: Mean fibre content of food products declared consumed in the NDNS Years 1 to 9, by product category



Notes: the mean fibre content of each category was calculated in years 1, 3, 5, 7 and 9 by averaging the fibre content of each food product belonging to that category in the NDNS databank. Numbers are simple averages, not weighted by consumption. The dotted lines are unadjusted time trends. Standard errors are not indicated, see Table 4-1.

Table 4-1: Mean and median NSP fibre content of foods in NDNS 2008-09 and 2016-17

	N products 2008-09	N products 2016-17	N paired products	median 2008-09	mean ± SD 2008-09	median 2016-17	mean ± SD 2016-17	p-val Mann-W U	p-val paired wilcox
Nuts & seeds	40	41	40	5.5	5.4 ± 2.7	5.4	5.7 ± 3.6	*0.8984*	*0.5839*
Breakfast cereals	130	176	123	4.3	5.3 ± 4.7	4.9	5.3 ± 4.1	*0.4790*	*0.3904*
Bread	106	121	103	3.15	3.6 ± 1.8	3.7	3.8 ± 1.9	*0.3414*	***0.0039***
Pasta, Rice & other cereals	185	194	183	1.3	2.7 ± 4.2	1.3	2.6 ± 4.1	*0.7532*	*0.1421*
sauces, soups and condiments	297	355	295	0.5	2.5 ± 6.4	0.7	2.9 ± 6.9	*0.0721*	*0.0847*
Vegetables	394	447	378	1.9	2.5 ± 2.3	1.9	2.5 ± 2.2	*0.4929*	*0.0759*
Fruit	209	257	208	1.3	2.1 ± 2.8	1.3	2.0 ± 2.7	*0.9431*	***0.0002***
Biscuits, pastries and puddings	467	501	461	1.4	1.8 ± 1.8	1.6	2.0 ± 2.4	*0.0773*	***0.0096***
Potato-products	138	139	129	1.5	1.6 ± 0.7	1.2	1.3 ± 0.7	***0.0000***	***0.0000***
Sugars, preserves & snacks	212	224	205	0.35	1.2 ± 1.9	0.7	1.3 ± 2.0	*0.0712*	*0.0602*
Meat and meat products	692	696	688	0.4	0.6 ± 0.6	0.5	0.6 ± 0.6	*0.1564*	***0.0000***
Supplements	301	594	294	0	0.3 ± 1.2	0	0.4 ± 4.2	*0.3023*	*0.9165*
Eggs	78	80	78	0	0.3 ± 0.5	0	0.3 ± 0.5	*0.6247*	*0.0830*
Fish & fish products	215	221	212	0	0.3 ± 0.4	0	0.3 ± 0.4	*0.9264*	*0.4151*
Milk & milk products	267	342	246	0	0.2 ± 0.5	0	0.3 ± 0.7	*0.0872*	***0.0047***
Fats and oils	55	71	51	0	0 ± 0.1	0	0 ± 0.1	*0.4806*	*1.0000*
Beverages	229	278	221	0	0 ± 0	0	0 ± 0.1	***0.0049***	*0.1198*
All foods	**4015**	**4737**	**3915**	**0.7**	**1.5 ± 2.8**	**0.7**	**1.5 ± 3.3**	***0.6502***	***0.0045***

Notes: Changes in the distribution of fibre content were tested using paired Wilcoxon-rank sum test (for food items present in the survey both years) and using Mann-Whitney U-test for comparing the full sample. Cells in bold show significance at 5%.

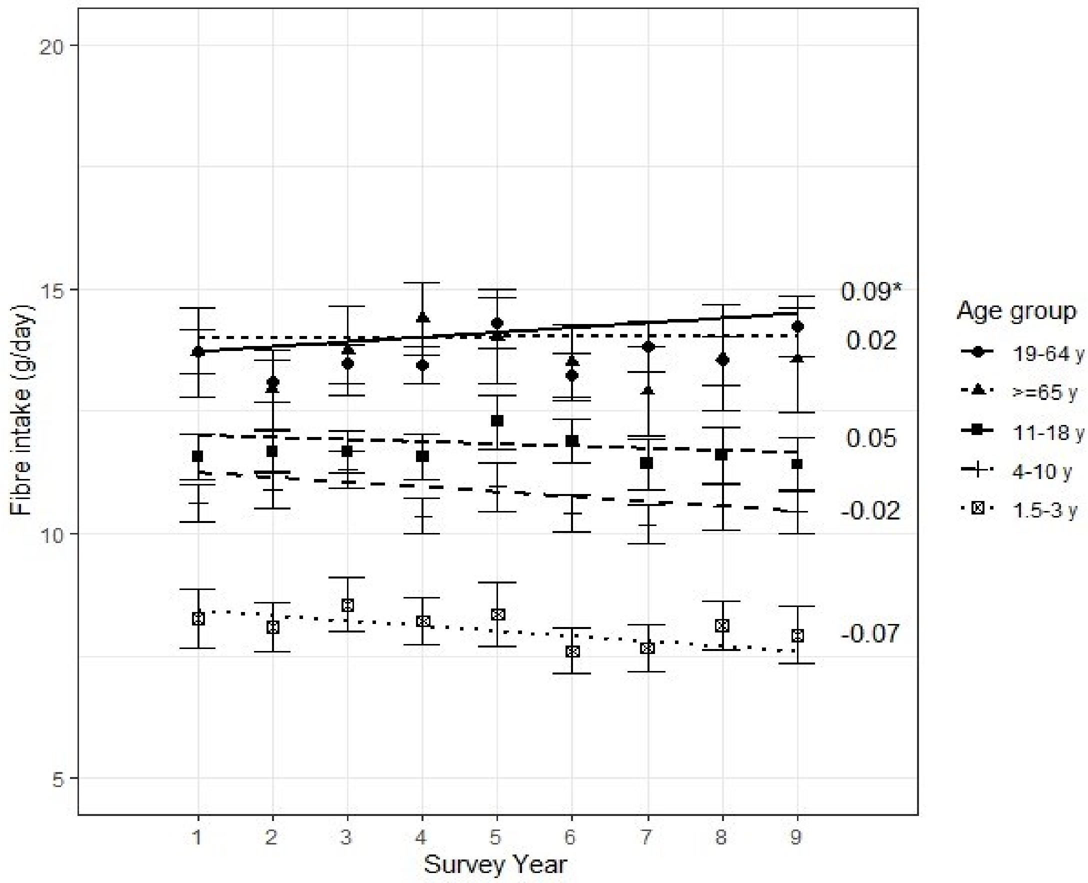
4.3.2 Changes in fibre intake

The fibre intake of the whole population marginally increased between year 1 and year 9. The adjusted population intake was 12.7 (SE 0.1) in year 1 and 13.0 (SE 0.1) in year 9, with a (statistically) significant increase of +0.06g/ year (SE 0.03, p-value= 0.032, adjusted for age group, sex, energy intake, BMI, ethnicity and equivalised income, full regression results in Appendix Table v). This increase is too small to have a physiological consequence. Nonetheless, it denotes a small shift in the distribution of the population intake of fibre.

After stratifying by age group, only adults showed a significant increase in their fibre intake (Figure 4-2). Trend for adults aged 19-64y was 0.09g/year (p-value=0.025). Model-adjusted means for adults was 13.2 (SE 0.1) in year 1 and 13.9 (SE 0.2) in year 9. Children aged 1.5-3y and 4-10y had a non-significant downwards trend in fibre intakes, while adolescents (aged 11-18y) and older adults (aged over 65y) had a non-significant upwards trend in fibre intake.

Controlling for different time trends across gender revealed a significant increase in fibre intake only in males (adjusted trend: +0.09g/day/year, p=0.041), and not in females. Males have higher absolute fibre intake than females, but a lower fibre intake per calorie.

Figure 4-2: Trend in mean fibre intakes of the UK population between 2008/2009 and 2016/2017, by age group.



Notes: The graph shows mean fibre intakes and 95% confidence intervals for each age group and each survey year of the NDNS. Trendlines were plotted for each age group. Corresponding estimates for the time trends are shown on the right of the graph (corresponding to the interaction term between survey year and age group). Asterisks (*) indicates a significant estimate at a 5% level.

4.3.3 Food sources of dietary fibre, and changes over time

The previous paragraph explained that fibre intake increased only for adults, and not children. Understanding the cause of this difference can help design policies that would be effective to increase fibre intake in the different age groups. To understand why we see different patterns in fibre intake in children, adolescents, and adults, we analysed the different food sources of dietary fibre. For all age groups, Cereals & cereal products was the category contributing the most to fibre intake (Table 4-2). It represented 40% of adults' fibre intake, and 45% of children and adolescents intake in year 1. While Vegetables was the second contributor to fibre intake in all age groups, the size of this contribution differed across age groups. Adults got 25% of their fibre from vegetables, while children and adolescents got only 17% of their fibre intake from vegetables. Potato products and Fruits were the categories having the 3rd and 4th highest contribution for all age groups.

Table 4-2: Contribution of different food groups to fibre intake, at baseline and per age group

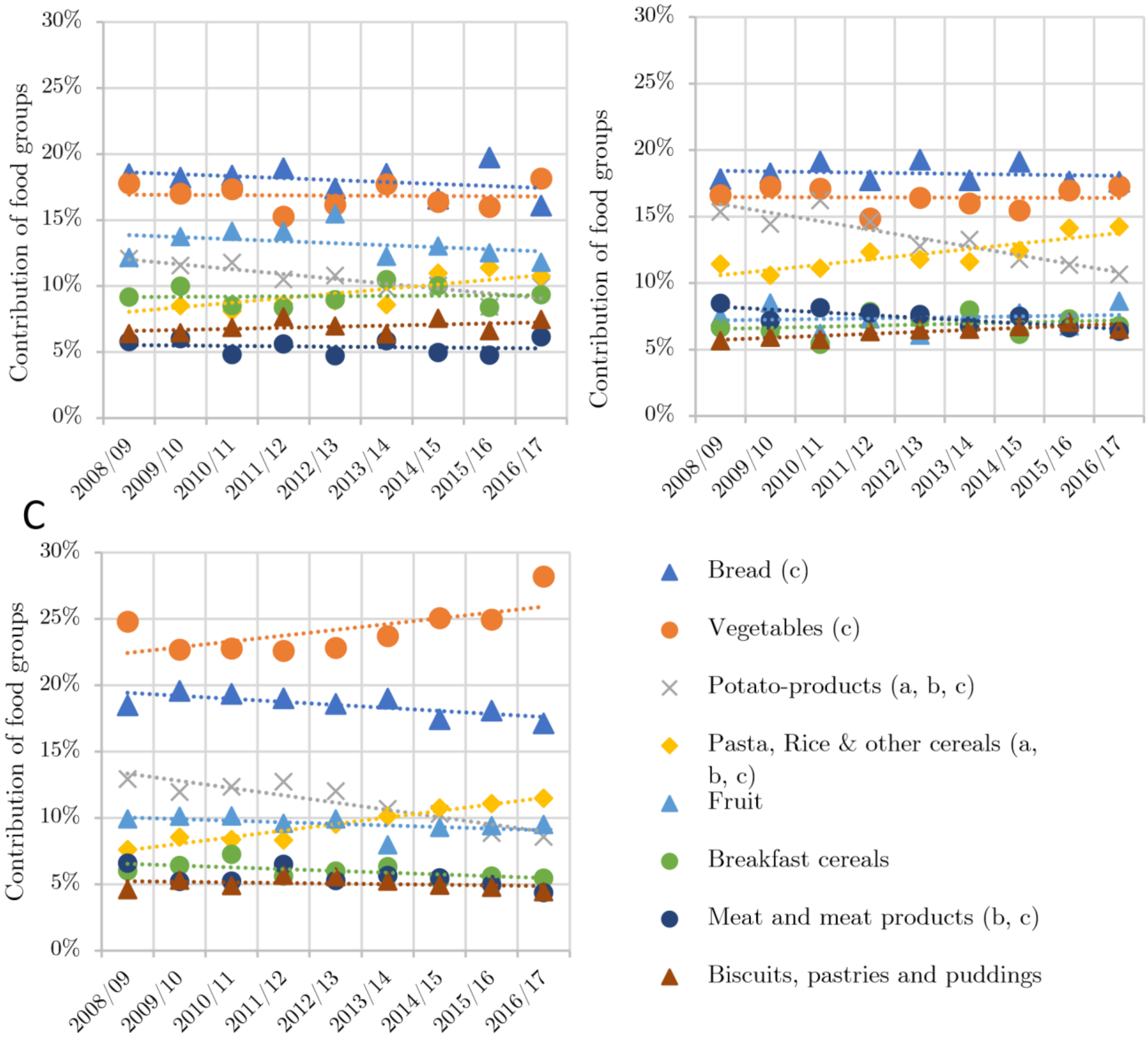
	1.5-3y	4-10y	11-18y	19-64y	over 65y
Cereals & cereal products:	39%	43%	42%	37%	37%
Bread	*16%*	*18%*	*18%*	*18%*	*19%*
Pasta, Rice & other cereals	*8%*	*9%*	*11%*	*8%*	*3%*
Breakfast cereals	*10%*	*9%*	*7%*	*6%*	*8%*
Biscuits, pastries and puddings	*5%*	*6%*	*6%*	*5%*	*7%*
Vegetables	19%	18%	17%	25%	26%
Potato-products	9%	12%	15%	13%	13%
Fruit	19%	12%	7%	10%	13%
Meat and meat products	4%	6%	8%	7%	4%
Sugars, preserves & snacks	3%	5%	6%	3%	2%
Sauces, soups and condiments	2%	2%	3%	3%	3%
Milk & milk products	3%	1%	0%	0%	0%
Nuts & seeds	0%	1%	1%	1%	1%
Fish & fish products	1%	1%	0%	1%	1%
Supplements	1%	0%	0%	0%	0%
Eggs	0%	0%	0%	0%	0%
Fats and oils	0%	0%	0%	0%	0%
Beverages	0%	0%	0%	0%	0%

Notes: Category names and numbers in italic indicate sub-groups from the ‘cereals and cereal product’ group

To understand how these contributions to fibre intake changed over time and could explain the different patterns of change in fibre intake observed by age group, we analysed time trends in those contributions (Figure 4-3). Trends in the contribution of food groups to fibre intake were different in children/adolescents and adults. The only similarities across age groups observed were a decrease in the contribution of potato-based products and no change for fruits. In adults, the contribution of vegetables increased to compensate for this decrease from potato products. In children and adolescents, the decreased contribution from potato products was compensated with an increased contribution from pasta, rice and other cereals, while the contribution of vegetables did not change.

Figure 4-3: Mean contribution of each food group to NSP fibre intake, by age group between 2008/09 (Year 1) and 2016/17 (Year 9).

Sub-figure A: children aged 4-10 years old, Sub-figure B: adolescents aged 11-18 years Sub-figure C: adults aged 19-64 years old. Letters ‘a’, ‘b’, or ‘c’ in the legend indicate a significant time trend (significant effect of year on mean fibre intakes), for the corresponding age group.

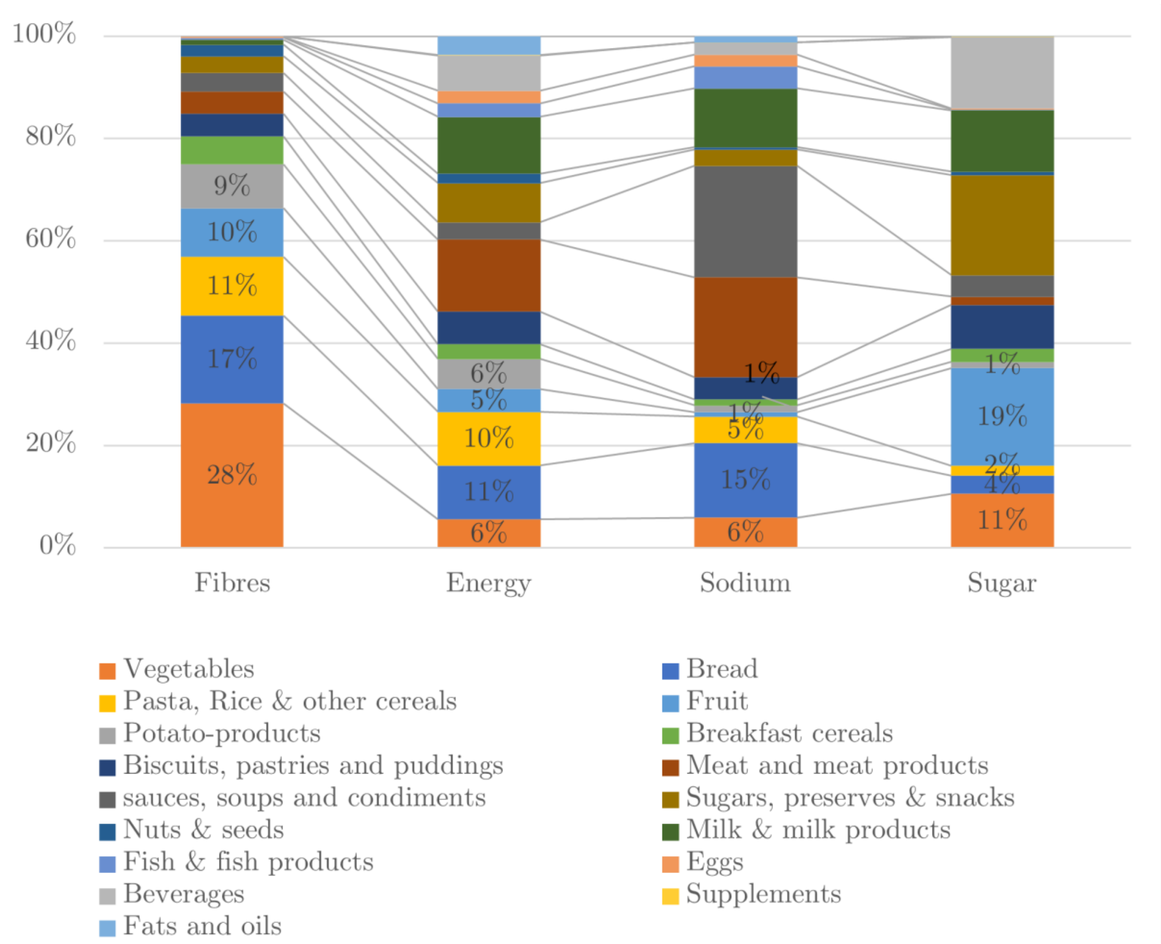


4.3.4 Dietary intake from food categories contributing to fibre intake

To estimate the impact that these changes in consumption could have on population health, we analysed the contribution of the food groups to other nutrients (sodium and sugar) and energy. In particular, we were interested in knowing what was the contribution to other nutrient intakes from the categories driving fibre intake. In adults, vegetables contributed to 28% of fibre intake, but only 6% of energy or sodium intake (Figure 4-4). In comparison, the contribution of bread to fibre intake

(17%) was similar to its contribution to energy (11%) or sodium (15%). The contribution to sodium and energy of pasta, rice and cereals and potato-based products showed different patterns. While these two categories had similar contributions to fibre intakes in Year 9 (11% for pasta, rice and cereals, 9% for potato-products), potato products had a lower contribution to energy (6 %, compared to 10% for pasta) and sodium (1% compared to 5 % for pasta) (Figure 4.4).

Figure 4-4: Mean contribution of food categories to energy, sodium, sugar and fibre intake in adults in Year 9 of NDNS.



Notes: Contributions are population averages. A contribution of for example 28% (for vegetables to fibre intakes) means that 28% of fibre intake come from vegetables. In comparison, vegetables provide only 6% of average energy and sodium and 11% of sugar.

4.4. Discussion

This study aimed at explaining the dynamics of fibre intake, related to different actions done to promote it. Overall, we found that, between 2008-2009 and 2016-2017, while adults had increased their fibre intake (by 0.09g/year), children and adolescents did not. In all age groups, there was a shift in consumption of fibre from potato-based products to pasta, rice, and cereals. These results showed that the hypotheses written in section 4.1.6 are not validated. There were no or small changes in behaviour leading to increased fibre intake (hypothesis 1). In addition, we found limited reformulation: the fibre content of foods did not increase (hypothesis 2).

The evaluation of time trends by the NDNS team found that total fibre intake increased by 0.3g/year across all age groups (Public Health England & Food Standards Agency, 2019). This difference is explained by several differences between the two studies. First, we used NSP fibre intake and not total fibre intake. This choice was driven by our need to use data taking into consideration the reformulation of foods. As NSP fibre are a subset of total fibre, it is expected that the increase in NSP fibre is smaller than the one of total fibre. Second, we measured adjusted trends, while the NDNS team used unadjusted trends. Third, the difference could also be explained by an increase in non-NSP fibre intake. Such fibres are resistant starches, inulin or polydextrose. Resistant starches are found naturally in rice, unripe bananas, pasta, lentils, while inulin is found amongst others in onions, garlic, or chicory roots (Lockyer & Nugent, 2017). This type of fibre is increasingly used as food supplements and is added as ingredients in food products to improve their nutrition or sensory profile (Foschia et al., 2013).

4.4.1 The public health relevance of changes in fibre intake observed

We found that, across the population, fibre intake showed a statistically significant increase by 0.06g/day (SE 0.03). The stratified analysis revealed that fibre intake increased only in adults, by 0.09g/day (SE 0.04). Although this increase is statistically significant, we can wonder if it is physiologically significant. For adult individuals, this increase represents a 0.71g/day increase over the 9 years of the survey, equivalent to a 5% increase in fibre, and negligible compared to the gap between mean intake and the recommendations. Nonetheless, at a population level, a shift in individual intake can have non-negligible consequences at the population scale. The pooled analysis of cohort studies by Pereira et al. (2004) found that the relative risk of CHD deaths was 0.81 per 10g/day increment in fibre intake (i.e. a 19% reduction) (Pereira et al., 2004). The relative risk for a 0.09g/day increase would hence be $0.81^{0.71/10}$=0.985, or a 1.5% reduction in CHD mortality. Given that the CHD mortality is approximately 58000 in the UK (in 2016, 57777 (Office for National Statistics, 2021)), the estimated reduction in CHD deaths associated with the measured increase in dietary fibre for adults is 858 deaths per year. This number is quite low, but still showing that a small shift in the diet of the population has non-negligible consequences in terms of death reduction.

4.4.2 "Increase your vegetable intake": a message only heard by adults

The different dynamics of the change in fibre intake between adults and children/adolescents can be explained with vegetable intakes. While adults increased their vegetable intake, children and adolescents did not. This was despite different campaigns promoting the consumption of vegetables targeting kids. In the US, campaigns to promote vegetable intake also exist. A study evaluating changes in vegetable intake between 2001 and 2010 found reverse trends from the one we found in the UK: children and adolescents increased their fibre intake while adults' intake did not change (McGill, Fulgoni & Devareddy, 2015). Interestingly, they found no increase in vegetable intake for adults but a decreased intake for children and adolescents.

This absence of change in vegetable intake in children and adolescents is worrying for children later health. Vegetables are not only a source of fibre but also many vitamins and minerals. Also, fresh vegetables are not energy-dense but nutrient-dense: their consumption is recommended to limit childhood obesity.

4.4.3 The difference in vegetable intake in children and adults: is it an age effect or a generation effect?

This difference in vegetable intake trend between adults and children increased the baseline difference in vegetable intake. In 2008/09, adults consumed about 22% of their fibre from vegetables, while it was 16% in children and adolescents. While this proportion did not change for children and adolescents, adults had in 2016/17 about 26% of their fibre intake from vegetables. Whether today's children will follow the pattern observed in adults and increase their consumption when they become adult is unsure. A study done using NDNS Years 1-4 suggested an answer to this question, by evaluating changes in vegetable intake in terms of age effects and cohort effects (Albani et al., 2017). Age effects are patterns observed for individuals of the same age, across cohorts. For example, the shift from liquid foods to solid foods during weaning is a shift that happens about the same age for all generations, linked to physiological growth. Cohort effects are markers of generations, that can have different eating patterns. For example, a study in the US found that Millennials spend more money on processed foods than older generations (Kuhns & Saksena, 2017). Similarly to what we found in this study, the study by Albani et al. (2017) found no change in vegetable intake for children and adolescents, in all cohorts (i.e. no age effect) (Albani et al., 2017). In addition, they found no difference in vegetable intakes across cohorts, meaning that children and adolescents from the different generations consumed the same quantity of vegetables. However, this study did not look at cohort effects in adults: we don't know if the trend observed in our study in current adults is an age effect or a cohort effect. In other words, we don't know if today children will have a similar vegetable intake as today adults, or if they will experience the same increase in vegetable intake observed in adults between years 1 and 9 of NDNS.

4.4.4 Consequences of the shift from potato-based products to cereal-based products

For all age groups, there was a shift in fibre intake between potato- and cereal-based products. This shift can have a different effect on dietary intakes and health whether the shift favoured products made of whole or refined grains. Indeed, whole grain products have a higher quantity of micronutrients and bioactive components than their refined counterpart (Lockyer & Spiro, 2020). To compensate for micronutrient losses due to the milling of the grains, white flours are often enriched in vitamins and minerals. Despite this, wholemeal bread remains a better source of minerals and vitamins than white bread (Lockyer & Spiro, 2020). However, we found that potato-based products had a smaller contribution to sodium intake than pasta, rice and cereals, at a similar level of contribution to fibre intakes. While we observed that the contribution to all categories to sodium decreased between Year 1 and Year 9, this decrease may have been limited by the shift from potato products to cereal-based products.

4.4.5 Changes in fibre intake and changes in the intake of other nutrients and energy

This study focused on changes in fibre intake. However, increasing fibre intake can have consequences on the consumption of other nutrients and energy. Indeed, fibre is found naturally in plant-based products such as vegetables or cereals. Fibre is also added as an ingredient in more complex foods such as breakfast cereals, biscuits, or other preparations based on cereals. To study fibre sources independently of the quantity of foods consumed, we used as outcome measure the contribution of food groups to fibre intake, and not the absolute quantity of fibre coming from the different food groups. A sensitivity analysis looking at trends in fibre quantities from the different food groups showed similar trends as trends in contribution. However, it is interesting to see if these shifts are linked to changes in the consumption of other nutrients. In particular, changes in the consumption of salt or sugar could be of concern, as those nutrients are already consumed in excess. Overall, there was a decrease in energy and sugar consumed (significant for children and adolescents) and sodium consumed (significant for all age groups) between years 1 and 9 of NDNS. The increase in fibre coming from pasta, rice and other cereals was not linked to an increase in sodium from this group, for none of the age groups studied. It was linked to an increase in energy intake for all age groups except young children and adolescents. This suggests that the increased fibre intake from this group came from an increasing quantity consumed, rather than a shift to the consumption of fibre-rich cereal-based products. Fibre coming from breakfast cereals did not change (in any of the age groups). However, sugar and energy from cereals decreased in adults and children. For all age groups, intakes of sodium from breakfast cereals decreased. This suggests a change in the type and/or the reformulation of breakfast cereals consumed.

4.4.6 Determinants of vegetable intake, and how to improve children's vegetable intake

This study found that vegetable intake in children is lower than the recommendation and did not change recently. To ensure that future campaigns would be successful in improving children vegetable intake, we need to understand the determinants of this intake. A previous study showed that children consumption of fruits and vegetables was determined by the context of the household they lived in. At-home consumption of fruit and vegetables by children was improved in households where fruits and vegetables were shopped frequently and were frequently available (Mak et al., 2013). In addition, children who frequently ate takeaway foods had a lower fruit and vegetable consumption than children rarely eating takeaways (Mak et al., 2013). These determinants of vegetable intakes in children should be used when designing campaigns aiming at promoting vegetable intakes in children.

In addition, when they eat vegetables, children tend to consume smaller quantities than the recommended portion size (Chawner, Blundell-Birtill & Hetherington, 2021). Campaigns educating people about what is an adequate vegetable portion size for children could increase the portion of vegetables consumed at each eating occasion, and hence increase the total intake of vegetables in children. A review of fruit and vegetable campaigns found that campaigns focusing on the frequency of consumption were more successful (than campaigns focusing on the quantity consumed) (Rekhy & McConchie, 2014). As multicomponent campaigns were also more effective than campaigns with a single focus (Rekhy & McConchie, 2014), the combination of the two aspects of consumption (frequency and quantity) could be helpful to improve consumption. As another determinant of vegetable intake was having a vegetarian diet (Chawner, Blundell-Birtill & Hetherington, 2021), favouring vegetarian meals at school could also increase children vegetable intake.

4.4.7 Wider determinants of vegetable intake

In addition to the determinants of children vegetable intakes cited in the previous section, some factors are common to the whole population. Price is a strong determinant of any food purchase.

The demand for fruits and vegetables is rather inelastic (with price-elasticities between 0 and -1) (Capacci & Mazzocchi, 2011). Given this effect of price on purchases, it is important to evaluate policies independently to possible changes in price. Such a study was performed to evaluate the impact of the 5-a-day campaign. The authors found that fruit and vegetable prices increased after the launch of the campaign (Capacci & Mazzocchi, 2011). Increases in price after such a campaign aiming to increase demand for a certain type of product can be expected. As demand is expected to rise, producers or retailers could take benefit of this increasing demand by increasing the price of fruits and vegetables. However, the price elasticity for fruits and vegetables decreased after the launch of the campaign (in absolute terms), meaning that after the campaign, consumers were less likely to reduce their purchases even if the price of fruits or vegetables increased. The campaign was evaluated to lead to an increase in 0.3 portions per person and per day (Capacci & Mazzocchi, 2011). When price increases were not considered, the campaign was estimated to lead to a 0.2 increase in portions purchased. This study highlighted the important role of price in consumer purchases and means that any campaign to promote fruit and vegetable consumption should make sure that the price of these foods will not increase.

4.4.8 Strengths and limitations

The strength of this study is to use a nationally representative survey of the UK, over 9 years. This good quality data allowed us to analyse changes in fibre intake across age groups and gender.

One limitation of this study is the use of cross-sectional data and not longitudinal data. Using cross-sectional data allows having a correct understanding of population average intakes, but it prevents us to evaluate the causes of the change in intake. For example, we cannot investigate the determinants of the changes in fibre intake or vegetable intake observed.Another limitation of this study is the use of NSP fibre as the outcome measure. We chose this measure because the total fibre content of foods has not been updated in the first waves of NDNS, hence preventing the assessment of reformulation while using this measure. However, using NSP fibre meant that we cannot compare observed intake to the latest recommendations from the SACN, designed for total fibre intake. In their 2015 report, the SACN defined dietary fibre as the total fibre measured using the AOAC methods, and designed recommendations using this measure (Scientific Advisory Committee on Nutrition, 2015). The recommendation was defined at 30g/day of total fibre for adults. This recommendation replaced the previous recommendation based on NSP fibre (measured using the Englyst method), of 18g/day for adults. There is no correct method to convert NSP fibre to AOAC fibre given that foods have varying levels of the ratio between NSP to total fibre. Nonetheless, the findings from this study show that UK adults are far from the recommendations, whether defined as NSP fibre or total fibre.

4.4.9 Conclusion

In this study, we found that the different initiatives to promote fibre intake was linked to the reformulation of some categories. Nonetheless, the absence of a unified approach resulted in only small changes in the average fibre content of products. As a result, fibre intake did not change a lot. There was a small increase in the average fibre intake of the population. This increase was led by adults who increased their vegetable intake. This change in food choices can be a result of the different awareness campaigns done to improve fibre intake. This favourable change in dietary habits was not seen in children or adolescents.

This study informed us of the importance of shifts in dietary patterns. In this study, we found that shifts between food categories led to no change in fibre intake in children and adolescents, because of compensation of the fibre intakes from the different categories. However, we don’t know what explain those shifts. Are they a consequence of a change in consumer trends? Or the result of product reformulation, that provoked a change in demand for those products? In the next chapter, I present a method that allows understanding shifts in food intake and compare their effects to the one of reformulation.

5. Chapter 5: The role of food reformulation in the decrease in salt intake in the UK between 2008/09 and 2016/17

This chapter aims at answering objectives 2 and 3 of the thesis. It aims at evaluating time trends in the salt intake of the UK population and explaining these trends in terms of changes in demand for, and changes in the supply of, foods. The research presented in this chapter was published in a peer-reviewed article (link to full text in Appendix II):

> Gressier, M., Sassi, F. & Frost, G. (2021) Contribution of reformulation, product renewal, and changes in consumer behavior to the reduction of salt intakes in the UK population between 2008/2009 and 2016/2017. *The American Journal of Clinical Nutrition*. doi:10.1093/ajcn/nqab130.

5.1. Background: excessive salt intake and cardiovascular diseases in the UK

Salt intake is too high in the UK. Mean salt intake was estimated at 8.8g/day in 2005/2006, high above the 6g/day recommended in dietary guidelines (Public Health England, 2017a). High dietary salt intake (i.e. high sodium intake) is a leading risk factor for high blood pressure (Lim et al., 2012). In the UK, high blood pressure affects more than 25% of adults (Steel et al., 2018) and is the third leading risk factor for premature deaths. The resulting cost of high blood pressure to the NHS is estimated to be £2.1 billion every year (Public Health England, 2017a). The high prevalence of high blood pressure in adults is not a problem for the UK only: most countries are facing this issue.

To limit the burden of high blood pressure, the WHO called governments to act to limit the salt intake of populations (World Health Organization, 2007). In 2003, the UK government was one of the first to launch its salt reduction strategy (Wyness, Butriss & Stanner, 2012). The strategy, led by the FSA, had two levers. The first lever was to educate the population to have a diet with less salt. The population was informed about foods high in salt, and about how to choose products with a lower amount of salt (Wyness, Butriss & Stanner, 2012). The second lever targeted food companies. Food companies were incentivised to reformulate their products to decrease the amount of salt they contained. The FSA published its first salt reduction guidelines in 2005, with a set of targets for the different food categories included in the programme. The programme was voluntary, but the government suggested that these targets could become mandatory if the guidelines were not met (He, Brinsden & MacGregor, 2014). To keep the reformulation going, and make it a continuous and step-by-step process, the guidelines were revised regularly based on the progress made by manufacturers

(Wyness, Butriss & Stanner, 2012). New sets of targets were published in 2009, 2011 and 2014 (Public Health England, 2020c).

The UK salt reduction strategy was estimated to be successful in reducing the salt intake of the population. Between 2005/2006 and 2014, it was estimated that salt intake decreased by 11% (Public Health England, 2017a). Published research suggested that the two levers, namely health education and reformulation guidelines, were effective in decreasing population salt intake. The education lever increased population awareness on salt: a study in 2007 found that approximately two-thirds of the population was aware of the need to reduce their salt intake (Millett et al., 2012). In addition, manufacturers reformulated their products with lower content of salt: between 2006 and 2011, the salt content of foods decreased by 7% on average (Eyles et al., 2013). Evaluations by PHE on the achievement of the 2017 targets in 2020 reported that 28/52 category targets have been met (Public Health England, 2020d). The achievement rate varied a lot across food groups, with high achievement for plant-based products, but low for meat-based products.

However, the role of the two levers in driving decreases in salt intake remains unclear. As the UK salt reduction strategy was a multicomponent strategy, it is difficult to assess what feature of the strategy was important to its effectiveness. Did increased awareness on salt make the population add less salt to their meals, or made them choose products with lower salt content? A partial answer to this question can be found in Griffith et al (2017). Applying an original decomposition method on purchases from supermarkets, they found that the reduction in salt purchased came mainly from changes to the products (i.e., reformulation), rather than changes in behaviours (Griffith, O'Connell & Smith, 2017). However, this study only considers foods purchased for at-home consumption, while out-of-home consumption represents 10-20% of energy intake in the UK (Lachat et al., 2012).

In this study, we are aiming to answer the question: how can we explain the success of the UK salt reduction strategy? To do so, we applied the decomposition method used in Griffith, O'Connell & Smith (2017) to the UK NDNS. This allowed us to explain how changes in the offer (i.e., the reformulation of existing products, and food product renewal) and changes in demand (i.e., change in consumer choices towards foods and the quantities eaten) participated in the decrease of the salt density of products eaten.

5.2. Methods: decomposition of the sodium density of foods eaten by the UK population

5.2.1 Data from the NDNS

(1) The choice of the NDNS for this study

The NDNS data, described in section 4.2.1, was used in this analysis (NatCen Social Research & MRC Elsie Widdowson Laboratory, 2019). For similar reasons than in the previous chapter, the NDNS was chosen in this analysis for its strong design, and the fact that the NDNS is a 9-year-time series. In addition to being representative of the UK population, the NDNS allows to study the change in sodium intake of different subgroup of the population, such as groups defined by their age, education level or income. Being able to study change in sodium intake for different socio-economic groups is needed to see if the UK salt reduction strategy had different impact across the population.

(2) Data from the NDNS

Briefly, food intake was taken from 3- or 4-day dairies, in a population representative of the UK population. Each food product declared consumed was linked to its year-specific nutrition data from the Nutrient Databank, including its sodium content. Discretionary salt added while cooking or eating was not expressly asked, but some participants voluntarily declared when they were adding salt in recipes or while eating.

In addition to the food survey, participants answered a questionnaire on their health habits (including questions on smoking, drinking and physical activity). Some questions focused on attitudes towards salt and included the three following questions:

- Is salt added during cooking? (Neither/Salt/Salt substitute)
- How often salt is added during cooking? (Always/Usually/Sometimes/not applicable)
- how often salt substitute is added during cooking? (Always/Usually/Sometimes/not applicable)

Some participants were selected for further health assessment, including blood pressure measurement, blood sampling and other anthropometric measurements. From year 1 to year 5, 24-urine samples were taken to measure sodium excretion.

5.2.2 Analysis of time trends

Different outcomes were tested for time trends. First, we assessed if usage of table salt changed over time. Binomial regressions were used, with the survey year (coded 1 to 9) as an independent variable. Analyses were further adjusted for gender, highest education reached, and income.

To assess if the NDNS data captures the decrease in sodium intake observed in the UK salt survey (Public Health England, 2017a), we evaluated changes in sodium intake from food diaries over time adjusting for age group, sex, total energy intake, BMI category, ethnicity, and income. In addition to estimating time trends in sodium intake from food diaries, we tested the adjusted time trends for change in sodium intake measured using 24h urine samples, available from year 1 to year 5. To evaluate if there were any changes in the health status of the population, we tested time trends in the blood pressure measurements (also adjusted with the same factors).

Time trends were tested using generalised linear models. A Gaussian link function was used for the continuous outcome variables, while a binomial link function was used for questions regarding salt use. Appropriate survey weights were used in all analyses. The significance of parameters was set for p-values under 0.05.

5.2.3 Decomposition of the changes in sodium density

(1) Calculation of the sodium density of the diet

The outcome variable in the decomposition analysis was the change in the sodium density of the average diet consumed by the UK population from year 1 to year 9. We first calculated the average proportion of each food product eaten by the UK population for years 1, 3, 5, 7 and 9. We got the participants' usual intake by averaging their food intake over the three or four days reported in the diaries. Then, we calculated the proportion (in weight of food) of each food code to the participants' usual intake. We averaged the participants' mean proportion of food eaten to get the mean proportions for the whole population. We calculated the year-specific sodium density of the diet (N_t) by summing over the proportion of each product consumed times its sodium density ($n_{i,t}$) (Equation 5-1).

Equation 5-1: Definition of the sodium density of the diet

$$N_t = \sum_i w_{i,t}\, n_{i,t}$$

with $w_{i,t}$ the mean proportion of product i eaten by the population defined as $w_{i,t} = \frac{weight\ product\ i}{weight\ all\ products}$

The sodium density of beverages is much lower than that of solid foods. Hence, the sodium density for both all foods and beverages and for solid foods only were calculated. In addition, we calculated the sodium density of solid foods excluding table salt added, as this measure is subject to declaration bias.

(2) Decomposition method

To explain a change in the sodium density of the diet by changes in demand for, and changes in the offer of foods, we used the decomposition approach used in Griffith, O'Connell & Smith (2017). The Equation 5-2 was used to decompose the change in sodium density ΔN_t of all food products i consumed into changes in supply and changes in demand. Changes in supply were changes in the composition of products (i.e. reformulation, first line of Equation 5-2) and relative changes in the composition of product consumed resulting from product turnover (third line of Equation 5-2). Changes in demand were changes in the proportion of food i eaten (second line of Equation 5-2, first sum) and changes in both the proportion and the composition of a food i (second line, second sum). This decomposition (in Equation 5-2) allowed disentangling the effect of changes in nutrition composition (i.e. reformulation, and the result of product turnover), from changes in the choice (and quantity) of products consumed.

Equation 5-2: Equation for the decomposition of a change in sodium content

$$\begin{aligned}\Delta N_t \quad &= \sum_{i \in C} w_{i,t_0} \left(n_{i,t_1} - n_{i,t_0}\right) \\ &+ \sum_{i \in C} \left(w_{i,t_1} - w_{i,t_0}\right)\left(n_{i,t_1} - N_{t_0}\right) + \sum_{i \in C} \left(w_{i,t_1} - w_{i,t_0}\right)\left(n_{i,t_1} - n_{i,t_0}\right) \\ &+ \sum_{i \in N} w_{i,t_1} \left(n_{i,t_1} - N_{t_0}\right) - \sum_{i \in X} w_{i,t_0} \left(n_{i,t_0} - N_{t_0}\right)\end{aligned}$$

This decomposition was applied on the density of all foods and beverages consumed, of solid foods only, and of solid foods only excluding table salt. It was first applied between year 1 and year 9, then in two-year intervals (i.e., years 1-3, years 3-5, years 5-7 and years 7-9).

(3) Adaptation of the decomposition method

In a second step, we were interested in evaluating the role of the different food groups in the changes in sodium density. We adapted the decomposition Equation 5-2 to include changes relative to the sodium density of a category k. Changes linked to a change in the proportion of a food product consumed were explained by changes towards a food product belonging to the same category and changes towards another category (Equation 5-3).

Equation 5-3: Equation for the decomposition of the diet, by category

$$
\begin{aligned}
\Delta N_{k,t} \quad &= \sum_{i \in k \cap C} w_{i,t_0}\,(n_{i,t_1} - n_{i,t_0}) \\
&+ \sum_{i \in k \cap C} (w_{i,t_1} - w_{i,t_0})(n_{i,t_1} - n_{i,t_0}) \\
&+ \sum_{i \in k \cap C} (w_{i,t_1} - w_{i,t_0})(n_{i,t_1} - \frac{N_{k,t_0}}{W_k}) - (Nt_0 - \frac{N_{k,t_0}}{W_k}) \sum_{i \in k \cap C} (w_{i,t_1} - w_{i,t_0}) \\
&+ \sum_{i \in k \cap N} w_{i,t_1}\,(n_{i,t_1} - N_{t_0}) - \sum_{i \in k \cap X} w_{i,t_0}\,(n_{i,t_0} - N_{t_0})
\end{aligned}
$$

Changes within categories were obtained by weighting the change in the proportion of a food i consumed $(w_{i,t_1} - w_{i,t_0})$ by the difference in sodium density between the food i and the sodium density of the category k, relative to the proportion of food i consumed $(n_{i,t_0} - \frac{N_{k,t_0}}{W_k})$. The term in $(N_{t_0} - \frac{N_{k,t_0}}{W_k})$ indicate the effects of switches from a category compared to the density of all foods, i.e., changes between categories.

In a third step, we calculated the reformulation effect inside each food category (i.e., irrespective of the reformulation in other categories, as is the case in Equation 5-2). We rescaled the proportions of each food consumed $(w_{i,t})$ such that for a category k, $\sum_{i \in k} (w_{i,t}) = 1$ and applied Equation 5-4.

Equation 5-4: Equation to calculate the reformulation effect for each category

$$Reformulation\ in\ the\ category = \sum_{i \in k \cap C} w_{i,t_0}^{k}\,(n_{i,t_1} - n_{i,t_0})$$

with $w_{i,t_0}^{k} = \frac{(weight\ food\ i)}{(weight\ all\ foods\ in\ k)}$

(4) Decomposition by subgroups of the population

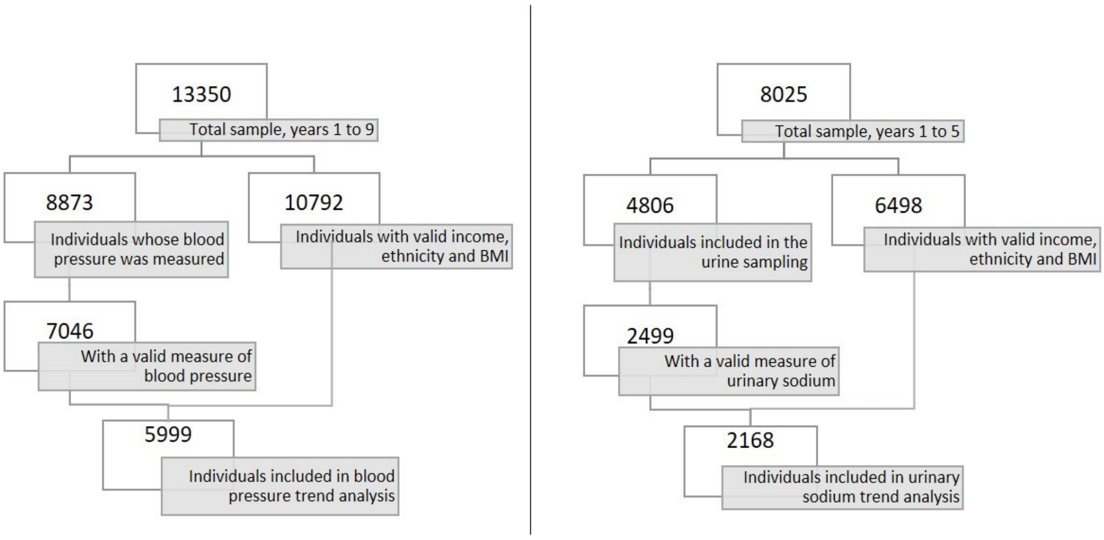
All the steps described in section 5.2.3 were first applied to the estimation of food eaten by the whole population. In a second stage, they were applied in subgroups of the population defined by age group, sex, income group and education level. The variable used to define income groups was the equalised income of the household. The variable used to make education groups (for adults only) was the highest education level reached.

5.3. Results

5.3.1 Sample studied

The NDNS had a total of 13350 participants over the nine years of the rolling programme used in this study. They all had valid food diaries. The nurse visit (when blood pressure was performed) was done for 8873 participants. We included 5999 participants from year 1 and year 9 in the blood pressure trend analyses, participants with valid blood pressure and demographics (Figure 5-1, left). In total, 4806 participants from year 1 and year 5 had a 24-h urine collection. A valid measurement of urinary sodium was available for 2499 participants, of which 2168 had also valid demographic characteristics, and hence were included in the study of trends in salt intake measured via 24-h urine (Figure 5-1, right).

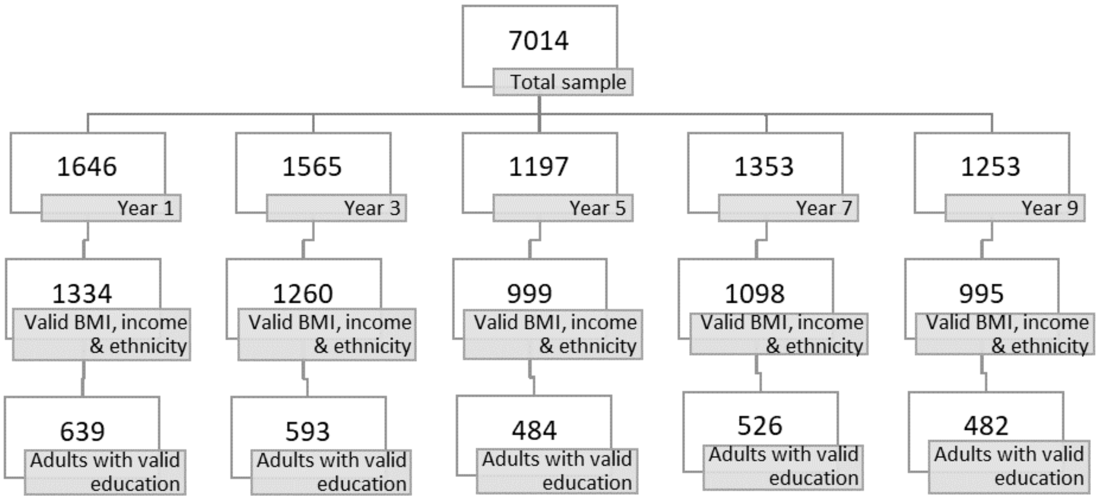
Figure 5-1: Flow charts for the selection of participants with valid bio-markers measurements



Notes: Left: participants with valid blood pressure measurement and demographic data. Right: Participants with valid participants from years 1 to 5 with a valid 24-hour urinary measurement

Salt intakes and salt intakes of foods consumed were obtained from the food diaries of 5686 participants (Figure 5-2). Those participants (of all ages) had a valid food diary, valid height and weight measurement (to calculate BMI), equalised income for the household and ethnicity.

Figure 5-2: Flow chart of the selection of NDNS participants with valid food diary data for this study



Notes: All participants in the total sample had valid food diaries. Participants with valid BMI, income and ethnicity were used to derive average population dietary intake. Only adults were included in the stratification by education.

Adults in the selected sample with valid BMI, income and ethnicity in years 1 and 9 had broadly similar characteristics as the whole adult sample (representative of the UK population) (Appendix Table vi). The selected sample had a different distribution of education, as adults with missing BMI or income or ethnicity were more likely to be also missing education.

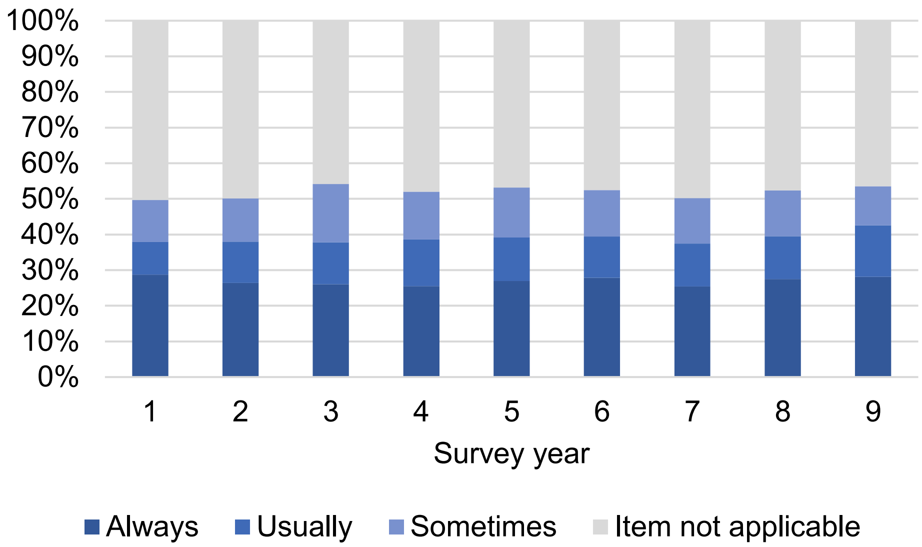
5.3.2 Attitudes towards the use of salt

(1) No change in the declared use of salt as an ingredient

Across all survey years, 51.9% (SE 0.8) of respondents answered adding salt during cooking, while 2% (SE. 0.2) added salt substitutes. The binomial regression done to evaluate if there was a change in this use of salt over time showed no change over time (the estimate for the Year variable was not significantly different from zero, regression outputs in Appendix Table vii).

There was also no change in the frequency salt is added during cooking (either for all participants or for participants who declared using salt only, Figure 5-3).

Figure 5-3: Answer to the question: How often salt is added during cooking?



Notes: this question was asked to participants having answered adding salt during cooking. Participants having responded adding salt substitutes or not adding either salt or salt substitutes are marked as 'item not applicable'.

(2) A change in the use of salt from food diaries

To test the validity of the question on self-reported use of salt while cooking, we evaluated the frequency of participants for which the food diary reported the use of table salt. We found a large increase in the proportion of participants who reported having added salt while cooking or eating: while in the year 1 of NDNS less than 10% of participants has table salt in their food diary, this proportion was about 80% in Y9 (Appendix Figure iv). This increased use of table salt from participants translated into an increase in the average sodium intake from table salt: while table salt provided on average 17mg of sodium per day (SE 3.8mg) per day in year 1, it provided 155mg (SE 15mg) in Y9 (Appendix Figure v). Given that the methodology of the NDNS has not changed between year 1 and year 9, this could reveal an increase in the use of table salt, contradicting the absence of change in the declared use of salt (Figure 5-3). To take into consideration this possible bias, we did the decomposition analysis with and without table salt.

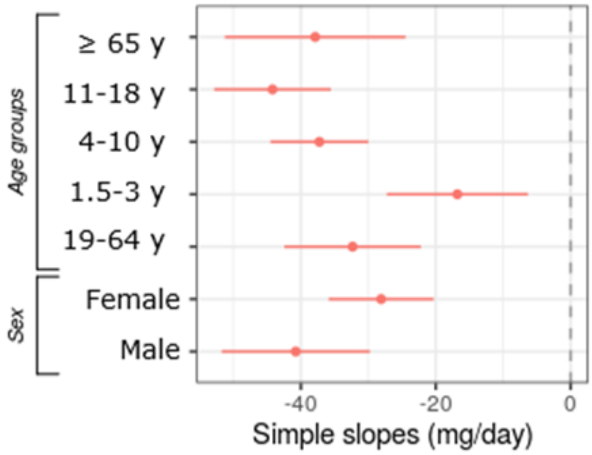
5.3.3 Changes in average sodium intake

(1) Changes in the sodium intake of the UK population

Data from food diaries showed that sodium intake decreased between year 1 and year 9 of NDNS. Sodium intake decreased by 16% (95% CI: -21%, -12%). Mean sodium intake was

2293 mg/day (SE=43) in year 1 and 1918 mg/day (SE=27) in Y9. for the whole population. This decrease was significant for all age groups, men, and women (Figure 5-4 and adjusted regression results in Appendix Table viii).

Figure 5-4: Estimated yearly changes in daily sodium intake between 2008/09 and 2016/17



Notes: Simple slopes are in mg/day per survey year. Data shows single slopes estimates and standard errors from adjusted time trends. All estimates have a p-value <0.05

Data from urinary sampling suggested a decrease in sodium intakes between year 1 and year 5. However, this decrease was not statistically significant (adjusted time trend of -25mg/day/year, p-value=0.4). Nonetheless, the decreasing trend in sodium from urinary excretion tended to follow the trend observed in the same period from diaries.

(2) Changes in the sodium intake by socio-economic group

All socio-economic groups, created using the highest qualification reached by the participant, had decreasing sodium intake between year 1 and year 9 (Table 5-1, and results of the regression in Appendix Table ix). The reduction was the highest for participants having the GCE, A level or equivalent or the GCSE, but lower for participants with a higher degree or no qualification (Table 5-1).

Not all socio-economic groups, created using the quintile of their income, experienced a decrease in sodium intake. Participants with the highest income (in groups 4 and 5) had a non-significant decrease in sodium intakes, while participants with lower income had their sodium intake significantly decreased.

Table 5-1: Adjusted yearly time trends in sodium intake (in mg/day) by socio-economic group.

		Estimated trend	SE	p-value
Highest qualification	Higher education	-47	11	0.0001
	GCE, A level or equivalent	-62	15	0.0001
	GCSE	-51	13	0.0000
	No qualifications	-39	11	0.0006
Quintile of income	5 (highest)	-9	16	0.4760
	4	-16	11	0.1516
	3	-23	10	0.0218
	2	-31	11	0.0036
	1 (lowest)	-39	11	0.0006

Notes: Time trends are simple slopes and were estimated from the general time trend and the interaction term between the time trend and the socio-demographic group. Data from NDNS 2008/2009 to 2016/2017. Only adults were used (as the qualification variable is only described for adults)

5.3.4 How to explain the change in sodium intake: results of the decomposition analysis

(1) Sodium density of the diet, and decomposition for the whole population

The average sodium density of the diet of the UK population decreased significantly between year 1 and year 9 (Table 5-2). For all foods and drinks combined, sodium density decreased from 94.8 (SE 1.5) mg/100g in year 1 to 78.7 (SE 1.6) mg/100g in year 9. The decrease was smaller (-15%, 95%CI: -19%; -10%) when evaluated in foods only, but higher when table salt was excluded from the analysis (-21%, 95%CI: -25%; -16%). It is important to note that the mean quantity of foods did not change between year 1 and year 9 (1088g/day, SE 13g in year 1, 1070g/day, SE 15g in Y9, p-value for adjusted trend: 0.4). The quantity of drinks consumed increased: in year 1 the population drank on average 1517g/day, SE 32g of drinks, but in year 9 it was 1572g/day, SE 38g (p-value=0.00003).

Table 5-2: Sodium density of foods consumed and changes in sodium density between year 1 and year 9 of NDNS survey

	All food and drink	Food only	Food only, no table salt
	Y1: n=2973 Y9: n=2897	Y1: n=2754 Y9: n=2677	Y1: n=2753 Y9: n=2676
Sodium density of foods, Year 1	94.8 ± 1.5	213.6 ± 3.4	212.0 ± 3.4
Sodium density of foods, Year 9	78.7 ± 1.6	182.1 ± 3.3	168.2 ± 3.2
% change in sodium density	-17% (-21%, -12%)	-15% (-19%, -10%)	-21% (-25%, -16%)
Change in density by:			
reformulation effect	-12.0	-27.5	-27
switching effect	-1.6	3.2	-9
product renewal effect	-2.5	-7.1	-7

Notes: Data show population mean sodium densities of food consumed (in mg/100 g of food) ± SEs; absolute and percentage changes in sodium density between Year 1 (Y1) and 9 (Y9) with their (95% CI); and the effects of reformulation, switches, and product renewals on the changes in density (in mg/100 g), obtained from Equation 5-2. Ns in year 1 and year 9 are number of food products included.

The decomposition of the change in sodium density of foods and drinks consumed by the population showed that most of the reduction came from the effect of reformulation (Table 5-2). This was true for the three measures (all food and drink, food only, and food only no table salt). The effect of product renewal was the second leading feature driving the reduction in sodium density. The effect of switches between products was inconsistent with the three measures: it contributed to a decrease in sodium density for all food and drink and food with no table salt, but to an increase when food only was evaluated.

(2) Temporality of the change in the sodium density of the diet, and of the decomposition effects

The changes were not consistent over time (Table 5-3). The only significant change in the sodium density of the diet occurred between year 3 and year 5, with a 13 % decrease (95% CI: -17%; -9%). In the other time intervals, changes were small and non-significant. The effect of reformulation and consumer switches was maximum between year 3 and year 5 (-7mg and -5mg of sodium/100g, respectively). While the effect of reformulation was always a decrease in sodium density, the sign of the effect of consumer switches varied over time (levelling off the effect of reformulation between year 1 and year 3). The effect of product renewal was marginal in all time intervals.

Table 5-3: Decomposition of the change in the sodium density of the diet, by two-years intervals

	Year 1 - Year 3	Year 3 - Year 5	Year 5 - Year 7	Year 7 - Year 9
Sodium density of foods, t0	94.8 ± 1.5	96.1 ± 1.6	83.9 ± 1.2	82.1 ± 1.2
Sodium density of foods, t1	96.1 ± 1.6	83.9 ± 1.2	82.1 ± 1.2	78.7 ± 1.6
% change in sodium density	1% (-3%, +6%)	-13% (-17%, -9%)	-2% (-6%, +2%)	-4% (-9%, +1%)
Reformulation effect	-2.6	-6.7	-1.6	-2.1
Switching effect	4.6	-5.4	-0.1	-1.5
Product renewal effect	-0.6	-0.1	-0.1	0.1

Notes: Data show population mean sodium densities of food consumed (in mg/100 g of foods) ± SEs; absolute and percentage changes in sodium density between two years (95% CI); and the effects of reformulation, switches, and product renewals on the changes in density (in mg/100 g), obtained from Equation 5-2.

(3) Decomposition of the average diet, grouped by food category

To explain the changes in the sodium density of the average diet, food products were grouped by food category. Given the different consumption of beverages between year 1 and year 9, the focus was given on solid foods only. The results of this aggregation showed that the reformulation effect came mostly from the reformulation of cereal and cereal-based products, a category for which the reformulation effect was -10.2 mg for 100g of all foods consumed (Table 5-4). Sodium reformulation also occurred for meat and meat products, sauces, soups and condiments, and vegetables. The reduction in sodium from product renewal came from the same categories (except sauces, soups and condiments), but of smaller intensity.

The split of the decomposition by food group revealed opposite switching effects explaining the total small increase in sodium from switches between products (Table 5-4). Whilst choices towards products with lower sodium were done in cereal products and meat products, choices towards higher sodium sauces soups and condiments resulted in a total switching effect being positive (i.e., corresponding to a sodium increase).

Table 5-4: Decomposition of the change in sodium density of solid foods, by food category

	Sodium from food group, Y1	reformulation effect	switching effect	product renewal effect	Sodium from food group, Y9	share Y1	share Y9
Cereals & cereal products	67.3	-10.2	-4.5	-1.8	51.3	21%	21%
Milk & milk products	19.4	0.0	0.9	-0.9	20.4	20%	20%
Eggs	3.7	-0.1	-0.9	-0.4	3.8	2%	2%
Fats and oils	4.7	-0.5	-1.8	0.3	2.7	1%	1%
Meat and meat products	57.5	-6.9	-4.8	-1.5	40.0	13%	11%
Fish & fish products	9.4	-0.9	-0.6	0.0	7.1	3%	2%
Vegetables	16.9	-3.6	0.2	-3.1	12.1	23%	24%
Fruit	1.2	-0.5	0.4	-0.9	1.1	9%	9%
Sugars, preserves & snacks	7.2	-0.6	0.2	0.1	6.7	4%	4%
sauces, soups and condiments	25.8	-4.1	14.7	1.2	36.3	5%	4%
Supplements	0.0	0.0	0.0	0.0	0.0	0%	0%
Nuts & seeds	0.4	0.0	-0.4	-0.3	0.7	0%	1%
total = ALL FOODS	**213.6**	**-27.5**	**3.2**	**-7.1**	**182.1**	**100%**	**100%**

Notes: Data in columns 2 to 4 show the effect of reformulation, switches and product renewal grouped by category (Equation 5-3). The changes in sodium density grouped by category indicate the contribution from each category to the total sodium density (i.e. for 100g of all foods consumed, not for 100g of foods from the category. Y1: Year 1 (2008/2009); Year 9: Year 9 (2016/17)

(4) Reformulation for each category

Assessed at the category level (i.e., for 100g of products from the category), reformulation ranged from -47% (for fruit-based products) to +20% for beverages. The categories for which the reformulation effect had an important role in decreasing the overall sodium density of all foods between 10-20% (-15% for cereals & cereal-based products, -12% for meat & meat products, -22% for vegetables).

Table 5-5: Change in sodium densities per food category, and percentage of change from reformulation

	Sodium density (in mg/100g of foods in the category)			% from reformulation
	Year 1	Year 9	% change	
Cereals & cereal products	318.7	240.3	-25%	-15%
Milk & milk products	92.1	95.3	3%	0%
Eggs	250.0	170.9	-32%	-4%
Fats and oils	518.3	305.0	-41%	-10%
Meat and meat products	428.1	349.4	-18%	-12%
Fish & fish products	347.4	303.2	-13%	-10%
Vegetables	72.1	50.4	-30%	-22%
Fruit	11.0	8.1	-26%	-47%
Sugars, preserves & snacks	196.1	189.0	-4%	-8%
Beverages	2.2	2.9	35%	20%
Sauces, soups and condiments	525.0	851.9	62%	-16%
Supplements	30.5	22.3	-27%	-4%
Nuts & seeds	170.5	97.1	-43%	2%

Notes: Data in columns 4 show the effect of reformulation in the change in the sodium content of the category, obtained with Equation 5-4.

(5) Sodium density of the diet, and decomposition by segments of the population

The decomposition by age group showed that all age groups except young kids had their sodium density reduced by a similar rate than for the whole population (Table 5-6). The youngest age groups (kids aged 1.5-3years) had no significant change in the sodium density of their diet. For all age groups, reformulation was the driving effect of this reduction. The effects of switches and product renewal varied across age groups. As the decrease in sodium density was of a similar intensity across age groups (17%), the difference in sodium density of the diet observed at baseline did not change between year 1 and year 9 (Table 5-6). Children aged 4-10y and adolescents aged 11-18y had, on average, a diet of a higher sodium intensity than adults.

Table 5-6: Decomposition of the sodium density of the diet (food and drinks), stratified by age group

Age group	1.5-3y Y1: n=106 Y9: n=75	4-10y Y1: n=292 Y9: n=221	11-18y Y1: n=283 Y9: n=197	19-64y Y1: n=526 Y9: n=391	>65y Y1: n=127 Y9: n=111
Sodium density, Year 1	97.6 ± 4.3	121.5 ± 2.6	121.7 ± 3	89.6 ± 2.1	82.6 ± 3.4
Sodium density, Year 9	93.1 ± 3.7	101 ± 2.4	98.4 ± 3.3	74.4 ± 1.9	67.8 ± 3.7
% change in sodium density	-5% (-16%,7%)	-17% (-23%,-11%)	-19% (-26%,-12%)	-17% (-23%,-11%)	-18% (-30%,-6%)
Change in sodium density	-4.5	-20.5	-23.3	-15.2	-14.7
reformulation effect	-13.5	-17.8	-16.9	-11.1	-9.1
switching effect	6.5	0.4	-5.2	-1.3	-2.8
product renewal effect	2.5	-3.0	-1.1	-2.7	-2.9

Notes: Data show population mean sodium densities of food consumed (in mg/100 g of foods) ± SEs; absolute and percentage changes in sodium density between Year 1 (Y1) and 9 (Y9) with their (95% CI); and the effects of reformulation, switches, and product renewals on the changes in density (in mg/100 g), obtained from Equation 5-2. N show the number of individual included in each group.

Similar results were obtained when the population was stratified by education or income. All groups had a decrease in the sodium density of the diet, and reformulation was the leading effect. Switches showed different effects, but no specific pattern could be observed (Appendix Table xii, Appendix Table xiii).

5.3.5 Changes in blood pressure

Concurrently to decreases in sodium intake and sodium density of the diet, a decrease in systolic blood pressure was measured. The estimated reduction was -0.4 mmHg (SE 0.1, p-value<0.0001) per survey year. The qualification or quintile of income stratification revealed that this decrease in blood pressure was not observed for all income and qualification groups (Table 5-7). The decrease in blood pressure was only observed in people with no qualification or only GCSE, and for people in the quintile 1 and 3.

Table 5-7: Adjusted time trends in blood pressure (in mmHg) by socio-economic group

		Estimated trend	SE	p-value
Highest qualification	Higher education	-0.3	0.2	0.15
	GCE, A level or equivalent	-0.5	0.3	0.05
	GCSE	-0.6	0.3	*0.02*
	No qualifications	-0.6	0.3	*0.04*
Quintile of income	5 (highest)	-0.3	0.2	0.08
	4	-0.2	0.2	0.47
	3	-0.6	0.2	*0.02*
	2	-0.3	0.2	0.26
	1 (lowest)	-0.7	0.2	*0.002*

Notes: Time trends are simple slopes and were estimated from the general time trend and the interaction term between the time trend and the socio-demographic group. Data from NDNS 2008/2009 to 2016/2017.

5.4. Discussion

This study showed that the implementation of the salt reduction programme in 2005 was followed by a decrease in the sodium content of products, in the average sodium density of the diet (17% reduction), in the average sodium intake (by 16%), and in the average blood pressure. Although the design of this study does not allow to make statistical inference between these events, they show an improvement in the quality of foods and diets. This improvement is likely to result in improvements in health.

5.4.1 Successful strategy: changes in the same direction

This study used an original method, the decomposition method, that allowed to distinguish between supply-driven changes and demand-driven changes. When considering all food and beverages, we found that the three effects worked towards a reduction in the sodium content of foods. It means that demand-driven and supply-driven effects worked in synergy to reduce the sodium content of diets.

Nonetheless, supply-driven effects had a higher impact on the reduction of dietary sodium via the reduction of salt in foods. The role of reformulation in the reduction of salt intakes has been shown in systematic reviews, where interventions including reformulation were more effective in decreasing salt intakes than interventions solely based on educating consumers to have a better diet (McLaren et al., 2016; Hyseni et al., 2017b). In the UK, the study that applied first the decomposition method on diet-related topics also found that reformulation was the driving effect in the reduction of the salt density of foods purchased in supermarkets (Griffith, O'Connell & Smith, 2017). Another study using this method, in French supermarket purchases, found that reformulation had a consistent effect reducing salt, sugar or fat of food purchases, while the effect of product renewal was inconsistent, and the effect of consumer switches was often not associated with improved nutrient profile of purchases (Spiteri & Soler, 2018).

5.4.2 Reformulation and disparities

Given the current disparities in diet quality of sub-populations, it is important to question the impact of a diet-related policy on these disparities. In this study, we found that reformulation had a consistent effect across age, gender, education, and income. The same was not observed for switches between products. The fact that reformulation had a similar impact across sub-groups of the population means that reformulation is unlikely to reduce disparities.

Contrarily to the findings of this study, the study by Griffith, O'Connell and Smith found a higher effect of reformulation on most deprived households (Griffith, O'Connell & Smith, 2017). However, this did not result in a higher effect overall as the effect of reformulation was partly offset with detrimental switches between products (Griffith, O'Connell & Smith, 2017). The long-term impact of the salt reduction campaign until 2011 showed no reduction in health disparities (Capewell & Kypridemos, 2017). In summary, this study adds to the evidence that reformulation policies are unlikely to change existing diet disparities. In other words, reformulation is unlikely to widen inequalities, an effect of concern for policies based on education that could have a higher effect on educated than on less-educated populations (Darmon & Drewnowski, 2015; Shankar et al., 2013).

5.4.3 Public health relevance of the changes observed

Mean dietary sodium intakes were estimated to have decreased by 16% between year 1 to year 9, to reach an average intake of 1918mg/day (SE 27) in Y9. This is equivalent to 4.8g of salt per day, but this estimate does not include all salt added while cooking or eating. Hence, it is not possible to compare estimates from this study to daily recommendations. Nonetheless, the reduction we observed is of significant size and is likely to have consequences on the health status of the population. In addition, we found a decrease in systolic blood pressure of -0.4 (SE 0.1) mmHg per survey year, after adjusting for BMI and blood-pressure drug use. The design of our study did not allow us to assume a causal relationship between decreases in salt intakes and blood pressure. However, a more robust study done on the same population also recorded decreases in blood pressure between

2003 and 2011 and attributed them to decreases in salt intakes (He, Pombo-Rodrigues & MacGregor, 2014). This suggests that such a link could explain the results of our study.

5.4.4 Validity of the changes in sodium intakes and blood pressure observed, and comparison with other studies

The decomposition analysis relies on food diaries. However, we know that such diaries are subject to bias, in particular under-declaration and omissions of snacks. We validated our estimations of salt intakes with urinary excretion, suggesting a decrease in salt intakes. Expectedly, estimates using urinary salt excretion were higher than those from the dietary diaries. Indeed, food diaries in NDNS did not consistently include table salt added while cooking or eating. Nonetheless, declared habits on adding salt while cooking or eating did not change over time, suggesting that an increase in table salt use is unlikely.

In this study, we found a 16% reduction in dietary salt intakes between 2008/09 and 2016/2017, estimated with food diaries. These changes were smaller than the unadjusted trends reported in the NDNS report using the same dataset (Public Health England & Food Standards Agency, 2019). This difference could be explained by the adjustments for socio-demographic characteristics and energy intakes we have made. On the other hand, we found a higher reduction than the UK salt survey that found no change in (unadjusted) salt intakes between 2008/09 and 2018/09 (after a decrease in salt intakes from 2005/06 to 2008/09) (Public Health England, 2020b). The UK salt survey used 24-h urinary excretion, a measure that covers all salt intakes, contrarily to diet surveys in which participants may omit some foods eaten. In our sensitivity analysis using the 24-h urine excretion data from NDNS, we found a small but non-significant decrease between 2008/09 and 2012/13, after adjusting for demographic factors and energy intakes.

5.4.5 Validity of the decomposition on a generic database

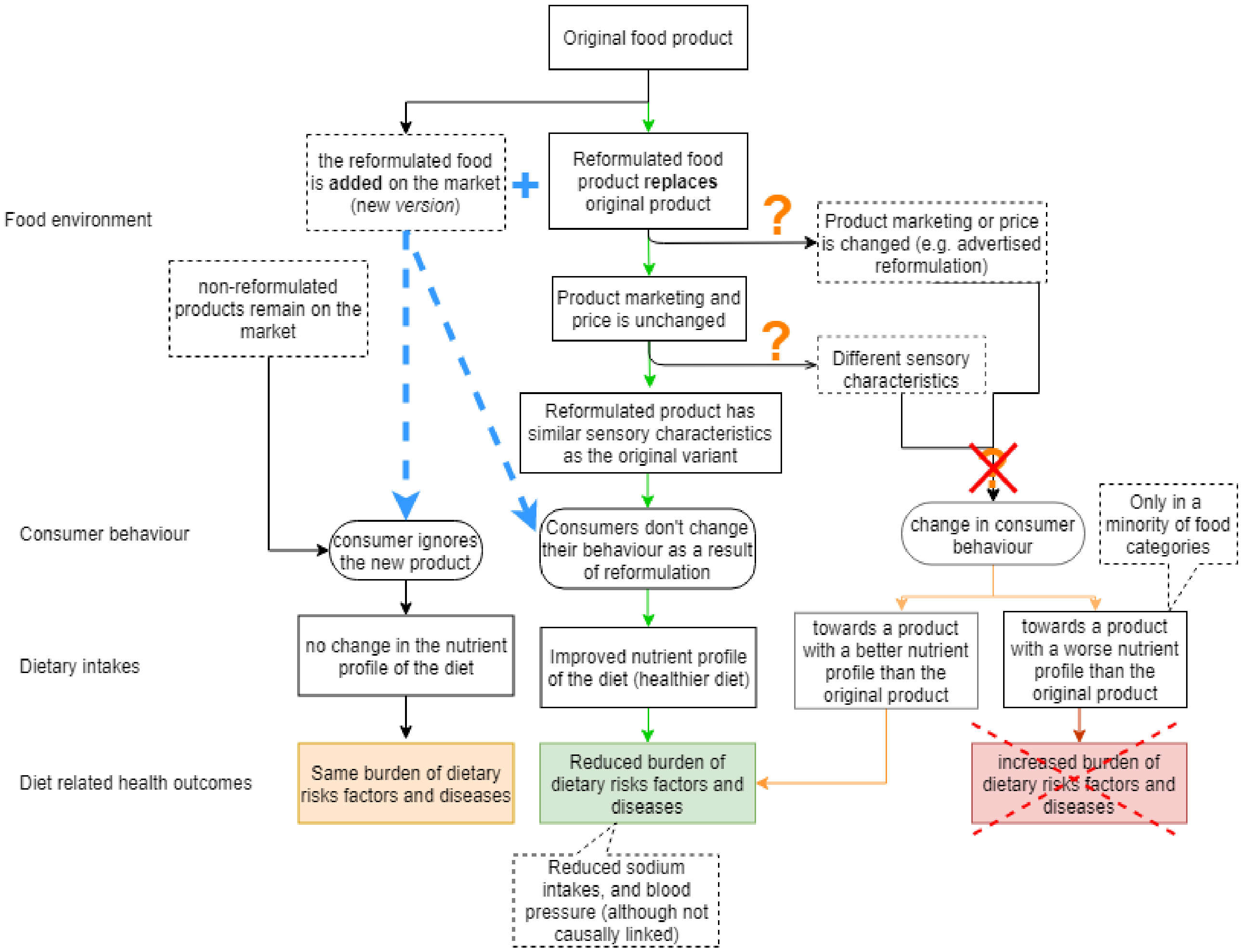
Several limitations linked to the granularity and update of the data need to be raised. First, applying the decomposition method on the NDNS generic food composition table implied that changes from the supply-side (reformulation and product renewal) may not reflect the true effect of reformulation and product renewal happening at the branded product level (Traka et al., 2020). Applying the decomposition method on aggregated food intake data may miss switches between similar products, or different reformulation strategies by manufacturers of similar products. Furthermore, because the population intakes were estimated from a sample of the population, product renewal may be overestimated, and represent switches between products still available on the market. As the NDNS food codes gather similar products, the difference in their sodium content should be small. A study done in France showed that estimating dietary intakes from branded foods only, retailer brands only or a full representation of products matching a generic description led to similar dietary intakes (Perrin et al., 2018), suggesting that what we observed using generic food codes should be similar to what we would observe with more granular data. Hence, we are confident that our estimates are close to what would have been obtained using more detailed information about food intakes and food composition.

In addition, the timing could be biased as nutrition information used in NDNS (from the UK Nutrient Databank) is not updated every year. The databank is updated regularly, however, this process takes time so may create a lag between the current composition of food products, and their reported nutrition composition in the NDNS. However, our estimates using a lagged nutrition composition should underestimate, and not overestimate the effect of reformulation. An unexpected result from this analysis is that most of the effects from reformulation and switches between products happened between year 3 and year 5, with non-significant changes during the other two-year periods. This could be the effect of the update of a key category at this time. Nonetheless, other studies have found that the effect of the UK salt reduction campaign was not sustained over time, with most of the effect happening in the early years (Laverty et al., 2019).

5.4.6 Learnings to bring to the logic model

Several elements of this study inform us about the hypotheses used in the logic model of Chapter 2. Figure 5-5 shows how this chapter contributes to the logic model. Firstly, this study showed that changes at the product level had an impact on dietary outcomes, and possibly on health outcomes. The fact that the decrease in salt intake from the food diaries matched a decrease in urinary excretion allows us to confidently say that salt intake decreased. This confirms the pathway with the green arrows in Figure 5-5. This suggests that there was no compensation for the salt removed from food products. Secondly, switches between products were not always towards products with lower salt, even with the context of awareness campaigns. In this study, the sodium density of the diet was only marginally changed by switches between products. This small effect was the result of opposite changes in the different food categories. Switches towards products with more sodium occurred in sauces, soups and condiments. Switches towards foods with lower sodium content (or a reduction in the consumption of high sodium products) occurred in categories that were also reformulated, such as cereal and cereal-based products, or meat and meat products. These pathways in the logic model have been highlighted in orange (Figure 5-5). This means that general awareness campaigns might not be enough to improve dietary choices. Targeted campaigns, highlighting where discretionary salt can be hidden could help improve dietary choices.

Figure 5-5: Learnings from the study of the decomposition of sodium intakes in the UK between 2008/09 2016/17 to complete the logic model of the action of reformulation on consumers health



5.4.7 Conclusion and next steps

This study showed that reformulation had a leading role in decreasing the salt content of the UK diet. However, some argue that improving the content of other nutrients may be more difficult. As salt has been the focus of policies for some years now, technologies were derived to allow this decrease in salt content, without altering consumer liking or the technical properties of products. Next, we need to assess if such results are obtained in other contexts than salt reduction.

Furthermore, we found that switches between products suggested different patterns across food categories individuals, but reformulation did not. While the effect of reformulation was for all categories towards a decrease in sodium content, consumers chose higher sodium products in some categories. These different salt preferences across categories should be investigated further to understand the drivers of consumer choices. In addition, it is then important to study inter-individual variability towards their answer to reformulation and other diet-related policies.

6. CHAPTER 6: INVESTIGATING SUPPLY- AND DEMAND-DRIVERS OF THE CHANGE IN THE SUGAR DENSITY OF FOOD PURCHASED, FOR THE UK POPULATION AND UK HOUSEHOLDS

The logic model established in chapter 2 showed that switches in consumer choices could offset the effect of reformulation if some foods were left with a worse nutrient profile than other products in the category. The analysis of the trend in fibre intake of the UK population showed that the increase in the fibre density of cereal-based products was not translated into a change in fibre intakes because of changes in consumption patterns (Chapter 4). In addition, the systematic review of chapter 3 showed that there was only small evidence on the impact of sugar reformulation on dietary intakes. In this chapter, I analyse the factors explaining the reduction in the sugar density of purchases observed in the UK between 2015 and 2018/2019. I used the decomposition method used in chapter 5 to study the changes at the population and household levels.

6.1. Introduction

After having launched programmes to reduce salt and TFA intakes, the UK launched in 2016 the Childhood Obesity Plan, a programme aiming at reducing sugar intake to try and improve dental health and reduce energy intake (HM Government, 2016). This programme consisted of two main components: the soft drinks industry levy (SDIL) and the voluntary sugar reduction programme.

The SDIL is a tiered tax for sugar-sweetened beverages. The SDIL was introduced in March 2018 and had two thresholds. Drinks with less than 5g/100mL of sugar were exempted, drinks with more than 8g/100mL sugar were subject to a high rate tax of 24pence/L and drinks between the two thresholds were taxed at a lower rate of 18pence/L. The SDIL had two objectives. The first one was to reduce consumer purchase of high-sugar drinks, which price is expected to increase as a result of the tax. The second one was to incentivize manufacturers of SSB to either reformulate them or sell lower volumes of high-sugar drinks by steering consumer purchase via marketing campaigns towards lower sugar drinks.

The sugar reduction programme is a voluntary reformulation programme. The objective of this programme was to incentivize manufacturers of product categories contributing the most to UK sugar intake to reduce the average sugar content of each category by 20% until 2020.

PHE was in charge of measuring the industry progress towards reducing sugar in their products and measuring the impact of the SDIL. The third-year progress report showed that the average sugar density of beverages purchased decreased by 40% (Public Health England, 2020e). This report also showed that there was some reformulation of some food categories.

Sugar reformulation is expected to translate into a reduction in sugar intake, as shown in chapter 2. But this effect can be offset by changes in consumer behaviour, such as increases in the quantity of products consumed, or a shift to products with more sugar. With the same mechanism, the effect of reformulation could be magnified if consumers switch to lower sugar products. Consumer choices are determined by external outputs, such as trends, campaigns, advertisement (Cohen & Babey, 2012). The sugar reduction programme in the UK made two situations. For drinks, the tax incentivised both reformulation and consumer switches to lower sugar products. For foods, only the reformulation campaign existed, with no specific education campaigns to help consumers choose products with less sugar. So far, the evaluation of the Childhood Obesity Plan showed that the sugar density of beverage and of some food purchases decreased (Public Health England, 2020e), but studies did not differentiate supply-driven effects (reformulation and product renewal) from demand-driven effects (changes in consumer choices). The proportion of drinks above 8g/100mL was shown to have decreased after the announcement of the SDIL (Scarborough et al., 2020), suggesting a response from manufacturers. Also, the quantity of sugar sold per capita in the UK decreased between 2015 and 2018, and this decrease came mostly from a change in the sugar content of the products sold, rather than a change in volume sold (Bandy et al., 2021). A change in the sugar content of products sold can be the result of reformulation or consumer switches to lower-sugar options. To answer this question, we performed in this study a decomposition analysis to estimate the contribution of supply- and demand-drivers to the change in the sugar density of purchases. We were, in particular, interested in evaluating if these effects were similar in the context of an increased consumer awareness linked to the taxation of beverages, and in the context of no specific consumer awareness for sugar in foods.

In addition, policy makers are concerned about the equity impact of the policies they launch. Indeed, social disparities in the diet of the UK population have been found. Households of higher social grades purchased a smaller proportion of less healthy foods than households from lower social grades (Pechey et al., 2013). Households with higher income or a more qualified occupation consumed fewer amounts of non-milk sugars (Maguire & Monsivais, 2014). These inequalities in diet were linked to socio-economic differences in the rates of chronic diseases and obesity. Individuals of lower SES were more likely to suffer from diabetes (Sacerdote et al., 2012), although this difference was not significant in the UK. The risk associated with a diet of lower quality was higher in the UK for people of low SES compared to people of higher SES (Foster et al., 2018). A study on the total sugar purchase in UK households between 2014 and 2017 (before the implementation of the SDIL) found that the disparities in sugar consumption has not changed recently, suggesting that health disparities are still a major concern (Berger et al., 2020b). In this study, we wanted to evaluate if the change in the sugar density of purchases of drinks and foods was different across households. Especially, we wanted to estimate if different socio-economic groups had different changes in food choices.

To summarize, in this chapter, purchases of the UK population were analysed to answer the following question: how changes in demand for, and supply of, foods explained the change in the sugar density of purchases? The heterogeneity of these effects between households was also investigated.

6.2. Methods

6.2.1 The decomposition method

As seen in Chapter 5, the decomposition method was used to explain a change in the nutrient density of foods with supply-side and demand-side drivers. Here, we investigated how these drivers influenced the change in sugar density of purchases. Supply-side drivers were the (sugar) reformulation of food products. Demand-side drivers were changes in the types of products chosen by consumers (within and between categories) and in the quantities purchased. Product renewal was the replacement (or launch) of new food products, while others were delisted. It often responded to trends in consumer demand. As such, product renewal was at the same time demand-driven and supply-driven.

The Equation 5-2 in chapter 5 was used to calculate the three effects:

- **Reformulation effect**: the effect of a change in the sugar density of a food, keeping its market share constant
- **Switching effect:** the effect of consumers switching between products (a change in the market share of products that were and were not reformulated)
- **Product renewal effect**: the difference between the sugar purchased from products exiting the market (i.e., not purchased anymore) and products entering the market (i.e., new products purchased).

Contrarily to chapter 5, here the decomposition was applied to the sugar density of food and beverage purchases, and not of the diet (or foods and beverages consumed). The average sugar density of purchases was calculated using a weighted average (Equation 6-1).

Equation 6-1: Definition of the sugar density of purchases

$$S_t = \sum_i w_{i,t}\, s_{i,t}$$

with $w_{i,t}$ the proportion of product i purchased defined as $w_{i,t} = \frac{weight/volume\ product\ i}{weight/volume\ all\ purchases}$ and $s_{i,t}$ the sugar content per 100mL or 100g of the product i purchased.

The decomposition method was applied to three outcomes:

- The sugar density of the average purchases of the population, for at-home consumption (all purchases, foods included in the sugar reduction programme, drinks included in the SDIL, and by food category)
- The sugar density of the average purchases of the population, for out-of-home consumption (all purchases, foods included in the sugar reduction programme, drinks included in the SDIL, and by food category)
- The sugar density of each household's purchases of all drinks, beverages included in the SDIL, and breakfast cereals purchased for at-home consumption.

6.2.2 Data: surveys of household purchases for at-home and out-of-home consumption

Whereas in chapter 5 the decomposition was applied to all foods consumed recorded in the national food survey, here, we used data of household purchases. Purchase data were used as a proxy for consumption. Such data, despite not measuring exactly consumption, have been shown to be valuable in the evaluation of nutrition policies (Bandy et al., 2019). As reformulation is done on individual products, having household purchases allowed us to estimate reformulation at a granular level. In the second part of the analysis, household-level data was used to estimate changes along time for each household. This allowed a better understanding of demographic drivers of changes in the sugar density of foods purchased. Two different datasets were used, one for purchases for at-home consumption (Kantar Worldpanel), the other for purchases for out-of-home consumption (Lumina Intelligence). Both datasets collect self-reported information.

(1) The Kantar dataset: a survey of household purchases for at-home consumption

The purchases of UK households were taken from the Kantar FMCG's take-home consumer panel (Kantar, n.d.). Approximately 30 000 households took part in the panel. The same households took part in the survey in the different years (with a retention rate of about 85%). The Kantar panel is built to be representative of the UK population. Survey weights were used in the building of indicators representative of the UK population (e.g., average quantity purchased). Nonetheless, survey weights were not used in the individual-level decomposition as this decomposition compares within-household purchases. Households recorded their purchases themselves using scanning equipment and receipts. They recorded all purchases that were brought back at home. The nutrition information of all products purchased was taken from food labels and updated regularly. Hence, each individual branded product is linked to its nutrition information.

The decomposition method required to distinguish between products that stayed in the market (and maybe reformulated) from products that exited or entered the market. To do that, we needed to match the same products across different years. As we aimed to evaluate the impact of product changes vs. changes in consumption patterns, a shift between two pack sizes of the same product was not considered as a change in shopping behaviour, but a change in the quantity chosen of the same product. Hence, product codes with the same product description, if they belonged to the same category, had the same manufacturer and brand were "grouped" within the same product. For example, all chocolate-covered digestive biscuits from the same brand were grouped as one product despite being sold in different pack sizes[2]. Then, we matched the grouped products between the different years.

(2) Differences in the datasets used for population- and household-level analyses

The data were first analysed to get estimates for the whole UK population. The dataset used for this analysis was aggregated, with total sales of each product for the whole UK population. The average sugar density of purchases was obtained using purchases-weighted estimates. Years used in the population-level analysis were 2015 and 2019. This database covered all purchases done in the UK for at-home consumption.

Secondly, the decomposition analysis was done at a household level. As this analysis was more data-intense, only two categories were selected, based on the results of the decomposition done at the population level. For this analysis, we calculated purchases by adult equivalent for each household. This allowed to compare purchases from households of different sizes and is a method commonly used in studies using household purchases (Murphy, Ruel & Carriquiry, 2012; Griffith, O'Connell & Smith, 2015; Smed et al., 2016). Estimated average requirements (EAR) for energy by sex and age group were used to calculate the number of adult equivalents per household. The number of male adult equivalents was calculated by summing the EAR of all household's members and dividing

2 For drinks, canned and bottle versions of the same product were kept separate for colas as canned colas and bottled colas, lemonades and soft drinks of other flavours are classified in different sub-categories in Kantar dataset.

this sum by 2605kcal, the EAR of male adults (Scientific Advisory Committee on Nutrition, 2011). Then, all purchases from the households were divided by the number of adult equivalents to obtain the purchase per adult equivalent.

We used data from the years 2015 and 2018. More recent data was not available for this study.

(3) The Lumina dataset: a survey of purchases for out-of-home consumption

Purchase data for out-of-home consumption was obtained from the Lumina Intelligence survey, for the years 2017 and 2019 (Lumina Intelligence, n.d.). While Lumina Intelligence collects purchases for out-of-home consumption in three surveys, only the two surveys related to adult purchases were used. One survey (of 6000 interviews per month) recorded the frequency of eating and drinking out, and the full details of what was purchased during the most recent eating and drinking out occasion. An additional survey of about 2000 adults was carried out to record drinks purchased out-of-home, in the absence of food purchased. The estimates from both surveys were combined for this analysis. Lumina Intelligence carried out an additional survey to assess children consumption. Descriptive statistics were performed using these data but showed unexpected patterns. For example, the sales of sugar from juice drinks and colas by children decreased greatly between 2017 and 2019, which is unlikely to have happened to such an extent. Hence, the children purchase data was not used because of confidence concerns over the quality of the data. Data for adults' purchases were used after checks that the sugar density of categories did not show unexpected changes.

(4) Limitations to the Lumina dataset

First, the nutrition information in the Lumina dataset is less detailed than in the Kantar Worldpanel data. Products nutrition information is sampled for each product sold in each outlet when possible. But most of the products in the database don't have their specific nutrition information. Instead, several products corresponding to the same definition but being sold in different outlets have the same nutrition information. In conclusion, this limits the ability of the decomposition method to evaluate reformulation precisely and at the product level. Nonetheless, the method is still valid for disaggregated data and informs about the reformulation done for each type of product rather than branded products. Similarly to the decomposition method applied on NDNS data in Chapter 5, the decomposition method applied on the Lumina data informs us of the reformulation of food categories.

Second, the Lumina dataset is not a longitudinal panel with the same individuals responding at different time points. As such, the Lumina dataset presents a series of cross-sectional data from UK adults. As a result of these differences, the results of the analysis of the two datasets are not directly comparable, and the estimates from the Lumina database are expected to be of a lesser quality than the ones from the Kantar database.

(5) Identification of foods included in the sugar reduction programme or SDIL

In this analysis, we focused on food and drinks included in the UK government's Childhood Obesity Plan. That meant we included either beverages in the scope of the SDIL or foods included in the sugar reduction programme (Public Health England, 2017b). We identified foods and drinks included in the Childhood Obesity plan using product categorisation, and insights from PHE.

In addition to the categories corresponding to the sugar reduction programme, additional categories were created for out-of-home purchases. As drinks represented a high share of out-of-home purchases, we wanted to get detail about the sugar density of drinks highly consumed but out-of-scope of the SDIL. We categorised coffees, milk-based beverages, and juices not made from 100% pure juice (which are all excluded from the SDIL but included in the sugar reduction programme). As the Lumina intelligence dataset does not allow differentiation between pure juices from juice-based products, they were all grouped in the category "Fruit juices and juice-based drinks". Similarly, all milk-based drinks were grouped in one category, regardless of whether they contained more or less than 80% milk.

6.2.3 Explaining heterogeneity in household-level data

Another reason for doing the household-level decomposition was to explore the heterogeneity observed across households. After having applied the decomposition equation (Equation 5-2) for each household, we used linear regressions to investigate if the three effects (i.e. decomposition, switches and product renewal) differed by demographic characteristics. For the three categories, each of the three effects was regressed against the baseline volume purchased from this category, the baseline sugar density of purchases as a proxy for sugar preference, and the demographic characteristics of the household. Household characteristics included the household size, income of the household, social class of the household, if the household lived in a rural or urban area, the ethnicity of the main shopper and the life stage of the household.

Equation 6-2: Regression to test demographic differences in the decomposition effects (example written for the reformulation effect)

$$Reformulation_h = \beta_0 + \beta_1 Volume_{h,2015} + \beta_2 Sugar\_density_{h,2015} + \beta\ H_{h,2015} + \varepsilon_h$$

$Volume_{h,2015}$ is the baseline volume of products purchased in 2015 by the household. This variable is an indicator differentiating high from low consumers of the product category studied. $Sugar\_density_{h,2015}$ is the average sugar density of purchases by the household in 2015. This variable controls for the preference for sugary products at baseline. $H_{h,2015}$ is a vector of the demographic characteristics of the households in 2015. They include the same variables as described before.

Lastly, we tested if the result of the decomposition (i.e. the three effects) could predict the change in the quantity of sugar purchased by the household between 2015 and 2018. We regressed the change in the quantity of sugar purchased per adult equivalent in a household from one category on the three effects and the demographic characteristics of the household (Equation 6-3). This regression was done for the three product categories separately.

Equation 6-3: Regression to test the predictive power of the three decomposition terms to predict change in sugar purchased by a household

$$Change\ sugar_h = \beta_0 + \beta_1 Volume_{h,2015} + \beta_2 Sugar\_density_{h,2015} + \beta_3 Reformulation_h + \beta_4 Switches_h + \beta_5 Pd\_renewal_h + \beta\ \ H_{h,2015} + \varepsilon_h$$

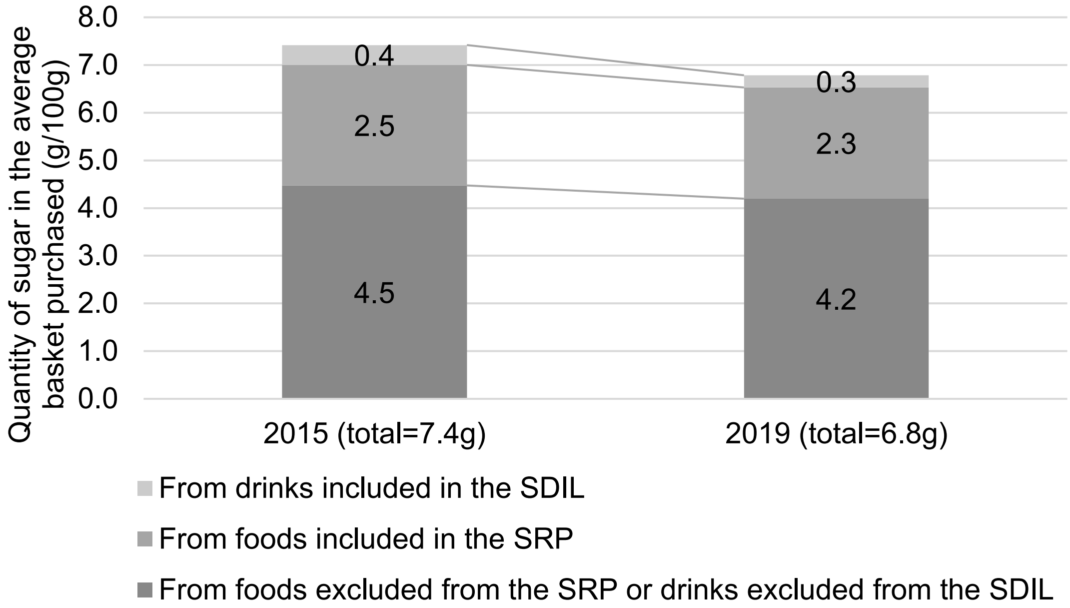
$Change\ sugar_h$ is the difference in the quantity (in grams/year) of sugar purchased by the household per adult equivalent between 2015 and 2018.

6.3. Results

6.3.1 A decrease in the sugar density of purchases, across sources

The study of household purchases in 2015 and 2019 showed that the average sugar density of all products purchased decreased from 7.4g/100g in 2015 to 6.8g in 2019 (Figure 6-1). This decrease in density was visible in foods included in the sugar reduction programme, drinks included in the SDIL but also foods not included in any sugar reduction programme.

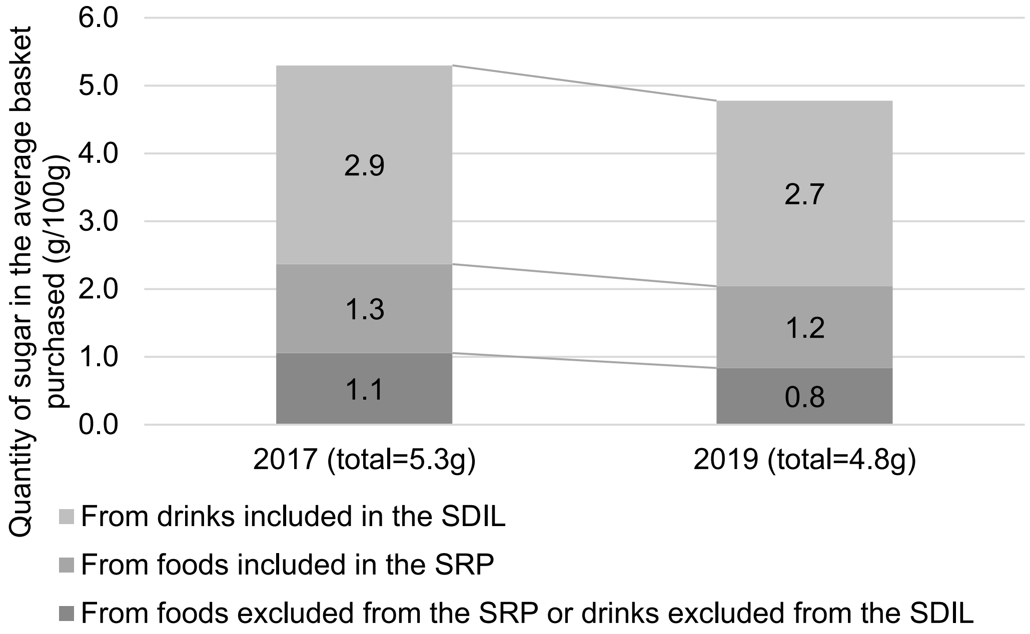
Figure 6-1: Average sugar density of foods purchased for at-home consumption, in 2015 and 2019.



Notes: SRP: Sugar Reduction Programme; SDIL: Soft Drinks Industry Levy

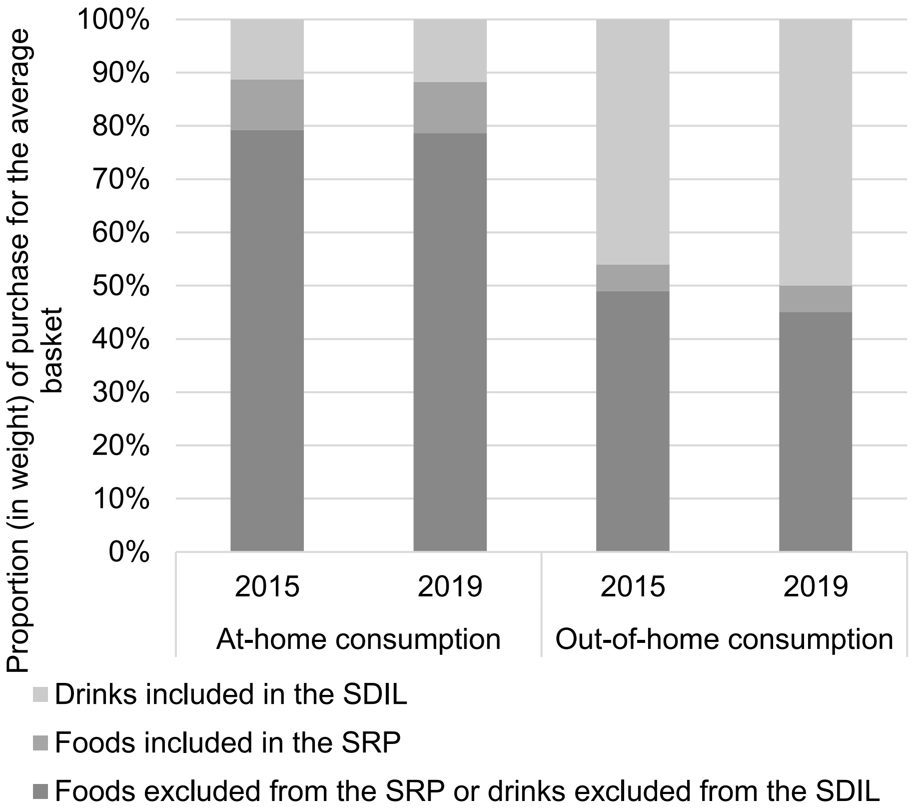
Similarly, the average sugar density of foods and drinks purchased for out-of-home consumption also decreased between 2017 and 2019 (Figure 6-2). Here also, the reduction in sugar density was visible for all types of foods (food and drinks, included and excluded from any sugar reduction programme). The sugar density of purchases for out-of-home consumption was lower than the sugar density of purchases for at-home consumption (in 2019: 6.8g/100g for purchases for at-home vs 4.8g/100g for purchases for out-of-home consumption). This difference was due to a different share of drinks in the average basket for at home vs. out-of-home consumption (Figure 6-3). Drinks, that are of a lower nutrient density than foods, were purchased in much higher proportions out-of-home than for at-home consumption.

Figure 6-2: Average sugar density of the basket of foods and drinks purchased for out-of-home consumption, in 2015 and 2019.



Notes: SRP: Sugar Reduction Programme; SDIL: Soft Drinks Industry Levy.

Figure 6-3: Share foods in the Sugar Reduction Programme (SRP), drinks included in the SDIL, and foods and drinks excluded in the average basket of purchases for at-home and out-of-home consumption.



6.3.2 Decomposition of purchases for at-home consumption

The decomposition of the all purchases for at-home consumption of the UK population showed different patterns for foods and drinks. For foods, the sugar density decreased by 2% and this reduction came mostly from the reformulation of foods (Table 6-1). The average sugar density of drinks purchased by the population decreased by 41%, and this decrease was explained by the three effects (Table 6-1). Nonetheless, the effect of reformulation and product renewal was larger than the switching effect.

Table 6-1: Sugar density of the average basket of food products purchased for at-home consumption in 2015 and 2019, and results of the decomposition of the change in the average sugar density into effects of reformulation, switches and product renewal.

SUGAR DENSITIES IN G/100MG OR G/100ML	FOODS IN THE SRP	DRINKS (IN THE SDIL)	ALL PURCHASES
SUGAR DENSITY, 2015	25.4	3.7	7.4
REFORMULATION EFFECT	-0.6	-0.7	-0.2
SWITCHING EFFECT	0.1	-0.3	-0.2
PRODUCT RENEWAL EFFECT	-0.1	-0.5	-0.3
SUGAR DENSITY, 2019	24.8	2.2	6.8
CHANGE IN SUGAR DENSITY (%)	-2%	-41%	-9%

‘All purchases’ means all food and drink items purchased in the Kantar panel; ‘Foods in the SRP’ means (solid) foods included in the Sugar Reduction Programme (SRP); ‘Drinks’ are only those subject to the SDIL.
The sum of the three decomposition effects equals the difference in the sugar density

The decomposition can be applied to all purchases in order to understand the extent to which excluded and included food and drinks contributed to the 9% decrease in sugar density observed for all purchases (Table 6-2). Despite having a lower sugar density at baseline (3.7g/100mL of drinks, Table 6-1), drinks included in the SDIL contributed similarly to foods included in the SRP to the decrease in the sugar density of all foods purchased (Table 6-2). The reformulation effect was of the same size for included foods and drinks, contributing each to decreasing by 0.1g/100g of sugar in the average basket of products purchased (Table 6-2). This is the result of the combination of an important percentage reformulation of soft drinks (-0.7g/100mL of soft drinks, -19%) and a higher sugar density at baseline for included foods (25.4g or sugar /100g of included foods) but a lower relative reformulation (-0.6g/100g of included foods, 2%).

Table 6-2: Sugar quantity in the average 100g basket of products purchased for at-home consumption, split out by included and excluded products.

	2015 (total =7.4g)	Reformulat-ion effect	Switching effect	Product renewal effect	2019 (total =6.8g)
From foods excluded from the SRP or drinks excluded from the SDIL	4.5	0.0 (-0.6%)	-0.1 (-0.8%)	-0.2 (-2.4%)	4.2
From foods included in the SRP	2.5	-0.1 (-0.8%)	-0.1 (-1.1%)	0.0 (-0.2%)	2.3
From drinks included in the SDIL	0.4	-0.1 (-1.0%)	0.0 (-0.7%)	-0.1 (-1%)	0.3

Notes: Data from aggregated Kantar panel. Cell values are sugar density in g for 100g of the average basket of products. SRP: Sugar Reduction Programme; SDIL: Soft Drinks Industry Levy

The food categories included in the sugar reduction programme experienced different changes in sugar density. In almost all categories, except morning goods and chocolate or sweet confectionery, the sugar density decreased (Table 6-3). Breakfast cereals and yoghurts were the categories with the highest sugar reductions (-15% and -13%, respectively). The sugar reduction of these two categories came from supply-side drivers: reformulation for breakfast cereals, and product renewal for yoghurts. Overall, the effect of reformulation and product renewal was often of a negative sign (i.e., towards a reduction in sugar density), while the effect from switches was small, and often towards an increase in sugar density (Table 6-3).

Table 6-3: Decomposition of the change in the sugar density of the different categories included in the sugar reduction programme, for foods purchased for at-home consumption.

	Sugar density 2015	Reformulation effect	switches effect	product renewal effect	Sugar density 2019	% change in sugar density[1]
Soft drinks	3.7	-19%	-9%	-13%	2.2	-41%
Breakfast cereal	16.8	-10%	-1%	-3%	14.3	-15%
Yoghurts	12.4	-4%	1%	-10%	10.7	-13%
Cakes	34.3	-3%	-2%	-2%	31.9	-7%
Ice cream	18.7	-7%	3%	-2%	17.5	-6%
Excluded	*5.7*	-1%	-2%	-3%	*5.3*	*-6%*
Spreads & sauces	28.8	1%	3%	-10%	28.1	-2%
Puddings	18.9	-3%	3%	-1%	18.6	-1%
Biscuits	31.2	-1%	-1%	1%	30.9	-1%
Sweet confectionery	60.4	-1%	0%	0%	60.4	0%
Chocolate confectionery	53.8	1%	0%	0%	53.9	0%
Morning goods	12.5	1%	-5%	4%	12.6	1%

The sugar densities are in g/100g or g/100mL, and the three effects are % change compared to baseline. The sum of the three effects equals the total % change in the sugar density of the category. Data from Kantar panel. The colour coding reflects the intensity of the change: green for decreases in sugar density, orange for increases.

[1] The % change in sugar density between 2015 and 2019 here are different than the same metric in the third year progress by industry report (PHE, 2020e) due to small differences in methodology (such as the classification of foods within the Programme categories, or the baseline year for morning goods and cakes.)

6.3.3 Decomposition of purchases for out-of-home consumption

The sugar density of foods included in the sugar reduction programme and drinks included in the SDIL purchased for out-of-home consumption decreased at a similar rate (-12% for foods and -14% for drinks, Table 6-4). For foods, switches and product renewal were the leading effects of the reduction in sugar density. For drinks, reformulation and product renewal were the leading effects.

Table 6-4: Sugar density of the average basket of food products purchased for out-of-home consumption in 2017 and 2019, and decomposition of the change in sugar density into effects of reformulation, switches, and product renewal.

SUGAR DENSITIES IN G/100MG OR G/100ML	**FOODS (IN THE SRP)**	**DRINKS**	**ALL PURCHASES**
SUGAR DENSITY OF ALL FOODS, 2017	25.1	6.4	5.3
REFORMULATION EFFECT	-0.1	-0.5	-0.3
SWITCHING EFFECT	-1.8	0.0	0.0
PRODUCT RENEWAL EFFECT	-1.2	-0.3	-0.3
SUGAR DENSITY OF ALL FOODS, 2019	22.0	5.5	4.8
CHANGE IN SUGAR DENSITY (%)	-12%	-14%	-10%

‘All foods’ means all food and drink items purchased in the Kantar panel; ‘Foods in the SRP’ means (solid) foods included in the Sugar Reduction Programme (SRP); ‘Drinks’ here includes also coffee-, milk- and juice-based products as the data does not allow to assess if they are included in the SDIL or not.
The sum of the three decomposition effects equals the difference in the sugar density

Given their high share in the average basket of products purchased for out-of-home consumption and their reformulation, drinks had a high contribution to the reformulation of all purchases (Table 6-5). In line with Table 6-4, the reformulation of foods included in the sugar reduction programme was minimal, and the decrease in the sugar quantity coming from included foods to the average basket of products came from switches between products (Table 6-5). Unexpectedly, the sugar coming from foods excluded from the sugar reduction programme decreased between 2017 and 2019 (Table 6-5). This effect is mostly coming from a decrease in their share in the average basket of products purchased (a decrease in weight purchased is equivalent to a decrease in sugar quantity from these products).

Table 6-5: Sugar quantity in the average 100g basket of products purchased for out-of-home consumption, split out by included and excluded products.

	2017 (total= 5.3g)	Reformulat-ion effect	Switching effect	Product renewal effect	2019 (total= 4.8g)
From foods excluded from the SRP	1.1	-0.1	0.3	-0.2	0.8
From foods included in the SRP	1.3	0.0	-0.2	0.1	1.2
From drinks	2.9	-0.2	-0.1	-0.1	2.7

Notes: Cell values are sugar density in g for 100g of the average basket of products. The sum of the three effects is not equal to the difference between the sugar density in 2017 and 2019 because the (weight) share of the three groups changed over time. Nonetheless, the sum of the three effects for the three groups equals the total difference in sugar density.

The decomposition by food group was similar for foods purchased for out-of-home consumption than those purchased for at-home consumption (Table 6-3 and Table 6-6). Breakfast cereals and yoghurts were the categories with the highest sugar reduction, but it was lower than for at-home consumption (-11% and -5% for breakfast cereals and yoghurts, respectively, Table 6-6).

Table 6-6: Decomposition of the change in the sugar density of the different categories included in the sugar reduction programme, for foods purchased for out-of-home consumption. Data from Lumina Intelligence

	category sugar density[1] 2017	Reformul-ation effect[2]	switches effect[2]	product renewal effect[2]	category sugar density[1] 2019	share 2017	share 2019	% change in sugar density[3]
Sweet confectionery[4]	54.7	-10%	-12%	-12%	35.7	0%	0%	-35%
Breakfast cereal	11.6	-11%	-3%	-11%	8.6	0%	1%	-26%
Soft drinks	6.2	-10%	1%	-7%	5.1	26%	31%	-17%
Yoghurts	13.0	-13%	1%	-5%	10.8	0%	0%	-17%
Milk-based beverages (excl.)	*12.7*	-13%	3%	-6%	*10.7*	*1%*	*2%*	*-16%*
Exclude	2.2	-7%	-4%	-4%	1.9	49%	45%	-14%
Biscuits	34.1	-3%	-1%	-6%	30.6	1%	0%	-10%
Fruit juices (partly excl.)	*7.6*	-14%	10%	-4%	*7.0*	*5%*	*4%*	*-8%*
Coffee (excl.)	5.8	3%	-7%	-3%	5.4	13%	12%	-7%
Cakes	29.3	-1%	-2%	-3%	*27.5*	*2%*	*1%*	*-6%*
Puddings	21.6	-1%	-3%	-1%	20.7	1%	2%	-4%
Morning goods	16.4	-1%	0%	-3%	15.9	1%	1%	-3%
Ice cream	20.6	8%	0%	0%	22.3	1%	0%	8%
Chocolate confectionery	44.6	13%	-4%	2%	49.8	0%	0%	12%

[1]The sugar densities are sales-weighted and expressed in g/100g or g/100mL
[2] The three effects are % change compared to baseline. The sum of the three effects equals the total % change in the sugar density of the category. The colour coding reflects the intensity of the change: green for decreases in sugar density, orange for increases.
[3] The % changes in sugar density between 2015 and 2019 here are different than the change in sugar densities in the third year progress by industry report (Public Health England, 2020e). Here, averages are sales-weighted whereas they are simple averages in the Third year progress report.
[4]The Sweet Confectionery category consists of only two product types consumed out-of-home: sweets and popcorn. The data records a shift in consumption towards popcorn, instead of sweets. Because of the high difference in sugar density between these two products, this creates the 35% reduction in sugar density in the above table.
Excl.: excluded (from the SDIL or the Sugar Reduction Programme)

6.3.4 Decomposition by household

(1) Unadjusted mean changes

On average, the sugar density of household purchase of drinks, soft drinks and breakfast cereals decreased significantly (Table 6-7). Decreases were of a magnitude of 1.5g/100g for breakfast cereals, and 1.1 and 1.3 g/100mL for drinks and soft drinks, respectively (Table 6-7). Nonetheless, the standard deviation of the change in sugar density was high (and higher than the mean) showing differences in change in sugar density across households.

While the volume of drinks purchased increased (per adult equivalent and for the household, although not significantly), the volume of soft drinks purchased decreased (Table 6-7). The volume of breakfast cereals purchased also decreased.

As a result of these decreased volume and sugar density of purchases, the mean quantity of sugar purchased per year per household and per adult equivalent decreased for the three categories between 2015 and 2018 (Table 6-7). Decreases were of 886g (SD 3315) per adult equivalent from all drinks including 586g (SD 2503) from soft drinks, and 185g (SD 1345) from breakfast cereals. The high standard deviations indicated that the spread of the difference in sugar purchased per household in 2015 and 2018 was wide, with some households having different behaviour than the average one.

Table 6-7: Mean volume and sugar purchased in a year, and sugar density of household purchases of all drinks, soft drinks and breakfast cereals in 2015 and 2018

	Unit	All drinks	Soft drinks	Breakfast cereals
N households		18,512	18,343	18,355
Volume in 2015	(kg/year or L/year)	175.9 (186.7)	92.9 (127.5)	17.3 (16.9)
Volume in 2018	(kg/year or L/year)	176.4 (191.2)	88.1 (122.5)	16.6 (16.3)
Mean change in volume for the household	(kg/year or L/year)	0.59 (125.9)	-4.83* (86.3)	-0.74* (11.5)
Mean change in volume per adult equivalent	(kg/year or L/year)	1.94* (71.1)	-1.32* (49.1)	-0.28* (6.7)
Sugar density of purchases in 2015	(g/100g or g/100mL)	4.49 (3.13)	4.56 (3.96)	15.94 (7.73)
Sugar density of purchases in 2018	(g/100g or g/100mL)	3.44 (2.69)	3.27 (2.98)	14.43 (7.46)
Mean change in density	(g/100g or g/100mL)	-1.06* (2.64)	-1.29* (3.58)	-1.51* (7.68)
Sugar quantity purchased in 2015	(g/year)	6,948 (9,082)	3,542 (6,653)	2,886 (3,337)
Sugar quantity purchased in 2018	(g/year)	5,087 (6,742)	2,272 (4,585)	2,505 (2,965)
Mean change in sugar for the household	(g/year)	-1,861* (6,314)	-1,270* (4,867)	-381* (2,401)
Mean change in sugar per adult equivalent	(g/year)	-886* (3315)	-586* (2,503)	-185* (1,345)

Notes: Cells shows weighted means (SD), except for the number of households

* means a significant paired t-test for household changes and adult-equivalent change in sugar, density and volume

(2) Results of the decomposition for each household: varying patterns

Overall, the decomposition of the changes in sugar density of the three categories showed similar patterns (Figure 6-4, Figure 6-5, Figure 6-6). Supply-driven effects (reformulation effect and product renewal effects) had a smaller spread and were for about 75% of households contributing to a decrease in sugar density of purchases (as for the three categories, Q75 was closed to zero, Figures 6-4 to 6 and Appendix Table xiv). On the other hand, the effect of households switching between products showed a larger variability. While for all drinks and soft drinks purchases, the median switching effect was negative, meaning that more than half of households made switches that contributed to decreasing the sugar density of purchase, for breakfast cereals the median was at zero, meaning that half of the households made choices towards products with higher sugar.

For drinks and soft drinks, the mean of the three effects is negative: on average, reformulation, product renewal and switches contributed significantly to a decrease in the sugar density of purchases (Figures 6-4 to 6 and Appendix Table xiv). For soft drinks, the mean reformulation effect was twice the size of the switching effect and triple the size of the product renewal effect. For breakfast cereals, the mean reformulation and switches effect was negative, while the mean switching effect was null.

Figure 6-4: Distribution of the change in the sugar density of all beverages purchased by households between 2015 and 2018, and its decomposition into reformulation, switching and product renewal effects

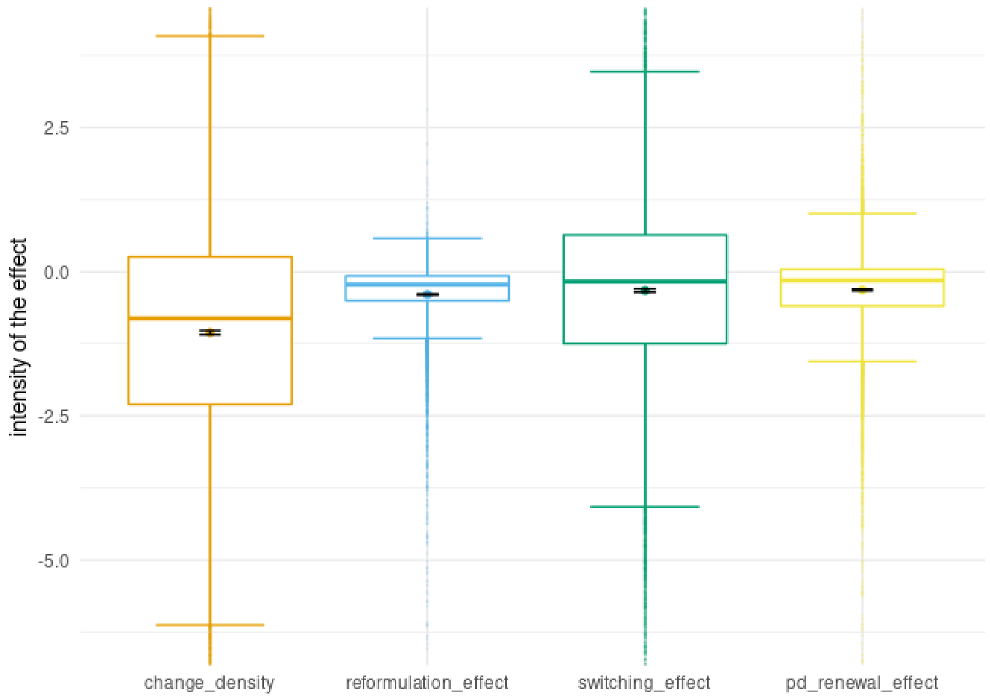


Figure 6-5: Distribution of the change in sugar density of soft drink purchased by households between 2015 and 2018, and its decomposition into reformulation, switching and product renewal effects

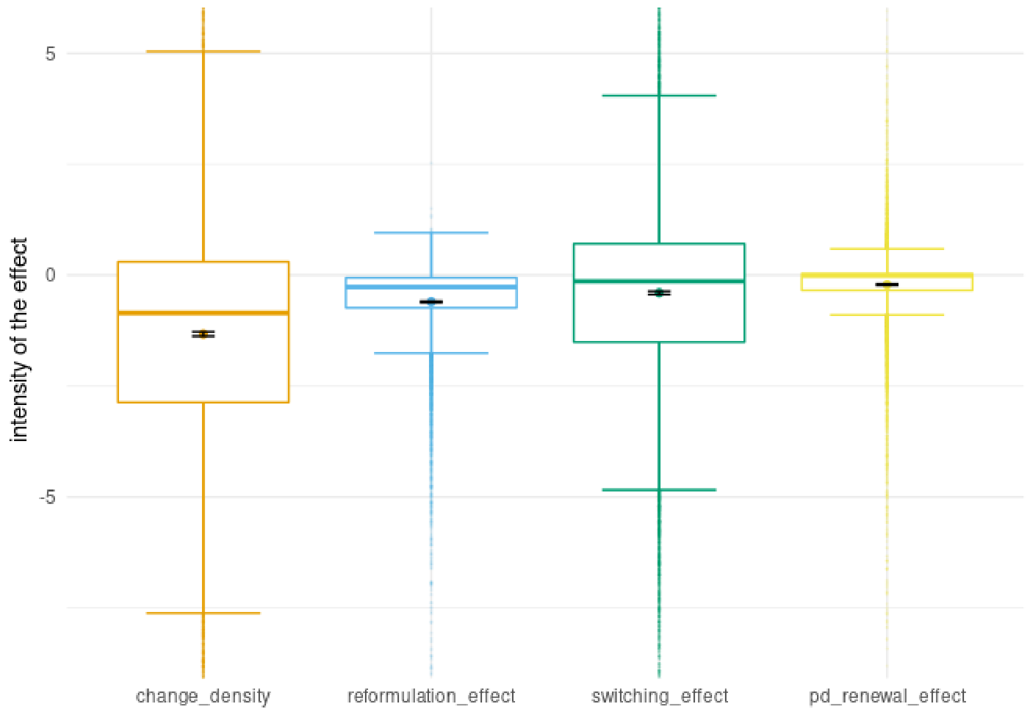
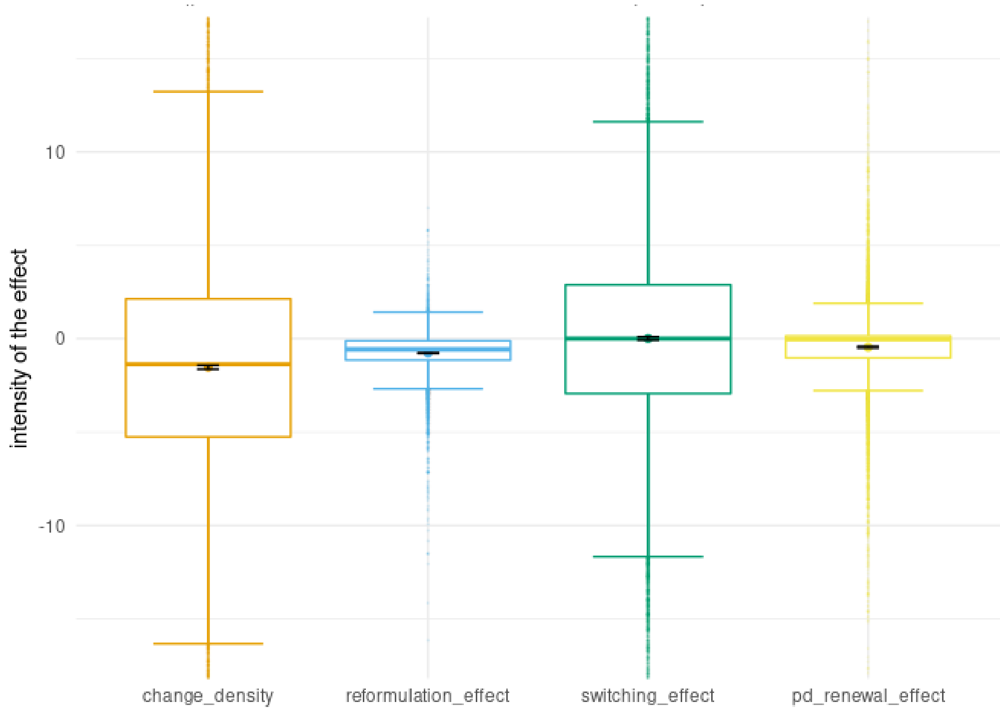


Figure 6-6: Distribution of the change in sugar density of breakfast cereal purchased by households between 2015 and 2018, and its decomposition into reformulation, switching and product renewal effects



(3) Differences in the decomposition result between households

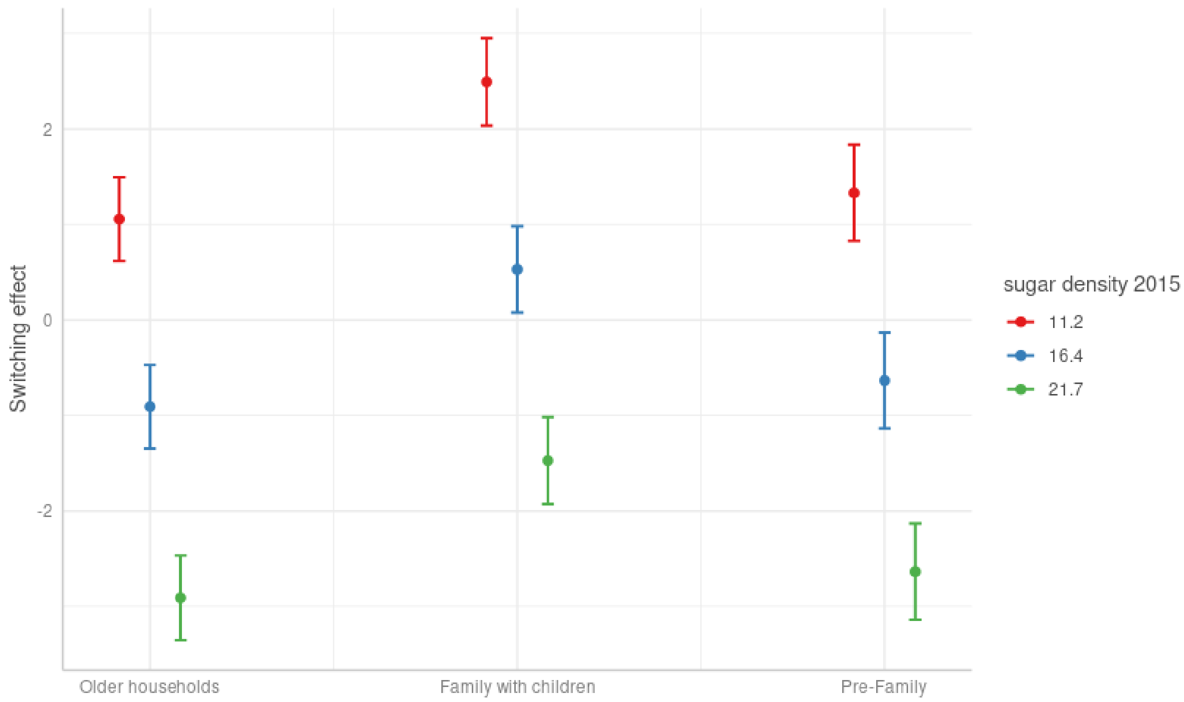
The regressions using Equation 6-2 showed that the baseline volume of products purchased, preference for sugar and demographic characteristics can partially predict the effects of reformulation, switches, and product renewal (Appendix Table xv to xii). More importantly, the models explained 16%, 20% and 20% of the variance of the switching effects of drinks, soft drinks, and breakfast cereals, respectively. That meant that it was possible to predict by some degree the direction of the change in density from switches between products.

For all drinks, the baseline sugar density of the purchases of a household was the main predictor of the value of the switching effect (Appendix Table xv). Households purchasing in 2015 drinks of a higher sugar density were more likely to switch to products with less sugar. In addition, some household demographics predicted the switching effect. People of social classes C2, D or E were more likely to switch to drinks with less sugar than households of social class A. Households in which the main shopper was not white were more likely to switch to products with higher sugar than households with a white main shopper.

The sugar density of soft drinks purchased at baseline had a similar effect on the switching effect in the soft drinks category as for all drinks (Appendix Table xvi). Ethnicity had the same role as for all drinks, but the effect of social class was not significant.

For breakfast cereals, the main predictors of the switching effect were the life stage of the household and the sugar density of purchases at baseline (Appendix Table xvii and Figure 6-7). Households with children had a more limited decrease (or higher increase) in the sugar density of their purchase than households without children. Households preferring at baseline breakfast cereals of a higher sugar density made switches more in favour of lower sugar products than households preferring at baseline lower-sugar density products (Figure 6-7).

Figure 6-7: Predicted effect of the number of children and the sugar density of breakfast cereal purchases on the switching effect for the breakfast cereal category.



Notes: The effects are predicted at the 25th, 50th and 75th centile of the distribution of the baseline sugar density.

(4) Are the decomposition effects dependant on specific households?

To test the importance of household characteristics in explaining the three effects, we calculated the correlation between the three effects obtained in drinks and breakfast cereals. The correlation between the switching effect in cereals and the switching effect in drinks was really low at 1%. This means that the behaviour of households was different in the two categories.

Table 6-8: Correlation table between the decomposition effects for all drinks and breakfast cereals

		Breakfast cereals		
		reformulation effect	switching effect	product renewal effect
All drinks	reformulation effect	0%	0%	0%
	switching effect	1%	1%	1%
	product renewal effect	0%	0%	1%

6.3.5 Role of supply- and demand drivers and demographics to explain changes in sugar purchases

The switching effect of a household had a high correlation with the change in sugar density of purchase by the household (Table 6-9). The correlation between the change in density and the reformulation and product renewal effects was smaller for the three categories.

Table 6-9: Correlations between the three effects and the change in sugar density of purchases by a household

Correlation with change sugar in density	All drinks	Soft drinks	Breakfast cereals
Reformulation effect	36%	45%	23%
Switching effect	87%	81%	86%
Product renewal effect	48%	42%	41%

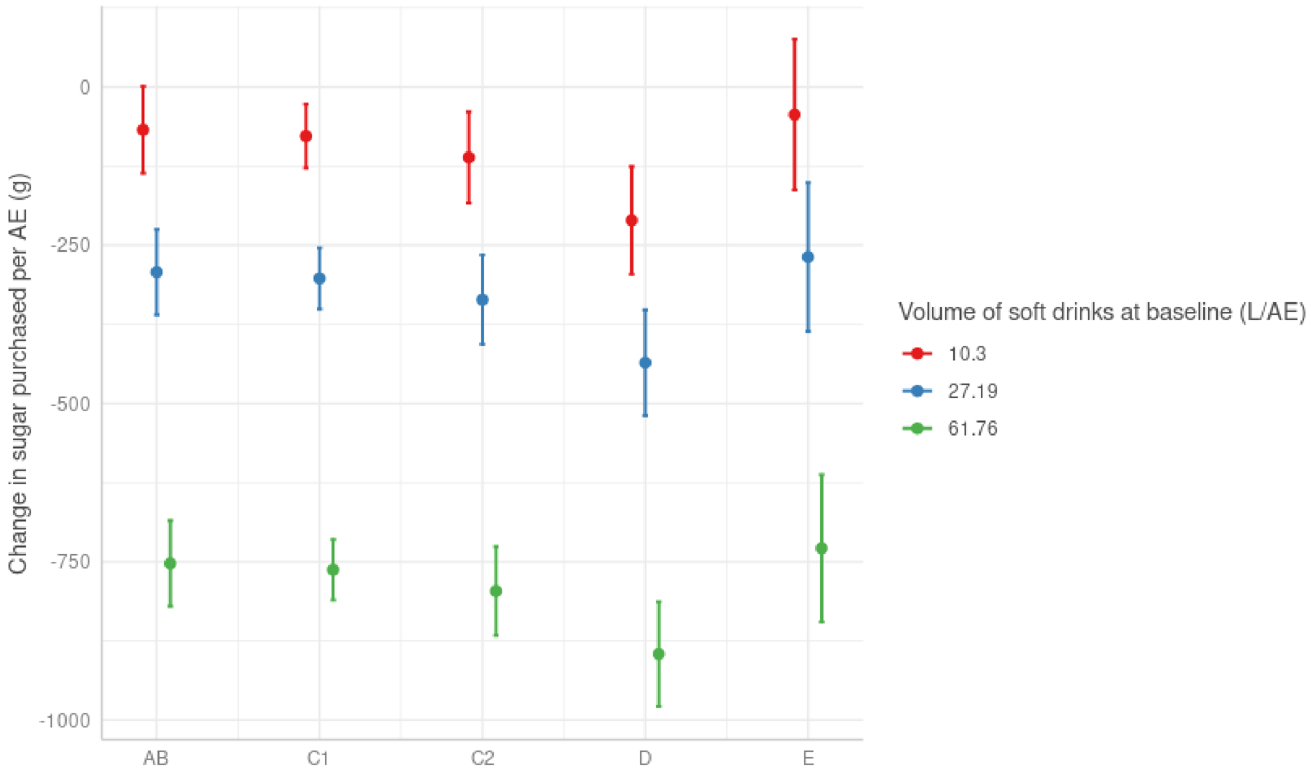
The regression using Equation 6-3 showed that, for the three categories, the three decomposition effects positively and significantly influenced the change in sugar purchased (Table 6-10). It did not seem that one of the three effects had a stronger effect on the change in sugar than others: the stronger effect was product renewal, switching, and reformulation for all drinks, soft drinks, and breakfast cereals, respectively.

In addition, households with a higher sugar density at baseline were more likely to have a higher reduction in sugar quantities purchased than households with lower sugar density. The change in sugar purchased from the three food categories was negatively linked to the baseline volume of products purchased. This means that higher consumers at baseline tended to decrease their purchase of sugar compared to lower consumers.

These analyses were controlled for demographic characteristics. Demographic characteristics had a strong influence on the change in sugar purchased. Larger households were more likely to decrease their purchase of sugar from the three categories than smaller households.

There was a small gradient for the change in sugar purchased from soft drinks by social class (Figure 6-8). Households of social class D purchased significantly less sugar from soft drinks than social class A or B. On the other hand, households from social class E had a smaller decrease in their purchase than households of other social classes (Figure 6-8). There was a stronger gradient by social class in the change in sugar purchased from breakfast cereals (Figure 6-9)

Figure 6-8: Predicted mean effect of social class and the baseline volume of soft drinks purchased by adult equivalent (AE) in the household on the purchase of sugar from soft drinks

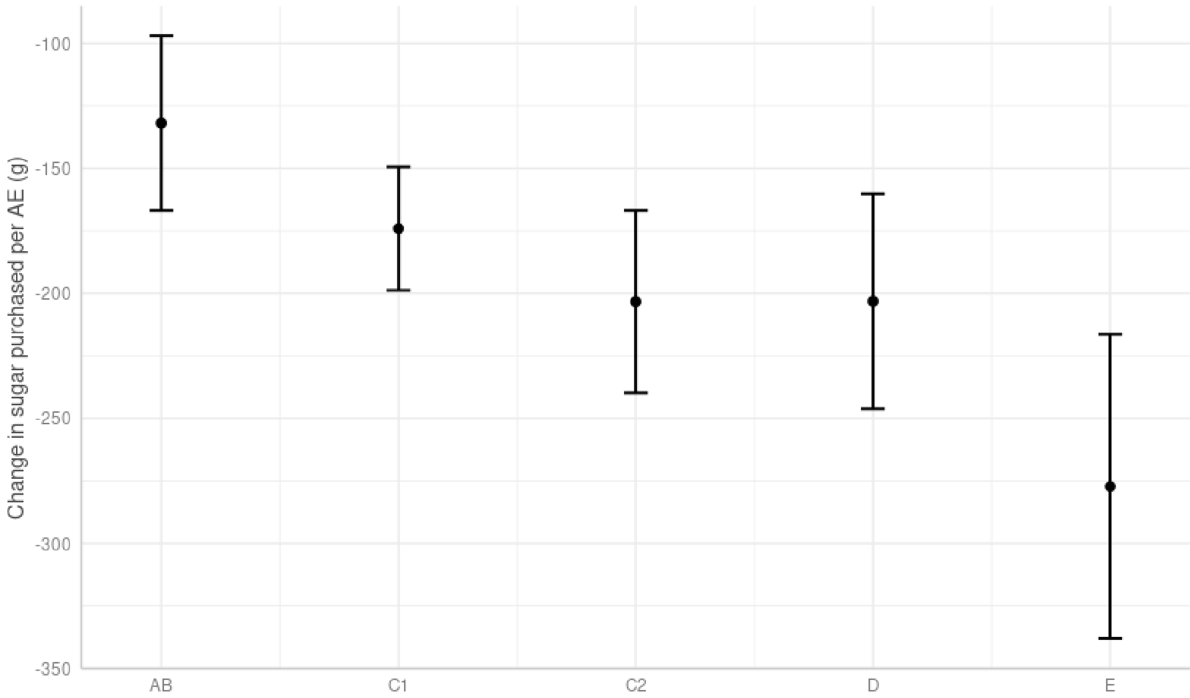


Notes: The effects were modelled at the 25th, 50th, and 75th percentile of baseline volume of soft drinks per adult equivalent purchased. Bars show the 95% confidence intervals.

Table 6-10: Regression of the change in sugar quantity purchased per adult-equivalent on household characteristics and decomposition results

	All drinks			Soft drinks			Breakfast cereals		
	estimate	SE	p.value	estimate	SE	p.value	estimate	SE	p.value
(Intercept)	1905.4	246.2	**0.000**	778.4	194.3	**0.000**	816.2	102.9	**0.000**
reformulation effect	337.4	32.5	**0.000**	73.8	16.2	**0.000**	77.3	7.8	**0.000**
switching effect	504.8	10.2	**0.000**	204.4	6.5	**0.000**	61.5	1.4	**0.000**
product renewal effect	522.9	21.4	**0.000**	128.8	14.4	**0.000**	60.1	3.3	**0.000**
Mean sugar density of purchases in 2015	-148.9	8.3	**0.000**	-126.7	5.9	**0.000**	-7.5	1.3	**0.000**
Volume of purchases in 2015	-13.2	0.2	**0.000**	-13.3	0.2	**0.000**	-58.5	0.9	**0.000**
N household members	-186.1	20.8	**0.000**	-85.4	16.5	**0.000**	-78.4	8.7	**0.000**
Household.Income £10,000 - £19,999 pa	66.2	88.3	0.453	120.6	70.7	0.088	57.0	36.9	0.122
Household.Income £20,000 - £29,999 pa	201.9	92.5	**0.029**	223.0	74.1	**0.003**	-4.8	38.6	0.901
Household.Income £30,000 - £39,999 pa	38.2	97.2	0.694	122.2	77.8	0.116	22.2	40.5	0.584
Household.Income £40,000 - £49,999 pa	96.5	103.5	0.351	130.9	82.7	0.114	13.7	43.1	0.750
Household.Income £50,000 - £59,999 pa	-5.2	115.1	0.964	158.5	91.9	0.084	-38.0	47.8	0.427
Household.Income £60,000 - £69,999 pa	92.6	135.5	0.494	94.7	107.9	0.381	23.2	56.3	0.680
Household.Income >£70,000	40.1	125.2	0.748	125.3	100.0	0.210	59.2	52.1	0.255
Household.Income Did not want to answer	64.0	94.8	0.500	93.3	75.9	0.219	31.7	39.6	0.423
Social.ClassC1	0.8	52.3	0.987	-10.0	41.6	0.811	-42.2	21.7	0.052
Social.ClassC2	14.6	63.2	0.817	-43.6	50.3	0.386	-71.4	26.2	**0.007**
Social.ClassD	-125.5	71.1	0.077	-143.1	56.6	**0.012**	-71.2	29.5	**0.016**
Social.ClassE	90.9	89.8	0.311	23.9	71.6	0.739	-145.3	37.3	**0.000**
Urban...RuralCity	9.6	209.2	0.963	15.9	165.9	0.924	-22.1	86.5	0.799
Urban...RuralRural	-48.6	219.0	0.824	-20.4	173.7	0.906	7.4	90.6	0.935
Urban...RuralSemi-rural	133.7	208.9	0.522	135.0	165.7	0.415	65.5	86.4	0.449
Urban...RuralSuburban	49.0	203.8	0.810	57.4	161.6	0.722	32.1	84.3	0.703
Urban...RuralUrban	57.8	204.4	0.777	54.7	162.1	0.736	16.6	84.5	0.845
Ethnicityother	17.6	72.2	0.807	68.2	57.5	0.236	3.7	29.9	0.903
Life_stage = Older households	-319.8	55.8	**0.000**	-88.0	44.3	**0.047**	-193.8	23.3	**0.000**
Life_stage = Pre-Family	-188.3	79.2	**0.018**	-60.0	63.0	0.341	-112.0	33.0	**0.001**
RegionEast	168.8	91.5	0.065	136.4	73.1	0.062	104.3	38.0	**0.006**
RegionMidlands	73.9	84.6	0.382	109.4	67.5	0.105	97.2	35.2	**0.006**
RegionNorth	150.4	79.8	0.060	139.4	63.7	**0.029**	86.7	33.2	**0.009**
RegionScotland	110.5	95.7	0.248	157.2	76.5	**0.040**	28.7	39.9	0.472
RegionSouth	168.4	81.2	**0.038**	101.0	64.9	0.119	111.8	33.8	**0.001**
RegionWales	222.3	112.9	**0.049**	194.3	90.1	**0.031**	51.9	47.0	0.269
R^2		0.34			0.27			0.31	

Figure 6-9: Predicted mean effect of the social class of the household on the purchase of sugar from breakfast cereals



Note: Bars show the 95% confidence interval.

6.4. Discussion

This chapter showed that the reductions in the sugar density of purchases of drinks came from both supply-driven and demand-driven factors, while the reductions in the sugar density of purchases of foods came mostly from supply-driven factors.

6.4.1 The role of supply- and demand-driven effects

For both drink categories (all drinks and soft drinks) and breakfast cereals, supply-driven effects were on average and for at least 75% of households contributing to decreases in the sugar density of purchases. Supply-driven effects were reformulation and product renewal, meaning that, between 2015 and 2018, manufacturers chose to reduce the sugar density of the foods they commercialised. This change was done by reformulating products with less sugar, delisting products with high sugar and introducing products with lower sugar contents. The analyses at the population and household level showed that the average switching effect was negligible in changing the sugar density of foods purchased, i.e., in categories for which only voluntary sugar reformulation targets exist. On the other hand, the switching effect for drinks was on average negative, meaning contributing to a lowering of the sugar density of drinks purchased. It seems that the SDIL was able to incentivise household switches to drinks with lower sugar content. This result is consistent with existing research, showing that households purchased less sugar after the announcement of the SDIL (Pell et al., 2021). Given that our household-level analysis ends in 2018, we can hypothesize that this shift happened even before the changes in the price of taxed drinks. The importance of supply-driven effects compared to demand-driven effects has been found in the other studies using the decomposition approach (Griffith, O'Connell & Smith, 2017; Spiteri & Soler, 2018; Cengiz, Rojas & Wang, 2019). The study by Cengiz et al. evaluating changes in the diet quality in the US found that the improvement in the US diet came exclusively from the supply-driven effects, while consumer switches worsened the diet quality (Cengiz, Rojas & Wang, 2019). In Spiteri et al. study, the impact of consumer switches was different across categories, while the reformulation effect was always an improvement of nutrient density of products (Spiteri & Soler, 2018). Contrarily to the case of soft drink reformulation studied here, other studies using the decomposition approach focused on reformulation instances done in the absence of a tax. This may explain why they found that demand-driven changes were limited: consumers were not incentivized to change their behaviour, and reformulation was probably less advertised.

6.4.2 Differences across households

Although the average sugar density of purchases decreased for both foods and drinks, there were important variations between households. The analysis at the household level showed that the variability in the household change in the density of their purchases was similar to the variability of the switching effect. The correlation between the switching effect and the change in density of purchases for drinks and breakfast cereals was above 80%. Some demographic characteristics explained partially the type of switches done. Social class was associated with the value of the switching effect for all drinks. We found that households with a lower SES were more likely to decrease the sugar density of the products they chose compared to households with a higher SES. Nonetheless, this effect was not observed in switches in soft drinks, suggesting a switch to non-taxed products for households with lower SES. This effect can be a result of increases in price in anticipation or after the implementation of the SDIL. The SDIL was responsible for price increases of drinks of approximately 30% (an increase of 7.5 pence/100mL) (Scarborough et al., 2020). The effect of the implementation of taxes on sugar-sweetened beverages had different effects across social groups: in Mexico, low-income groups purchased fewer drinks after the implementation of an SSB tax, but the reverse was observed in Chile (Teng et al., 2019). Using purchases from a large number of supermarkets in the UK, a study evaluated the role of reformulation and change in consumer behaviour on total population purchases between 2014 and 2020. Overall, it found that 20% of the volume sold were from reformulated products (Dickson, Gehrsitz & Kemp, 2021). Authors estimated that 83% of the sugar reduction observed in brands' sales came from the reformulation of products, while only 17% came from changes in consumer behaviour (i.e., consumers switching to other brands). In comparison, we found that 30% of the decrease in sugar density of drinks purchased came from changes in consumer behaviour.

6.4.3 The role of baseline household preference for sugar

For the three categories, a higher sugar density of purchases at baseline, used to measure the sugar preference of the household, was linked to a switching effect towards products with less sugar. In the literature, the opposite relationship was observed by which a higher preference for a nutrient was linked to a lower odd of reducing one's consumption. A study on the effect of awareness of the Mexican tax on soft drinks found that people with a higher liking for soft drinks were less likely to self-report a decrease in their consumption (Álvarez-Sánchez et al., 2018). Similarly, UK individuals disliking soft drinks were more likely to perceive the SDIL as an effective policy (Adams et al., 2021). The effect observed in this study can result from the choice options available to households. As such, households purchasing products with a higher sugar density at baseline had the possibility to switch to products with less sugar as these exist in the market. In addition, maybe awareness campaigns made households with a high sugar preference realise that they were consuming lots of sugar. Similar results were found in Australia, where a campaign aiming at decreasing SSB consumption lead to reductions in SSB consumption for frequent consumers, but not occasional consumers (Morley et al., 2018).

Nonetheless, household characteristics and household habits and preferences could only partially explain the different behaviours observed across households. This finding is similar to one study on the acceptability of suggested food switches to products with lower salt, which found that the acceptability of food switches was not different by sex, age, ethnic group, BMI, education or income (Koutoukidis et al., 2019). This meant that the switching effect was mostly explained by unobserved variables. Furthermore, there was no correlation between the switching effect of drinks and of breakfast cereals. This means that it may not be adequate to design education policies for specific groups of the population, as this study failed to identify ideal target groups defined by their demographic characteristics. Switches between foods may more be determined with concerns for health than demographic characteristics. A study on food swaps aiming at lowering salt purchases found that participants who considered health as important while choosing foods, or declared using food labels had a larger reduction in sodium purchased than those who did not consider health nor use food labels while choosing foods (Payne Riches et al., 2019).

6.4.4 The homogenous effect of reformulation

Contrarily to the high variability of the switching effect denoting high variability between households' behaviours, the reformulation effects had lower variabilities: the change in sugar density from reformulation was rather homogeneous within households. A few demographic characteristics were significantly correlated with the reformulation effect. Of interest, households from lower social classes were more likely to have a reformulation effect linked to an increase in density, suggesting that the drinks they consumed were reformulated with increased sugar contents. Nonetheless, the size of the effect was small, and negligible compared to other drivers of the sign of the reformulation effect, such as the density of soft drink purchases at baseline. The fact that demographic characteristics were not meaningfully linked to the reformulation effect means that reformulation had a similar effect across all households. In other words, reformulation should not create disparities nor exacerbate existing ones. A study on total sugar purchases by UK households found no change in the disparities in sugar purchases between 2014 and 2017 (Berger et al., 2020b). During the study period, only the voluntary reformulation programme was in place, the SDIL was not yet implemented. The PHE evaluation of the first three years of the SDIL showed that similar reductions in sugar purchased from drinks happened in the different social groups (Public Health England, 2020e). This homogeneous effect of reformulation across social classes shows that reformulation is a useful policy, as it is not expected to widen existing disparities.

6.4.5 Strengths and limitations

The strength of this study is to combine a population level and a household level analysis to investigate heterogeneity across households. To our knowledge, this is the first study that investigated disaggregated decomposition and its heterogeneity across a population. In addition, we performed the population-level analysis for purchases for both at home and out-of-home consumption, to compare these two occasions when soft drinks are consumed. Also, the decomposition was applied to disaggregated products, meaning that the reformulation effect we measured come from the 'real' reformulation of individual products.

Nonetheless, this chapter uses non-probabilistic and probabilistic methods that did not allow to make causal inferences. This means that we don't know if the shifts between products and their determinants are caused by the reformulation of products or the implementation of the SDIL. In addition, we don't know if the reformulation observed was an effect of the different policies (i.e., the sugar reduction programme and the SDIL), or if it would have happened in the absence of them.

This study also has limitations linked to the type of data used: household-level data. First, the household-level analysis does not capture purchases made out-of-home. It fails to capture the entirety of choices for beverages that a household can make. Second, the reduction in the sugar density of purchases of soft drinks observed in a majority of households could hide different behaviours across household members. But the aggregation of purchases at the level of a household prevents us to study individual behaviours. Especially, we cannot differentiate the behaviours of children from the ones of adults. Third, the different survey methods used for the at-home and out-of-home purchase collection make them difficult to compare.

Lastly, contrarily to the decomposition analysis done in Chapter 5, the decomposition done at the household level does not cover all food categories. Instead, we focused on understanding the behaviours in two food and drink categories. It means that we can't assess if compensation across categories happened. However, this hypothesis is limited by the fact that in the population-level analysis, we observed a decrease in the sugar density of all products purchased.

6.5. Conclusions

In this chapter, we found that the small reduction in the sugar density of foods purchased was coming from supply-driven effects only (reformulation and product renewal), while the larger reduction in the sugar density of drinks purchased came from both changes in supply and demand. It appeared that the taxation of sugar-sweetened beverages created at the same time a stronger incentive to reformulate and pushed consumers to change their purchase habits towards lower sugar products.

Switches to lower sugar products happened in the context of the SDIL, but not in the absence of such incentive. Switches between products were heterogeneous across households, but this heterogeneity was not determined by the demographic characteristics of households.

The reformulation that happened in both foods and drinks had a homogenous effect across households, making reformulation a policy that should not widen disparities

7. CHAPTER 7: CONSUMER RESPONSE TO THE REFORMULATION OF DRINKS

In this chapter, I aim at answering the fifth objective of this thesis: to understand how consumer respond when they are facing reformulated products. We used the example of soft drinks reformulation triggered by the SDIL, as discussed in Chapter 6. In Chapter 6, we found that the reformulation of soft drinks had favourable consequences on population- and household-level sugar density of drink purchases. Nonetheless, there were disparities between households, that could not be explained by demographic characteristics. This chapters investigates if prior purchase of reformulated products has a role in consumer response to the reformulation of soft drinks.

7.1. Introduction

7.1.1 Sugar intake and consumption of soft drinks in the UK

The majority of the UK population is having a too high sugar intake. The average intake has been estimated three times higher than the WHO recommendation in children and teenagers, and twice higher for adults (Public Health England, 2015). One major contributor to sugar intake is soft drinks. The consumption of soft drinks is widespread across UK households. Over a period covering two years (from January 2012 to December 2013), 69% of households purchased low/no sugar soft drinks (with a sugar content <5g/100ml) while 49% purchased high-sugar soft drinks (Smith et al., 2018b). Using consumption data from the NDNS, it was estimated that on average, a UK adult consumed 123mL of sugar-sweetened soft drink per day (Briggs et al., 2013). This represented an average energy intake from soft drinks of 50kcal per day for adults (Briggs et al., 2013).

Furthermore, the consumption of soft drinks shows disparities across income groups, with individuals from lower-income groups consuming more soft drinks than individuals from higher-income groups (Public Health England, 2015). Using household purchases from Kantar data (in 2012-2013), Smith et al. (2018) found that low-income households purchased more sugar from sugar-sweetened beverages than middle or high-income households (Smith et al., 2018b). The share of food expenditure for soft drinks was also higher for low-income households compared with high-income households. High-income households purchased more alternative to soft drinks such as fruit juices and milk-based beverages (Smith et al., 2018b). Results from the NDNS were similar, with high-income households having a higher consumption of milk, fruit juices, and tea and coffee than low- and mid-income households) (Briggs et al., 2013).

The consumption of sugar-sweetened beverages is not recommended as they are energy-rich and nutrient-poor, meaning that they are a source of energy without being a balanced source of macro-nutrients. That is a reason why several governments implemented taxes on soft drinks. The UK implemented in 2018 a tax on sugar-sweetened beverages, described in the previous chapter (see section 6.1).

7.1.2 Trends in the purchase and intake of drinks, before the implementation of the tax

Volumes of all soft drinks sold increased between 2008 and 2014. Even accounting for the growth of the UK population, this represented an increase in the volume of soft drinks sold per person between 2008 and 2011, followed by a stabilization until 2014 (The British Soft Drinks Association, 2015).

Before the announcement of the SDIL, different time-trends in purchase existed across the different soft drinks categories. Volumes of drinks with high sugar content (i.e. subject to the higher levy) were declining (Pell et al., 2020). Conversely, volumes of drinks with a medium level of sugar (i.e., subject to the lower levy) and volumes of drinks with low sugar (i.e., not subject to the levy) were increasing. Trends from the NDNS survey showed a decrease in the percentage of consumers of sugar-sweetened soft drinks between 2008 and 2017, for children, adolescents and adults (Public Health England & Food Standards Agency, 2019).

7.1.3 Literature on the effects of the SDIL announcement and implementation

Despite being young, the literature on the impact of the SDIL on the UK population is quite rich.

First, the SDIL announcement was correlated with a change in the type of drinks available in supermarkets (Scarborough et al., 2020). The number of products eligible for the highest tax tier (>8g of sugar /100mL) decreased between 2015 and 2019. This number decreased slowly after the announcement of the tax, but the decrease accelerated three months before the implementation of the tax. After the implementation of the tax, the number of high-sugar soft drinks continued to slowly decrease (Scarborough et al., 2020). The price of SDIL-eligible drinks also changed, although the pass rate was different across brands. The average pass-through rate of the tax was 31%, but with great variations from branded products (49% pass rate) and own-brand products (-260% pass rate) (Scarborough et al., 2020). There was a small decrease in the price (per volume) of drinks within the low threshold of the tax. Products not taxed had their price increasing slightly (Scarborough et al., 2020).

In addition, the SDIL was shown to have reduced the average sugar content of purchases of sugar-sweetened drinks. A study found a 34% decrease in the sales-adjusted mean sugar content of soft drinks sold between 2015 and 2018 (Bandy et al., 2020). Between 2015 and 2019, PHE found that the sugar content of soft drinks sold by retailers (weighted by sales) decreased by 43.7% (Public Health England, 2020e). In the meantime, the (non-weighted) mean sugar content of drinks from the out of home sector decreased by 38.5%. Chapter 6 showed that this decrease came both from the reformulation of drinks, and switches towards lower-sugar drinks. Changes in consumer behaviours accounted for 30% of the decrease in sugar density of purchases. A study on purchases from one retailer in the UK also found that both reformulation and changes in behaviour contributed to decreasing sugar purchases, although changes in consumer behaviour accounted for 17% of the decrease in sugar purchases (Dickson, Gehrsitz & Kemp, 2021). Nonetheless, no study was published on the determinants of the changes in consumer choice towards soft drinks. Chapter 6 explored the reasons for the switches between soft drinks observed but found no explanation in the demographic characteristics of households.

7.1.4 Aim of this chapter

In this chapter, we wanted to investigate in more detail who is benefitting from the SDIL, and from the reformulation linked to it. In particular, we wanted to investigate if households' preferences for certain types of drinks influenced their responses to the reformulation of drinks they used to purchase. The research questions were the following:

- ➔ Does reformulation impact consumers of reformulated drinks differently from the general population?
- ➔ What is reformulated drink consumers' response to reformulation?
    - o RQ1: Have consumers of reformulated drinks changed their drink purchase pattern?
    - o RQ2: Have consumer responses offset the sugar reductions from reformulation?

7.2. Methods

7.2.1 The Kantar panel dataset used in this chapter

The Kantar panel dataset was used in to study consumer reaction to the reformulation of soft drinks as it is longitudinal and provides data at the branded product level.

Household purchase data was obtained from the UK Kantar panel. The panel collects the purchases of around 30'000 households in the UK. The panel is longitudinal with a retention rate of about 85% per year. Household purchases are recorded by the main shopper, scanning the receipts of all purchases done for consumption at home for the household. Information about household demographic characteristics and composition is obtained through a yearly survey answered by the household main shopper. The Kantar panel is representative of the UK population and allows to study subgroups of the population (stratified by demographic or socio-economic characteristics).

The fact that the panel is a longitudinal panel allows to study the same individuals over time. As such, changes in their consumption are assumed to be evaluated with limited endogeneity as within-household changes are the main outcome studied. In addition, having purchase and nutrition information at the level of branded products allowed us to study reformulation and changes in behaviour at a detailed level.

7.2.2 Data and selection of valid households:

Data used in this study are purchases of non-alcoholic drinks from 2015, 2017 and 2018. Households were included in the analysis if they purchased drinks on more than 10 occasions per quarter, and at least during two quarters of 2015, 2017 and 2018. As the aim of this study was to evaluate the responses to the reformulation of initially sugar-containing drinks, households purchasing only sugar-free drinks in 2015 were excluded.

Information on food products was also provided by Kantar. Product information included its package size and format, the price paid by the household for each purchase occasion, and nutrition information. The nutrition label of each product (identified by Kantar through its barcode) is collected regularly by field workers and linked to the products recorded by households. Label information is updated at least every year.

7.2.3 Data preparation: linkage of products over the years

Purchases are detailed at the product level. Products were identified with their barcode. A barcode corresponds to a product in a specific pack size and format. This creates two challenges to assess the reformulation of food products. First, reformulation can be done together with a change in the packaging (e.g., adding a "new" claim or changing pack size) and can result in a change in barcode. Second, we thought that the impact of the reformulation of a specific product should be assessed regardless of consumer choice of pack size. We were interested in understanding how the purchase of this specific drink changed, considering all pack sizes together. For example, we wanted to evaluate the volume and sugar from a specific cola purchased, regardless of whether the household purchased cans or bottles. To do so, we first grouped the same products across the different pack types and sizes the product is sold into. For example, if a household purchased during a week two 1L bottles of a branded cola, and six 330mL can of the same branded cola, we created the purchase of 3.98L of this branded cola. Then, we matched products across the years (2015, 2017 and 2018) using product description (after having removed information on packaging) and characteristics such as brand or category (the same grouping was done in Chapter 6).

7.2.4 Definition of drinks, sugary drinks, and reformulated drinks

The focus of this study is the purchase of drinks, and the sugar purchased from these products (definitions in Text box 1). As such, we did not limit our study to sugar-sweetened beverages, or soft drinks. The drinks we analysed were products eligible to the SDIL, as well as non-eligible products, including water. The choice of studying the total volume, and most importantly sugar for all drinks, was driven by the fact that we wanted to evaluate shifts in the purchase of all drinks, including possible shifts to non-eligible products.

Sugary drinks were defined as drinks containing more than 1g of sugar per 100mL (definitions in Text box 1). Sugary drinks can contain naturally occurring sugar such as fructose in 100% juices, lactose in milk-based beverages, or sugar used as a sweetener. We constructed the variable controlling for the total volume of sugary drinks purchased to estimate household preference for sugary drinks, across sources of sugar.

Reformulated drinks were identified across all drinks (eligible or not to the SDIL). The reformulation of a drink was identified using the average sugar content of drinks in 2015 and 2018. A drink was considered reformulated if either it crossed the SDIL thresholds in the study period (2015-2018), or if it had its sugar content decreased by 5%. This definition allowed us to identify both drinks that were substantially reformulated and drinks that were reformulated by a small amount but to change their SDIL category. The 5% threshold was chosen after analysing the distribution of the reformulation magnitude across all products. The 25th percentile was a 4% decrease in sugar content, meaning that three-quarters of reformulation done was by more than 4%. The 5% threshold was chosen to match the estimation of the “worse case scenario” reformulation used in the paper by Briggs and colleagues to estimate the health impact of the SDIL (Briggs et al., 2017).

Text box 1: Definition of drinks, sugar drinks and reformulated drinks used in this chapter

Drinks: all non-alcoholic drinks purchased by households. Contains both eligible and non-eligible drinks to the SDIL **Sugary drinks**: drink containing sugar (defined as >1g/100mL). All types of sugar are accounted for in this definition **Reformulated drinks**: drink which sugar content decreased by at least 5% between 2015 and 2018 (see explanation in section 7.2.4), or which sugar content crossed the SDIL thresholds (5g/100mL and 8g/100mL) **Individual drinks**: drinks considered at the detailed level, as defined in section 7.1.2. These are drinks having the same manufacturer, brand name, and product name, but grouped across the different pack size they are sold into.

7.2.5 Definition of household preferences

Household preferences were estimated and accounted for in both studies analysing the change in the purchase of individual drink products and the change in the total purchase of drinks. Household preference for sugary drinks, for drinks with high sugar density, for reformulated drinks and price preference were estimated.

Household preference for sugary drinks was estimated with the baseline (2015) volume of sugary drinks purchased by the household, per adult equivalent.

The household preference for sugar intensity of drinks was estimated using the volume-weighted average sugar density of purchases at baseline. Household preference for sweetness (including sweetness obtained from non-nutritive sweeteners) was not possible to assess because the sweetness of drinks is not labelled, and it's not possible to estimate it.

The household preference for reformulated drinks was estimated using the proportion of drinks purchased at baseline that were reformulated between baseline and follow-up. We used the proportion (in volume) and not the volume purchased to account for the relative preference of households for reformulated drinks.

Similarly, household preference for drinks that were delisted was calculated using the percentage of household purchases in 2015 from products that were later delisted.

Finally, the price preference of households was estimated at baseline using the average price paid per litre of drinks purchased in 2015. The price paid includes possible promotions applied on drink products in-store or by the manufacturer (such as 6+2 cans).

7.2.6 Analyses at the household and product level

First, we performed analyses at the level of household and product purchased to understand how consumer preference for individual products changed between 2015 and 2018. The aim of these analyses was to understand how the announcement and implementation of the SDIL and the reformulations done in this context influenced household choice of individual drinks. In particular, we were interested in understanding if different choices were made towards reformulated *versus* unchanged drinks.

(1) Outcome variables

To analyse changes in household choice, we focused on estimating the change in volume and sugar purchased from individual drinks. Household purchases were calculated as purchases per male-adult-equivalent (called adult equivalent in the rest of the chapter). This allowed us to get a measure of purchase per individual. The equalizing index, to calculate the number of adult male equivalents in the household, was obtained using the sum of the dietary requirements of the household members in 2015. Dietary requirements from the SACN were used (Scientific Advisory Committee on Nutrition, 2011). The age and sex of household members were used to estimate their energy average requirement. Reference values were used with 1-year intervals for children until 18 years, and the average value for adult males and adult females were used. The sum of the energy requirements of all household members was divided by 2605kcal, the estimated average requirement for a male adult.

(2) Statistics

The following equation was estimated to explain the change in volume or sugar purchased from individual drinks, per household:

Equation 7-1: Model of the change in volume or sugar purchased per product and household

$$\begin{aligned}\Delta Q_{j,h} = \beta_0 + \beta_1 Status_j + \beta_2 \%\, reformulated_h + \beta_3 Status_j * \%\, reformulated_h \\ + \beta_4 Volume\ sugary\ drinks_h \quad + \beta_5 sugar\ density_h + \beta_6 price\ preference_h \\ + \beta_x X_{h,2015} + \varepsilon_{h,j}\end{aligned}$$

$\Delta Q_{h,j}$ is the change between 2015 and 2018 in the sugar or volume purchased of product j, for one adult equivalent in household h. $\%\ reformulated_h$ is the proportion of reformulated products purchased in 2015 by the household. $Volume\ sugary\ drinks_h$ is the equivalised volume of sugary drinks purchased by the household at baseline. $sugar\ density_h$ is the average sugar density of purchases at baseline, and $price\ preference_h$ is the average price per litre of drink paid by households in 2015. More details on the definition of these variables are in section 7.2.5.

$X_{h,2015}$ is a vector of household characteristics at baseline. This includes the Herfindahl-Hirschman index (HHI) of the household, a marker of the diversity of drinks purchased. This marker was used to control for household loyalty for a product. The HHI is calculated as $HHI_h = \sum_i S_{h,i}$ with $S_{h,i}$the share of product *i* for household *h,* calculated as the share of total weight of drinks purchased by the household coming from product *i*.

Other demographic characteristics included are household size, household income, social class, region, rurality of the household, ethnicity, and life stage of the household.

(3) Estimation method

The data present a repeated structure: households purchase different products, and products are purchased by different households. Lemmerrer demonstrated that consumer purchases should be estimated using a cross-category random-effects model (Lemmerer, 2016). Nesting products within households or the reverse would result in biased estimates of the variance of random effects. Following Lemmerrer advice, we applied these crossed random effects for household clustering and product clustering.

We also estimated the models using OLS, as we found that the household and product cross-clustering defined above left most of the variance unexplained. This unexplained variance can be explained by the fact that we estimated change in purchase patterns, and not the choice of a product (in volume or number of products) purchased at two time points.

7.2.7 Analyses at the household-level

Secondly, we analysed changes in the volume and sugar from drinks purchased across all drinks purchased by a household. The aim of this analysis was to investigate if there were compensation between products, and how the household preference for reformulated drinks impacted changes in volume or sugar purchased from drinks.

(1) Outcome variables

Outcome variables were the change in the total volume of drinks purchased, in the average sugar density and in the total quantity of sugar purchased from all drinks by each household between 2015 and 2018. Purchase by adult equivalent was calculated using the index described in section 7.2.6. This analysis was performed to evaluate the consequence of the SDIL (including the reformulation of drinks) on the total quantity of sugar purchased from all drinks. To account for possible shifts between soft drinks to fruit juices, we analyse the sugar coming from all drinks (and not only soft drinks). And to explain the observed changes in the quantity of sugar purchase, we estimated if the change came from a change in the volume of drinks purchased, and/or a change in the average sugar density of drinks purchased.

(2) Statistical analysis

Equation 7-2: Model of the change in volume, sugar density, or sugar quantity purchased from *all* drinks per household (as a change per adult-equivalent)

$$\Delta Q_h = \beta_0 + \beta_2 \%\,reformulated_h + \beta_3 \%\,delisted_h + \beta_4 Volume\ sugary\ drinks_h + \beta_5 sugar\ density_h + \beta_6 price\ preference_h + \beta_x X_{h,2015} + \varepsilon_h$$

ΔQ_h is the change in sugar, volume (both per adult equivalent), or sugar density from all drinks purchased by the household between 2015 and 2018. $\%reformulated_h$ is the proportion of reformulated products purchased in 2015 by the household, $\%delisted_h$ is the proportion of products purchased at baseline that were later delisted. $Volume\ sugary\ drinks_h$ is the volume of sugary drinks purchased per adult equivalent in the household at baseline. $X_{h,2015}$ is a vector of household characteristics at baseline (same vector as in section 7.2.6(2)).

This regression was estimated using OLS. Survey weights were not used in this regression as the regression estimate correlations between the outcome variable and explanatory variables. Here, the outcome variable was a change in household purchases, meaning that the purchase of the same household is compared at two time points.

Nonetheless, survey weights were used in descriptions of the population studied.

7.3. Results

7.3.1 Reformulation of drinks

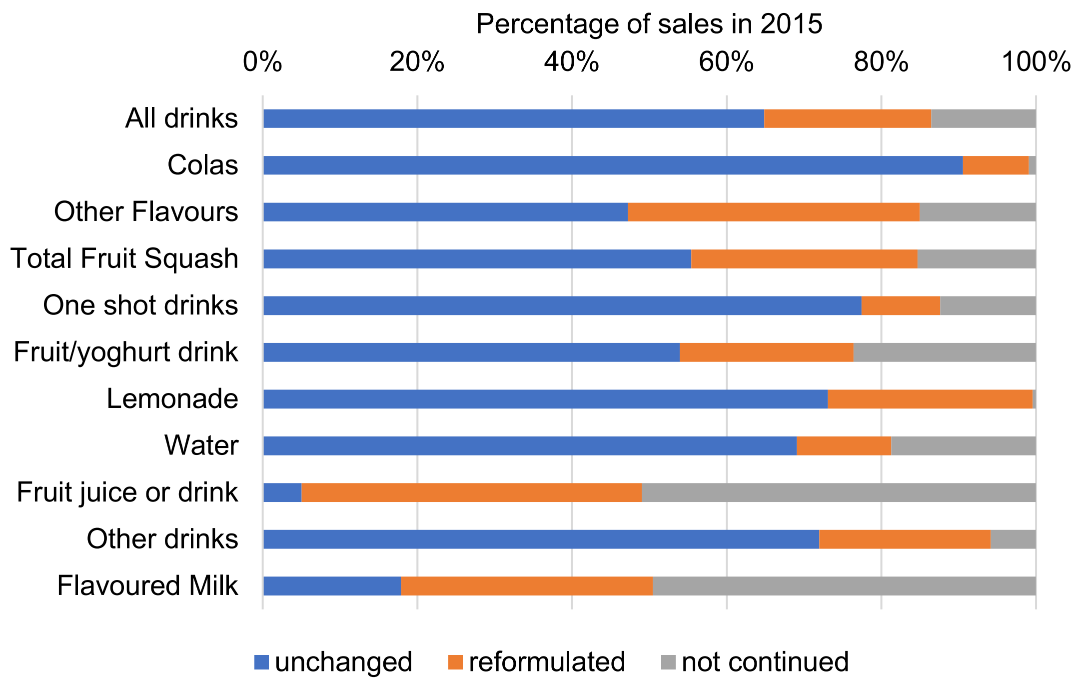
Between 2015 and 2018, we found that 740 drinks in the market in 2015 or 2018 were reformulated (Table 7-1). They represented 30% of drinks present in 2015 and 2018 (i.e., unchanged or reformulated). There were reformulated drinks in all categories of drinks.

Table 7-1: Baseline sales of drinks by type of drink, and number of products by status (unchanged, reformulated, not continued, or new)

	Total baseline sales (millions of litres)	Number of products (2015 or 2018)	Drinks in 2015 and 2018		Drinks in 2015 only	Drinks in 2018 only
			unchanged	reformulated	not continued	new
All drinks	**3912**	**7473**	**1787**	**740**	**2551**	**2395**
Colas	1094	156	57	22	34	43
Other Flavours	612	1621	339	208	532	542
Fruit Squash	403	653	187	123	202	141
One shot drinks	398	1720	453	102	629	536
Fruit/yoghurt drink	332	977	271	84	361	261
Lemonade	310	115	46	24	21	24
Water	304	657	189	38	172	258
Fruit juice or drink	280	750	54	72	340	284
Other drinks	119	305	141	27	60	119
Flavoured Milk	60	477	50	40	200	187

Drinks that were later reformulated represented 22% of total sales in 2015 (Figure 7-1). But they did not represent the same proportion of sales across drink types. Only 9% of the 2015 sales of Colas were later reformulated, while it was 38% for other flavours of soft drinks (Figure 7-1). Despite having a proportion of products excluded from the SDIL, there were important reformulation rates in fruit juices and drinks (including 100% fruit juices) and milk-based beverages (some of which were not eligible to the SDIL as contained more than 80% of milk).

Figure 7-1: Percentage of sales for unchanged, reformulated and not continued products, by drink type. Drink types are in descending order of total sales in 2015.



7.3.2 Descriptive statistics by type of products

In 2015, unchanged drinks were purchased in larger quantities than reformulated drinks (Table 7-2). But there were larger quantities of sugar purchased from reformulated drinks than from unchanged drinks. Unadjusted statistics show that while the purchase of reformulated products by households increased from 2015 to 2018 (by 0.03L per adult equivalent in the household in a year) the purchase of unchanged products decreased (by 0.08L per AE in the household in a year). There was a larger reduction in sugar purchased from reformulated drinks than from unchanged drinks. The average price paid by households for reformulated and unchanged drinks remained essentially stable (changes in price paid of -2% and +3%, respectively).

Discontinued products were purchased in rather large quantities and provided important quantities of sugar in 2015.

Table 7-2: Descriptive statistics on the change in the purchase of individual drinks between 2015 and 2018, by type of drink.

	Reformulated	Unchanged	New	Not continued	p (ANOVA)
N (products*households)	194,734	523,919	134,751	112,419	
% sugar change	-44.95 (36.94)	1.25 (20.91)	NA	NA	<0.001
Average volume of individual drink purchased in 2015 (in L/HH in 2015)	2.84 (11.25)	5.39 (22.70)	NA	4.10 (12.52)	<0.001
Change in volume purchased (L/AE in the HH)	0.03 (6.31)	-0.08 (11.70)	1.97 (6.91)	-1.86 (6.04)	<0.001
Quantity of sugar purchased in 2015 from individual drinks (g/HH)	180.10 (830.69)	169.91 (1,021.85)	NA	243.76 (808.07)	<0.001
Change in sugar purchased (g/AE in the HH)	-24.08 (414.98)	-16.51 (465.96)	63.81 (249.64)	-109.14 (406.09)	<0.001
Change in price (£/L)	-0.03 (0.25)	0.03 (0.39)	NA	NA	<0.001

Notes: Data show means (SE). AE: adult equivalent; HH: household; NA: not applicable (for example, new products are not defined in 2015).

7.3.3 Purchase patterns of individual drinks, by their status

Adjusted analyses were performed to analyse the effect of the different determinants of the purchase of individual drinks. Hierarchical random-effect models were not efficient in explaining our data: the intra-class correlation was low (0.008). Neither the clustering at the product level nor the clustering at the household level was able to explain the variation between purchases (table of variance for the random-effects models in Appendix Table xix). As these hierarchical models were not able to explain our data, we used OLS instead (results of the regression estimated with OLS in Appendix Table xx).

We predicted the change in volume and sugar purchased for unchanged, reformulated, new, and delisted drinks (using marginal effects at the mean of other predictive variables). There were small increases in the volume purchased of reformulated drinks between 2015 and

2018 (average increase of 0.06L per adult equivalent during the year in households), while the volume of unchanged drinks purchased per household did not change (Figure 7-2).

The sugar quantity purchased per household decreased for both reformulated and unchanged products (Figure 7-3), but the decrease was larger for reformulated drinks.

Expectedly, the marginal effect for new products was an increase in volume and sugar, while the effect for delisted products was a decrease in volume and sugar (Figure 7-2 and Figure 7-3).

Figure 7-2: Predicted change for an average household (i.e., marginal effect), between 2015 and 2018, in volume of individual drinks purchased per adult equivalent in households during a year by type of drink.

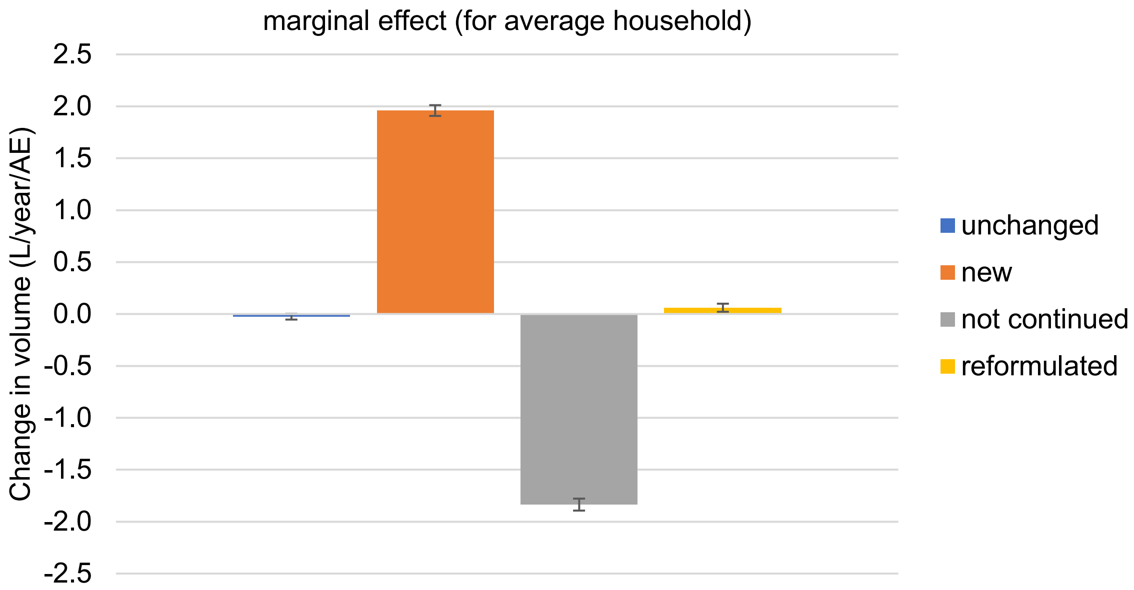
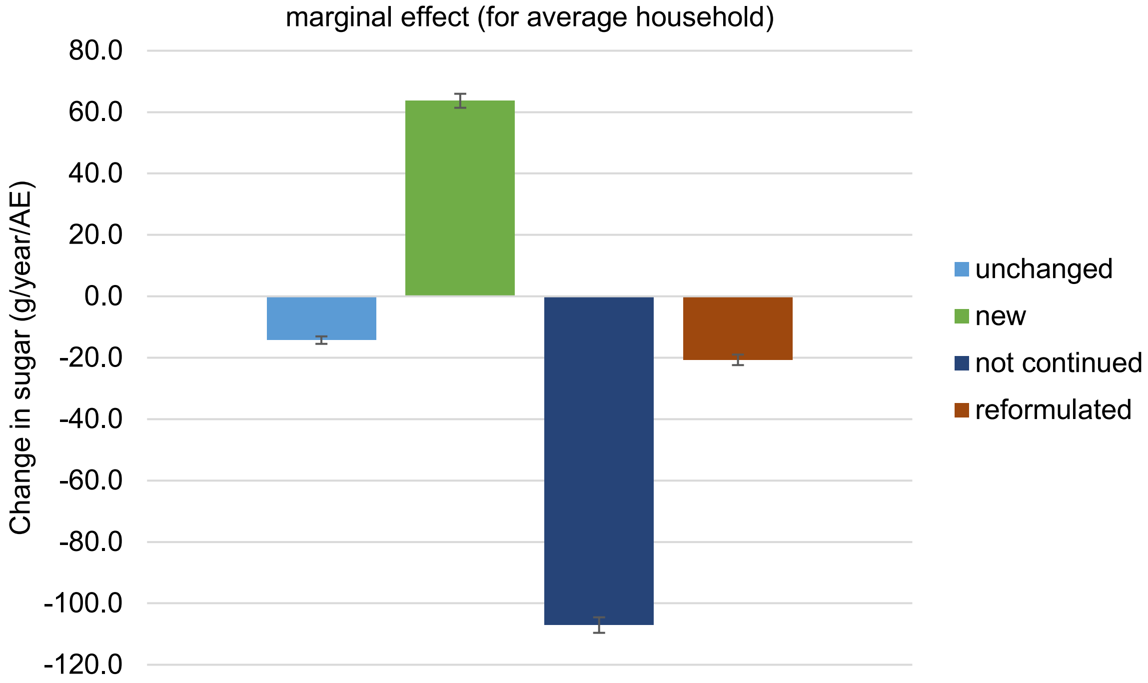


Figure 7-3: Predicted change for an average household (i.e., marginal effect), between 2015 and 2018, in sugar purchased from individual drinks per adult equivalent (AE) in households during a year by type of drink.



Despite being purchased in larger quantities, reformulated drinks provided smaller quantities of sugar in 2018 than in 2015.

7.3.4 Different responses by type of consumer

The results of the adjusted regression using Equation 7-1 showed that low consumers of reformulated drinks purchased the same volume of individual drinks in 2018 and 2015 (Table 7-3, full regression estimates in Appendix Table xx). On the other hand, high consumers of reformulated drinks purchased a higher volume of individual drink products in 2018 than in 2015. The increase was of 0.31L (SE=0.05L) over the year per adult equivalent in households purchasing 95% of reformulated products in 2015 (Table 7-3). While the purchase of sugar from individual drinks decreased in low consumers of reformulated drinks (by 20.4g in a year, Table 7-3), it did not change for high consumers.

Table 7-3: Estimated effects for the change in volume and sugar purchased between 2015 and 2018 from individual drink products per adult equivalent, by the proportion of reformulated products purchased at baseline

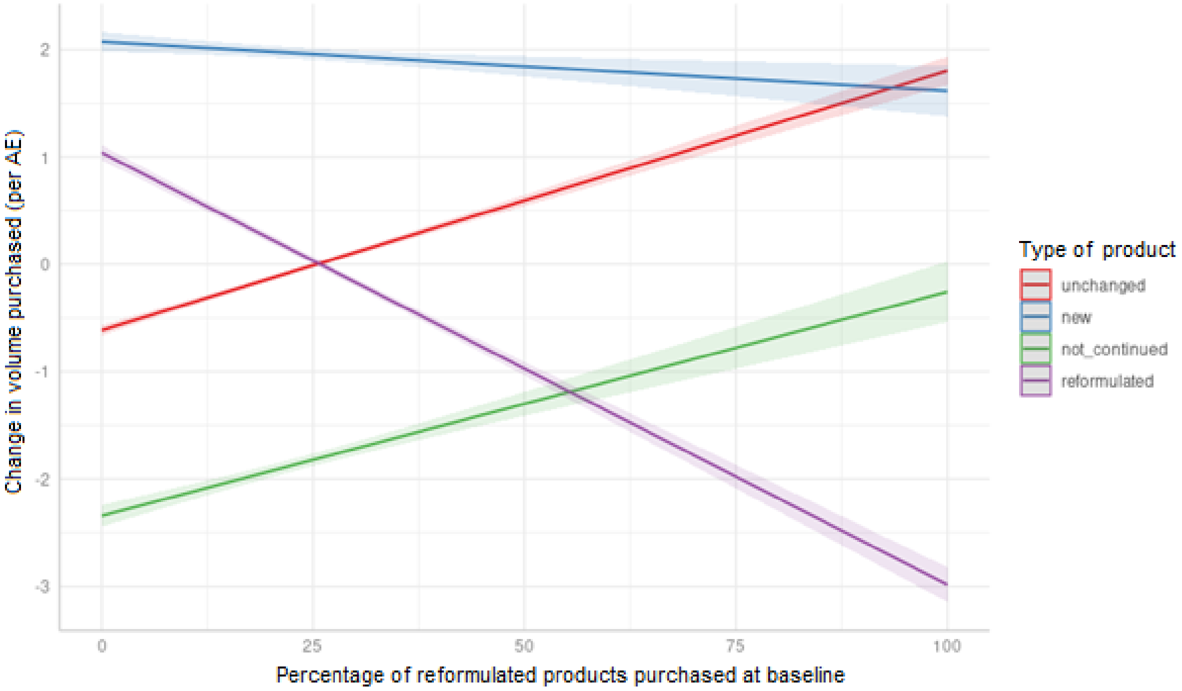
		Estimated effect for change in volume purchased (L/year/adult equivalent)		Estimated effect for change in sugar purchased (g/year/adult equivalent)	
		predicted	SE	predicted	SE
% of reformulated drinks purchased in 2015	**0**	-0.02	0.02	-19.9	0.8
	25	0.07	0.01	-15.7	0.4
	50	0.15	0.02	-11.4	0.8
	75	0.23	0.03	-7.1	1.4
	100	0.31	0.05	-2.8	2.1

The interaction between the consumption of reformulated products at baseline and the type of product purchased allowed us to investigate whether high and low consumers of reformulated products differed in the way they adapted their drink purchases following reformulation.

The absence of change in the volume of individual drinks purchased by low consumers of reformulated drinks was explained by a balance between an increased purchase of reformulated and new drinks and decreased purchase of unchanged and delisted products (Figure 7-4).

High consumers of reformulated drinks purchased in 2018 a smaller volume of reformulated drinks than in 2015. Compared to low consumers of reformulated drinks, high consumers reduced marginally their purchase of discontinued drinks (probably meaning that the volume purchased at baseline was low in this group). On the other hand, high consumers of reformulated drinks increased their purchase of new and unchanged products (Figure 7-4).

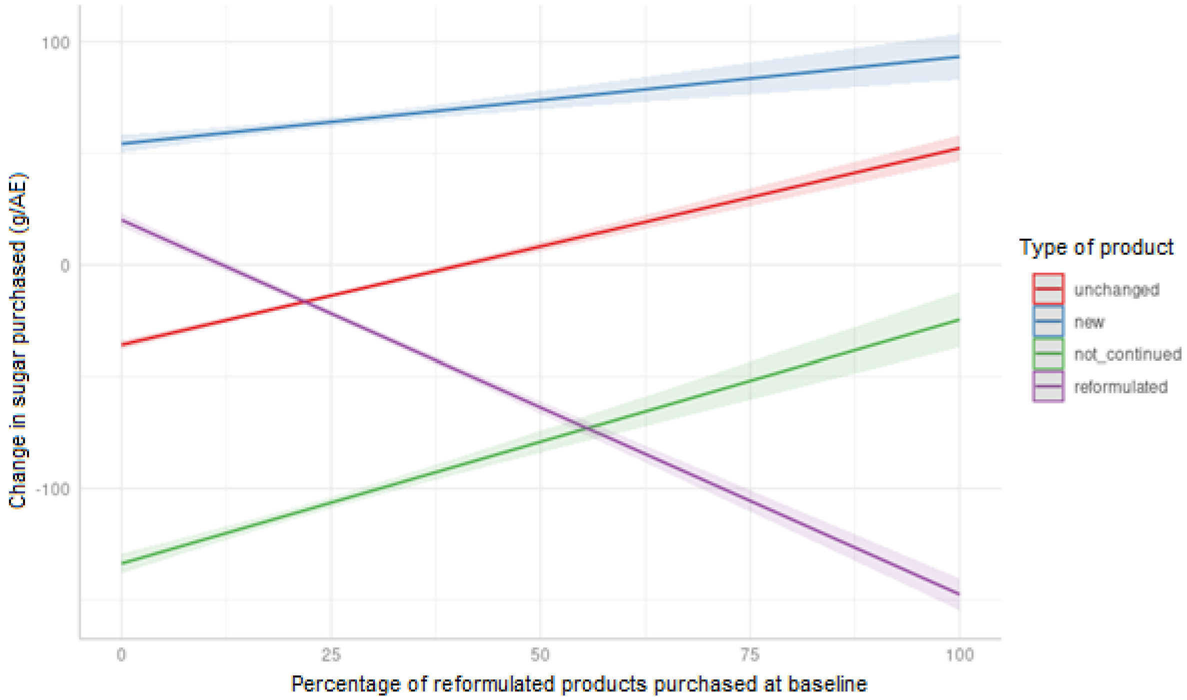
Figure 7-4: Predicted change in volume purchased of individual drinks by consumer type (defined with the percentage of reformulated products purchased at baseline)



Notes: Changes in volume purchased are in L per adult equivalent (AE).

The decrease in sugar purchased by low consumers of reformulated drinks was explained by an important reduction of sugar purchased from delisted and to a lesser extent unchanged products. Increases in the purchase of sugar from new and reformulated products were smaller in absolute values (Figure 7-5). Compared to low consumers, high consumers of reformulated drinks purchased more sugar from new products.

Figure 7-5: Predicted change in sugar purchased of individual drinks by consumer type (defined with the percentage of reformulated products purchased at baseline)



Notes: Changes in sugar purchased are in g per adult equivalent (AE).

These estimates informed us about consumer choices for individual products. We saw that heavy consumers of reformulated products increased their purchase of individual products, resulting in the absence of a decrease in sugar quantity purchased from these products. In addition, despite purchasing smaller quantities of individual new products than low consumers, they derived more sugar from these products. But this study did not inform about the total purchase of drinks, across different brands. To understand if heavy consumers of reformulated drinks responded to reformulation, we studied total purchases by households.

7.3.5 Description of households at baseline, and unadjusted statistics

17337 households were present in the panel in 2015 and 2018 and fulfilled the inclusion criteria in our study. The full sample that is representative of the UK population differed from the selected sample used in the analyses, as the analyses focused on households purchasing sugar-sweetened soft drinks at baseline (Appendix Table xviii). The selected sample contained a higher proportion of 2-members households and a lower proportion of single households. Also, the age of the head of the household was higher in the selected sample than in the original database.

Unadjusted analysis showed that while the total volume of drinks purchased by households in 2015 and 2018 was similar (a significant increase of 2L in a year representing a 2%

increase), the volume of sugary drinks decreased by 12% (Table 7-4). The sugar density of purchases decreased (by 1g/100mL), associated with a decrease in the total quantity of sugar purchased from drinks (by 1kg/adult equivalent per household and in a year). Reformulated products were purchased by most households (97%, data not shown). On average, 25% of products purchased in 2015 were later reformulated (in volume) (Table 7-4).

Table 7-4: Descriptive statistics of the change in the household purchase of soft drinks between 2015 and 2018. Statistics (means (SD)) calculated using survey weights.

	2015	2018	p[1]
N households	17337	17337	
Volume of drinks purchased (L/year/AE)	98.19 (98.28)	100.30 (103.60)	0.002
Volume of *sugary* drinks (L/year/AE)	41.94 (47.99)	36.72 (44.89)	<0.001
Sugar density (g/100mL)	4.47 (3.04)	3.42 (2.62)	<0.001
Quantity of sugar purchased (kg/year/AE)	3.8 (4.6)	2.8 (3.7)	<0.001
percentage of discontinued products purchased (% in volume / household)	13% (16)	NA	NA
percentage of reformulated products purchased (% in volume / household)	25% (21)	24% (20)	<0.001

[1]: p-value of t-tests comparing the distribution of 2015 from 2018 data.

NA: not applicable; AE: adult-equivalent

Purchase patterns at baseline were different across life stages and social classes (Table 7-5 and Table 7-6). Households with children purchased a smaller volume of drinks per adult equivalent, but a similar volume of sugary drinks (Table 7-5). Linked to this observation, the sugar density of the drinks they purchased was higher than the sugar density of pre-families or older households. Households with children also purchased a smaller proportion of drinks that were later reformulated than older households (Table 7-5).

Households of lower social classes purchased a higher volume of drinks and of sugary drinks than households of higher social classes (Table 7-6). Similarly, there was a trend of increasing quantities of sugar purchased from social class AB to E. While the proportion of products to be discontinued was similar across social classes, households from social class A or B purchased a higher proportion of reformulated drinks than other social classes (Table 7-6).

Table 7-5: Descriptive statistics of baseline household purchase of drinks, by life stage.

	Pre-Family	Family with children	Older households	p-value
N households (before weighting)	1640	5727	9970	
Volume of drinks purchased (L/year/AE)	114.78 (112.98)	91.29 (75.28)	97.43 (102.59)	<0.001
Volume of *sugary* drinks (L/year/AE)	45.94 (51.96)	41.79 (40.24)	41.15 (49.90)	0.011
Sugar density (g/100mL)	4.36 (3.02)	4.67 (2.90)	4.42 (3.10)	<0.001
Quantity of sugar purchased (kg/year/AE)	4,203.35 (4,983.37)	3,856.06 (3,930.67)	3,667.10 (4,711.68)	0.001
% of discontinued products purchased (% in volume / household)	13.67 (15.67)	14.55 (14.48)	12.77 (16.04)	<0.001
% of reformulated products purchased (% in volume / household)	24.24 (19.69)	23.81 (17.14)	26.13 (22.13)	<0.001

Notes: Statistics (means (SD)) calculated using survey weights. The test performed is a pairwise comparison

Table 7-6: Descriptive statistics of baseline household purchase of drinks, by social class.

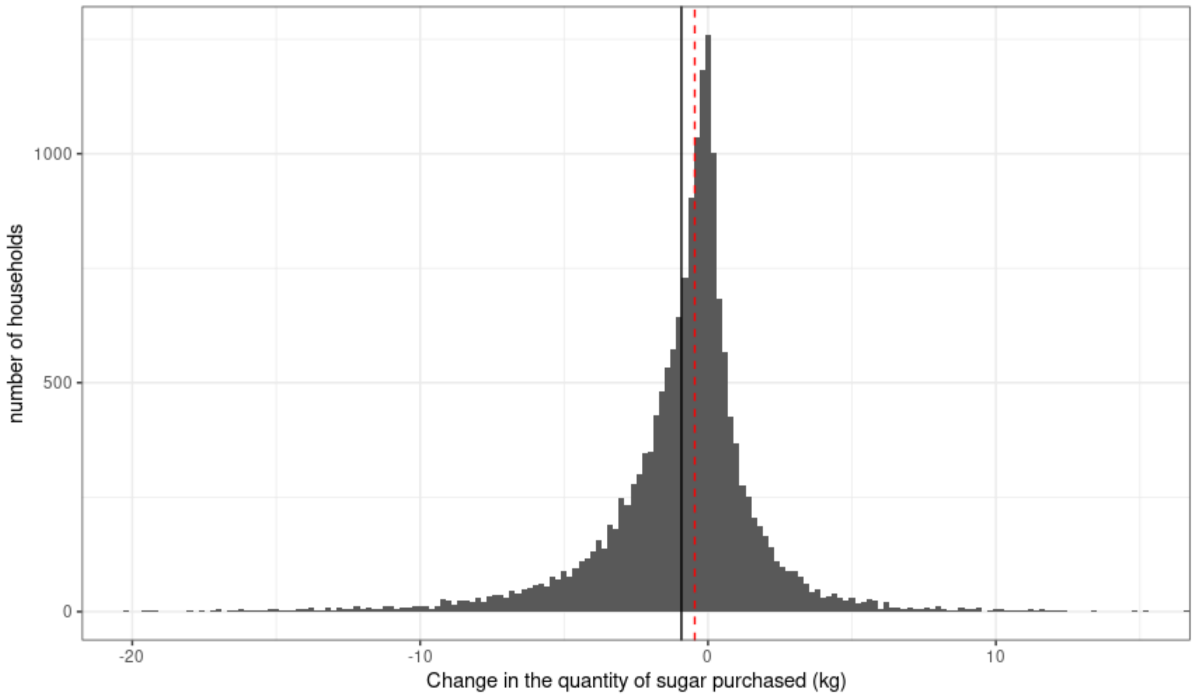
	AB	C1	C2	D	E	p-value
N households (before weighting)	3838	6746	3160	2328	1265	
Volume of drinks purchased (L/year/AE)	88.21 (83.66)	99.28 (100.24)	94.37 (89.45)	100.34 (97.63)	123.90 (132.82)	<0.001
Volume of sugary drinks (L/year/AE)	38.21 (42.24)	41.99 (47.25)	40.66 (44.28)	43.60 (49.21)	50.99 (64.50)	<0.001
Sugar density (g/100mL)	4.68 (3.21)	4.46 (3.04)	4.37 (2.87)	4.40 (2.97)	4.34 (3.05)	0.001
Quantity of sugar purchased (kg/year/AE)	3,478.70 (3,945.75)	3,766.61 (4,465.83)	3,649.98 (4,208.60)	3,946.03 (4,795.33)	4,610.02 (6,237.04)	<0.001
% of discontinued products purchased (% in volume / household)	12.85 (15.82)	13.56 (15.99)	13.37 (15.03)	13.64 (15.15)	13.32 (16.06)	0.348
% of reformulated products purchased (% in volume / household)	26.62 (21.77)	25.61 (20.85)	24.41 (19.67)	24.08 (19.43)	24.85 (21.28)	<0.001

Notes: Statistics (means (SD)) calculated using survey weights. The test performed is a pairwise comparison

7.3.1 Household's change in volume and sugar purchased from drinks

The distribution of the change in sugar purchased per adult equivalent by households showed that more than 50% of households decreased their purchase of sugar between 2015 and 2018 (Figure 7-6). The distribution was skewed to the left: households decreasing their purchase of sugar had higher decreases than the increase in purchase for households increasing their purchases. That explained why the mean change was lower than the median change.

Figure 7-6: Distribution of the change in sugar purchased between 2015 and 2018, per adult equivalent.



Note: Median is shown by the red dotted line while mean is shown by the black line.

7.3.2 Effects of being a high consumer of reformulated drinks on total purchase of soft drinks and sugar from soft drinks

When considering all drinks purchased during the year by households, we observed marginal differences for the change in volume, sugar, or sugar density of purchases between high and low consumers of reformulated drinks (Table 7-7). The difference in sugar purchased from drinks came mostly from the baseline preference for high-sugar drinks. Households purchasing products with a higher sugar density at baseline were more likely to decrease their purchase of sugar than households purchasing products of a lower sugar density (coefficient of -82.2g of sugar purchased per year per additional 1g/100mL of sugar density, Table 7-7). Also, households who purchased at baseline higher quantities of sugary drinks had higher reductions in sugar purchased than low consumers of sugary drinks (coefficient of -40.4g of sugar purchased per year per additional litre of sugary drink purchased in 2015, Table 7-7).

Table 7-7: Estimated coefficients of the regressions at household level (using Equation 7-2) estimating the change in volume, sugar, and sugar density of drink purchases between 2015 and 2018

		Change in volume (L/AE)	Change in sugar density (g/100mL)	Change in sugar (g/AE in households)
(Intercept)		23.30*** (4.07)	1.01*** (0.12)	1,313.49*** (158.18)
% reformulated		0.02 (0.03)	0.001 (0.001)	2.14** (1.03)
Volume of sugary drinks		-0.35*** (0.01)	0.0005 (0.0004)	-40.07*** (0.48)
Sugar density 2015		1.77*** (0.21)	-0.48*** (0.01)	-95.68*** (8.04)
% discontinued products		0.002 (0.03)	0.001 (0.001)	1.44 (1.34)
Average price paid in 2015		3.93*** (1.23)	0.18*** (0.04)	243.73*** (47.78)
HHI		-0.002*** (0.0003)	0.0000* (0.0000)	0.001 (0.01)
Number of people in the household		-6.06*** (0.56)	-0.03** (0.02)	-220.50*** (21.80)
Household Income	**£10,000 - £19,999 pa**	-1.35 (2.43)	-0.05 (0.07)	91.19 (94.45)
	£20,000 - £29,999 pa	-1.80 (2.54)	0.02 (0.08)	214.86** (98.55)
	£30,000 - £39,999 pa	-3.07 (2.66)	-0.10 (0.08)	4.01 (103.15)
	£40,000 - £49,999 pa	-2.31 (2.82)	-0.15* (0.08)	-12.53 (109.40)
	£50,000 - £59,999 pa	-2.96 (3.11)	-0.21** (0.09)	-126.07 (120.94)
	£60,000 - £69,999 pa	-5.42 (3.64)	-0.06 (0.11)	19.22 (141.21)
	£70,000 +	-4.77 (3.40)	-0.09 (0.10)	-33.59 (132.05)
	Did not want to answer	-2.33 (2.60)	0.01 (0.08)	86.11 (101.00)
Social Class	**C1**	1.17 (1.40)	-0.0032	22.47 (54.53)
	C2	4.52*** (1.69)	-0.21*** (0.05)	15.86 (65.67)
	D	-0.65 (1.91)	-0.26*** (0.06)	-106.92 (74.22)
	E	4.12* (2.44)	-0.24*** (0.07)	108.07 (94.91)
Urban/Rural	**Rural**	-1.81 (2.82)	0.38*** (0.08)	120.78 (109.36)
	Semi-Rural	-0.28 (2.18)	0.19*** (0.06)	204.97** (84.61)
	Suburban	-1.03 (1.77)	0.08 (0.05)	86.18 (68.69)
	Urban	2.20 (1.80)	-0.02 (0.05)	67.52 (69.71)
Ethnicity	**other (than White)**	-0.87 (1.94)	0.18*** (0.06)	-2.85 (75.27)
Life stage	**Family with children**	9.04*** (2.11)	0.10 (0.06)	322.95*** (81.86)
	Older households	-6.102	-0.04 (0.05)	-158.59** (69.93)
Region	**London**	-2.67 (2.47)	0.03 (0.07)	-128.31 (96.01)
	Midlands	2.02 (1.96)	-0.07 (0.06)	-94.94 (76.14)
	North	1.81 (1.83)	-0.005	-68.02 (70.95)
	Scotland	3.03 (2.34)	0.01 (0.07)	81.84 (90.76)
	South	0.32 (1.85)	0.06 (0.05)	-0.82 (71.67)
	Wales	6.71** (2.80)	0.03 (0.08)	142.35 (108.59)
Observations		17,337	17,337	17,337
Adjusted R^2		0.05	0.33	0.35

Notes: *p<0.1 **p<0.05; ***p<0.01

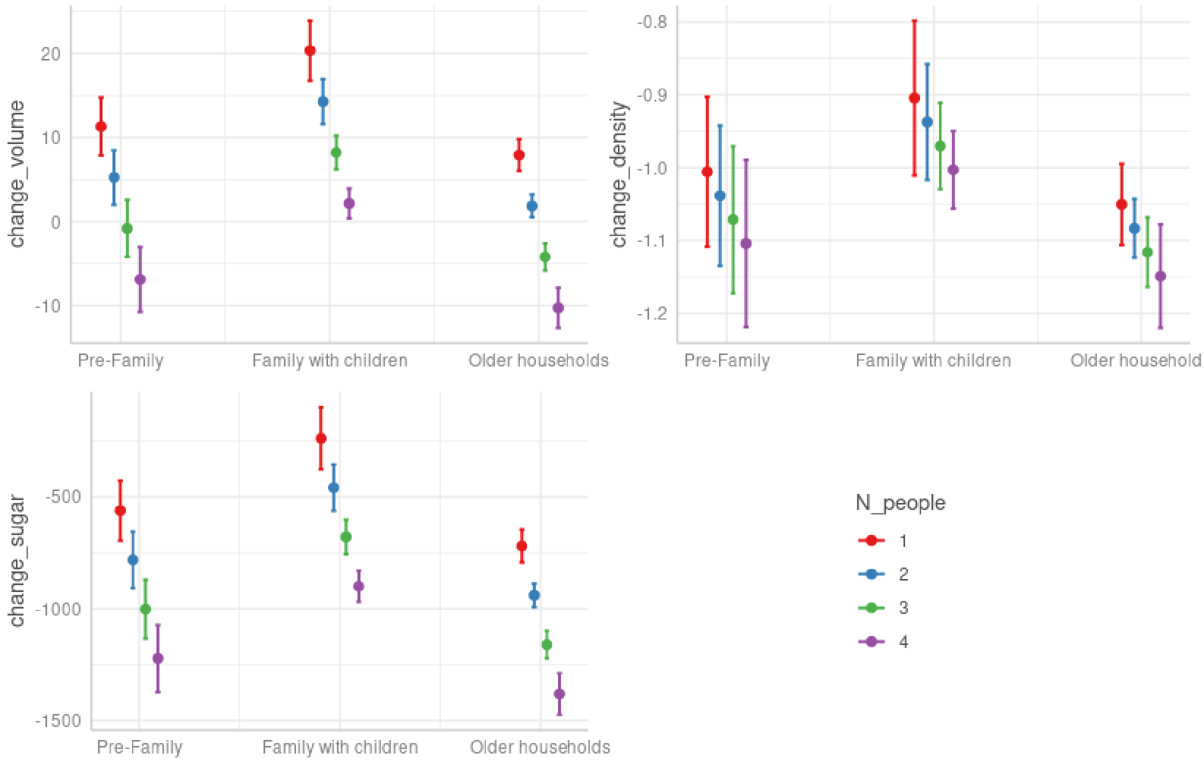
The influence of being a high or low consumer of reformulated products at baseline was small compared to the volume of sugary drinks or the sugar density of purchases at baseline (Table 7-8 and Appendix Table xxi). The difference between the 25th and the 75th percentile of consumers of reformulated drinks was 58g of sugar, while it was -440g between the 25th and 75th percentile of consumers classified with the sugar density of their purchases, and -1021 between the 25th and 75th percentile of consumers of sugary drinks at baseline (Table 7-8 and Appendix Table xxi).

Table 7-8. Estimated marginal effects in the change in sugar purchased (in g/year) from soft drinks, at the first and third quartile of consumer characteristics

	25th percentile	75th percentile	Difference as the percentage of average purchase in 2015
sugar density of purchases at baseline	-689	-1129	-12%
volume of sugary drinks purchased	208	-1429	-43%
% reformulated products purchased	-960	-902	+2%

Household characteristics also independently influenced the change in the purchase of drinks observed. Larger households purchased in 2018 a smaller volume of drinks than in 2015, compared to smaller households. Having an additional household member was linked to -6L purchased, and -220g of sugar from drink purchased (Table 7-7). Given that households with children had more people living in the households than pre-families and older households, there was no significant difference in the change in sugar density, sugar quantity or volume purchased by the different life stages (Figure 7-7).

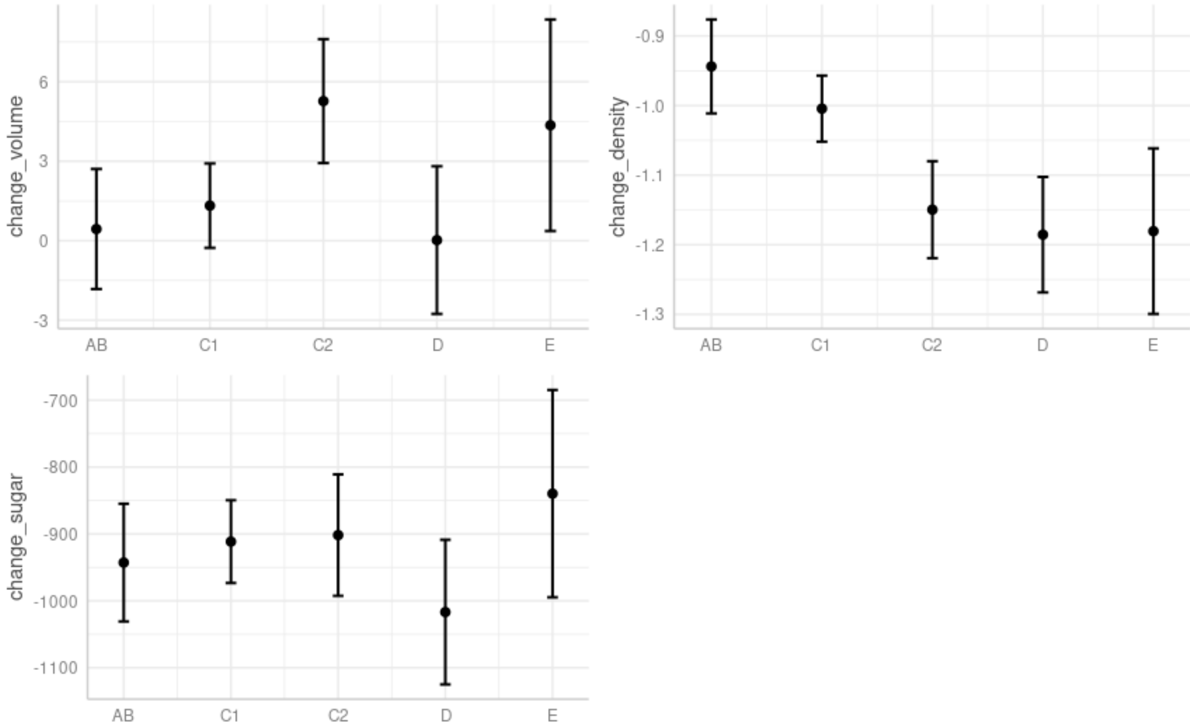
Figure 7-7: Predicted effect of life stages and number of people in the household on the change in volume, sugar density, and sugar purchased from all drinks. Changes are in L, g/100mL and g per adult equivalent per household over a year.



Notes: Change in volume/density/sugar is the difference in the total volume/sugar density/sugar quantity purchased from drinks between 2015 and 2018, per adult equivalent (AE) and per household. Units are respectively L/AE, g/100mL and g.

Households with higher income purchased a smaller volume of drinks in 2018 than in 2015, compared to households with lower income (Table 7-7). There was no clear pattern for the change in sugar density of purchases between households of different income. As a result, the change in the quantity of sugar purchased did not show a clear pattern between households of different income (Table 7-7). Social class also influenced the change in volume or sugar density of purchases, but with no clear pattern (Table 7-7 and Figure 7-8). Households of social classes C2, D or E decreased further the sugar density of the drinks they purchased than households from social class A, B or C1. But because households of social classes C2 and E increased the quantity of drinks purchased (while it did not change for other social classes), the change in the quantity of sugar purchased did not vary on average by social class (Figure 7-8).

Figure 7-8: Predicted effect of social class on the change in volume, sugar density, and sugar purchased from all drinks. Changes are in L, g/100mL and g per adult equivalent per household over a year.



7.4. Discussion

This study found that, in the context of the SDIL and the reformulation of drinks, households adopted different behaviours towards their purchase of drinks. While consumers who used to purchase drinks that were reformulated did not react differently from consumers of non-reformulated products, heavy consumers of sugary drinks decreased substantially their purchase of drinks, and their purchase of sugar from these drinks.

7.4.1 Public health relevance of the change in sugar purchased observed

We found in unadjusted statistics that the total volume of drinks purchased stayed broadly stable between 2015 and 2018 across households, while the volume of sugary drinks purchased decreased. Households purchased in 2018 on average a slightly higher volume of all drinks than in 2015 (+1-2L), but they purchased a smaller quantity of sugar from drinks. Households purchased in 2018, per adult equivalent, about 900g less sugar than in 2015 (estimate from adjusted models). This represented a 25% reduction of sugar purchased compared to average baseline levels. This important reduction is likely to be relevant for public health. The reduction in sugar purchased is equivalent to 4.3 sugar cubes per week, or half a can of Coca-Cola or Pepsi per week.

The reduction in sugar purchased was equivalent to a reduction of 10kcal purchased per day (in 2018 compared to 2015). If we assume that all drinks purchased are consumed (and that there is no compensation with other products), this 10kcal reduction per day can result in a 466g weight loss over the year[3]. Although small, this change in sugar purchased should not be neglected given the high obesity rates in the UK.

7.4.2 Comparison with published studies

The study by Pell et al (2021) found that accounting for pre-existing trends, the purchase of sugar from soft drinks decreased by 12.5g per person and per week (Pell et al., 2021). The estimate from our study is within the same range, and the difference is explained by the fact that our estimate includes pre-existing trends. Studies modelling the effect of taxes, and accounting for reformulation, estimated a reduction in the purchase of sugar from drinks of similar ranges (Salgado Hernández & Ng, 2021; Briggs et al., 2017). A study compared the impact of different tax systems and estimated sugar reductions by about 20% (Salgado Hernández & Ng, 2021). A study estimating the change in sugar-sweetened drink

3 This estimate was obtained using a simple static weight loss model, using the 7715kcal/kg gained/loss used in (Scheelbeek et al., 2019)

consumption under a best case and worse case reformulation found a calorie reduction between 10kcal/day and 2kcal/day (Briggs et al., 2017). The fact that our estimate is of the same magnitude as the best-case scenario shows that manufacturers reformulated their drinks in the context of the SDIL.

7.4.3 Heavy consumers of reformulated drinks had similar reactions as non-consumers

In addition, our study shows that the decrease in sugar purchased is similar for consumers and non-consumers of reformulated products. Indeed, the difference in the change in sugar purchased per year between high and low consumers of reformulated products was 58g (i.e., about 1g per week). This difference along household preference for reformulated products is unlikely to be of clinical relevance. This means that the reformulation of products is not followed by compensation mechanisms from consumers of those products. An experimental study testing the substitution of sugar-sweetened beverages by diet products found that the substitution resulted in lower daily sugar consumption (Markey, Le Jeune & Lovegrove, 2016). Our study showed that this result seems to be visible in real-life settings. However, the experimental study found no change in energy intake because of compensation resulting in higher protein and fat intakes. Because we don’t have information on total consumer purchases, we can’t verify if this happened in the studied population.

7.4.4 No socio-economic difference in the response to reformulation

There was no significant difference in the change in sugar purchased across economic groups, meaning that households across social class groups, income, ethnicity, or regions benefited from the same reduction in sugar purchased. This finding was unexpected in the light of the different consumption patterns of drink consumption existing in the population. The pattern of drinks purchases has been linked to demographic characteristics (Berger et al., 2020a). Households with higher income tended to have a more diverse basket of purchases than households with lower income (Berger et al., 2020a). Households in lower social classes were more likely to purchase a higher volume of sugar-sweetened and diet soft drinks (Berger et al., 2020a). In our study, we found that households of lower social classes purchased higher volumes of drinks and of sugary drinks at baseline. The fact that the decrease in volume and sugar purchased was similar across social classes suggest that the pre-existing disparities remained unchanged. The same finding was found in a study evaluating sugar purchased from both food and beverages in the UK from 2014 to 2017 (i.e. before the implementation of the SDIL) (Berger et al., 2020b). The authors found that the decrease in sugar from sugar-sweetened drinks and juices were the second and third contributor to this decrease in total sugar purchased (after table sugar) (Berger et al., 2020b).

Previous studies on the impact of the announcement or implementation of the SDIL did not evaluate the changes in consumption or purchase by demographic characteristics. A systematic review on the effect of soft drinks taxation on purchases and intake concluded that unclear effects existed across socio-demographic groups (Teng et al., 2019). Contrarily to our findings, a study evaluating the change in the purchase of branded colas (built aggregating purchases for Coca-Cola and Pepsi) found that the reduction in volume purchased was higher for less affluent households than for more affluent households (Fearne et al., 2021). In our study, we did not evaluate purchase by SDIL tier (or sugar level). We found that households of lower social classes decreased further the sugar density of their purchases. It is possible that less affluent households decreased more their purchase of high-sugar products but compensated by purchasing more lower-sugar products (or exempted products containing sugar).

7.4.5 Heavy sugary drink purchasers were the most impacted

The difference in the change in behaviour between households was linked to household preferences. Households with the highest decrease in sugar purchased were those who purchased the most sugary drinks at baseline or purchased drinks with the highest sugar density. High consumers of sugary drinks decreased their volume of drinks purchased, with no specific change to the type of drinks purchased for this group compared to other households (as the sugar density of purchases did not change differently from low consumers of sugary drinks). On the other hand, households with a preference for high sugar density drinks changed the type of drinks purchased. These households purchased a higher volume of drinks, but of a lower sugar density. These changes resulted in a higher decrease in sugar purchased than the average observed across households. These observations allowed us to conclude that the SDIL is likely to have had an important impact on heavy consumers of sugary drinks, and on households liking high-sugar drinks. The SDIL was probably a high burden for both types of households, as the former purchased high volumes, and the latter purchased drinks from the highest levy tier. The systematic review on the effect of soft drink taxes on purchases reported also that higher consumers were more price responsive (Teng et al., 2019). More recent studies also found a higher response to soft drink tax for heavy consumers (Capacci et al., 2019). The study by Capacci et al. (2019) found that while heavy consumers decreased their purchase of soft drinks, they did not change their habits towards diet drinks, or juice-based beverages (Capacci et al., 2019).

Heavy or frequent consumers of soft drinks were also more impacted by awareness campaigns than low consumers (Morley et al., 2018).

7.4.6 Manufacturers did not experience a decrease in sales after reformulation

This study also informs manufacturers about the consequences of reformulating products on consumer choice for the reformulated products. The product-level analyses showed that purchased volumes of reformulated products did not decrease after the reformulation, and even slightly increased. In opposition, the volume purchased of unchanged drinks did not change. We can hypothesize that reformulating products can mitigate the possible change in purchase resulting from the implementation of a tax. Switches between products were observed, but opposite trends between high and low consumers of reformulated products cancelled each other. As such, the sales of a manufacturer who had a diverse portfolio should not be impacted by reformulation. A study evaluating the impact of the SDIL on manufacturers' turnover found that, after a short-term decrease in revenue after the announcement of the SDIL, there was no further change after the implementation (Law et al., 2020). Studies on other soft drink taxes found that the implementation of the tax (and the possible reformulation by manufacturers) had no effect on revenue (European Commission, 2017) nor employment (Popkin et al., 2021).

7.4.7 Strengths and limitations

This study is, as far as our knowledge, the first to estimate households' responses to the reformulation of drinks they are used to consuming. It used longitudinal household data to study how purchases changed after the reformulation (and the absence of reformulation) of drinks. Also, we studied the household reaction to the reformulation of drinks for different socio-economic groups. The analysis of potential different responses to a food policy by socio-economic groups is essential to understand if this policy changes existing disparities.

We were not able to design a model establishing a causal relationship, meaning that we cannot causally link the reformulation of foods to the changes in behaviour observed. Specifically, we found that the change in the quantity of sugar purchased did not vary between consumers and non-consumers of reformulated drinks. This meant that consumers of reformulated drinks compensated for the decrease in sugar coming from the reformulated drinks, but we cannot rule out a bias coming from intrinsic differences between consumers and non-consumers of reformulated products. We found that the majority of households purchased reformulated products, preventing us from building a comparison between consumers of only reformulated products, and consumers of only non-reformulated products. Such design could have been evaluated using a difference-in-differences framework.

Nonetheless, we studied the differences in purchases within households, limiting the risk of having a result coming from a change in the population studied. But pre-existing trends could not be accounted for, and we know that there were existing declining trends in the purchase of high-sugar drinks. Our estimates (including pre-existing trends) are larger than the estimates found in studies accounting for pre-existing trends, suggesting we measured an extra decrease in sugar purchases coming from the implementation of the tax.

In addition, this study focused on understanding the shifts in purchases of all drinks. We wanted to know how the quantity of sugar purchased from these products changed from before to after the implementation of the SDIL. But we did not study the total quantity of sugar purchased per household. As such, we are unable to assess if households compensated by purchasing sugar from other sources (such as confectionery or cakes).

Lastly, our analysis focused on the purchases of soft drinks, and not their consumption. There are two limitations linked to it. First, we only accounted for purchases of soft drinks for at-home consumption. Purchases of soft drinks on-premises were not accounted for, as well as drinks consumed on the go. The BSDA estimated that in 2019, 86.5% of purchases of soft drinks were made off-premise, suggesting we captured in this analysis most of the soft drink purchases (The British Soft Drinks Association, 2020). Also, drinks purchased on the go, or by other household members than the main shopper, could have been omitted. Second, the use of household purchases prevented us from analysing individual variations in consumption. For example, for a household decreasing their quantity of sugar purchased, we don’t know if all household members experienced a similar decrease in the sugar quantity they consumed, or if that decrease was pooled for one household member.

7.5. Conclusions

Reformulating soft drinks was linked to a decrease in the sugar purchased from these drinks. Nonetheless, consumers and non-consumers of reformulated drinks had a similar decrease in the quantity of sugar purchased from drinks. The absence of difference between consumers and non-consumers of reformulated drinks suggested that consumers of reformulated drinks compensated for the decrease in sugar density of drinks they were used to purchasing. Heavy consumers of drinks or consumers preferring high sugar drinks experienced a higher reduction in sugar purchased than low consumers, or consumers of lower sugar drinks. Also, households of different socio-economic conditions experienced similar decreases, showing that reformulation affects similarly households of different socio-economic backgrounds. As such, reformulation of soft drinks does not appear to have changed pre-existing disparities.

8. CHAPTER 8: GENERAL DISCUSSION

Despite many initiatives initiated by governments to promote reformulation, and initiates adopted by manufacturers themselves, our understanding of the consequences of reformulation has been limited. This thesis aimed at better understanding how reformulation impacts consumer behaviour, dietary intake, and health.

8.1. Review of the thesis and learnings for the logic model of food reformulation

8.1.1 Review of the thesis

The main hypothesis of this thesis is that “reformulating food products lead to improvements in populations’ diet, assuming that there are no changes in food choices offsetting the benefits of reformulation” (page 74). The different studies presented in this thesis tend to support this hypothesis, with some nuances about the second part of the hypothesis as (partial) compensation was observed in chapters 5 and 7.

Studies of this thesis showed that food reformulation was mostly linked to improvement in populations’ diet (first part of the hypothesis). The systematic review reported in Chapter 3 showed that, in principle, reformulation can lead to improvement in the health status of populations. A common limitation of reformulation initiatives was to not incentivise reformulation sufficiently. That suggested that the limitation of reformulation policies was the policies themselves, but not population response to reformulation. The absence of significant improvement in the fibre intake for children and adolescents in chapter 4 supports the findings of the systematic review. Indeed, the low reformulation rates could partly explain this absence of improvement in fibre intake. The lack of improvements in food choices also contributed to this non-increase in fibre intake. In chapter 5, the sodium reformulation of foods between 2008/09 and 2016/17 was linked to a decrease in the average sodium intake in the UK. It is important to note that these studies show a correlation between reformulation and improvement in dietary intakes but not a causal relationship (more details below in section 8.2.3).

Reformulation was found to be the main driver of changes in intake or purchases in different studies of this thesis. Although the reduction in the sugar density of drinks purchased came from both changes in consumer choice and changes in the composition of products, the sugar density of food purchases was only decreased by changes in the composition of products. Similarly, the reduction in salt intake came mainly from changes in the composition of foods and not changes in food choices. It appeared that the taxation of soft drinks created at the same time a stronger incentive for manufacturers to reformulate and urged consumers to change their purchase habits towards lower sugar products. This latter effect may have been provoked by a change in advertising strategies towards more advertisement of lower sugar products.

The studies of this thesis showed that some compensation happened, without offsetting the effect of reformulation (second part of the hypothesis). In chapter 5, the average effect of switches between food products was overall null on the sodium density of foods consumed. Despite favourable choices in some categories (i.e., towards products with lower salt contents), detrimental choices in another category offset the favourable choices. As a result, the size of the decrease in sodium intake (-17%) was similar to the size of the sodium reduction in foods (-16%). In Chapter 6, changes in consumer choice had no effect on the sugar density of food purchases, meaning that there was no compensation for the decreased sugar contents of foods from reformulation. The reformulation of drinks was not linked to compensation, but in contrary to changes in consumer choices in favour of lower sugar products. In chapter 7, consumers of reformulated drinks had a similar decrease in the quantity of sugar purchased than non-consumers. The absence of difference between consumers and non-consumers of reformulated drinks suggested that consumers of reformulated drinks compensated for the decrease in sugar density of drinks they were used to purchasing, by purchasing other drinks of higher density.

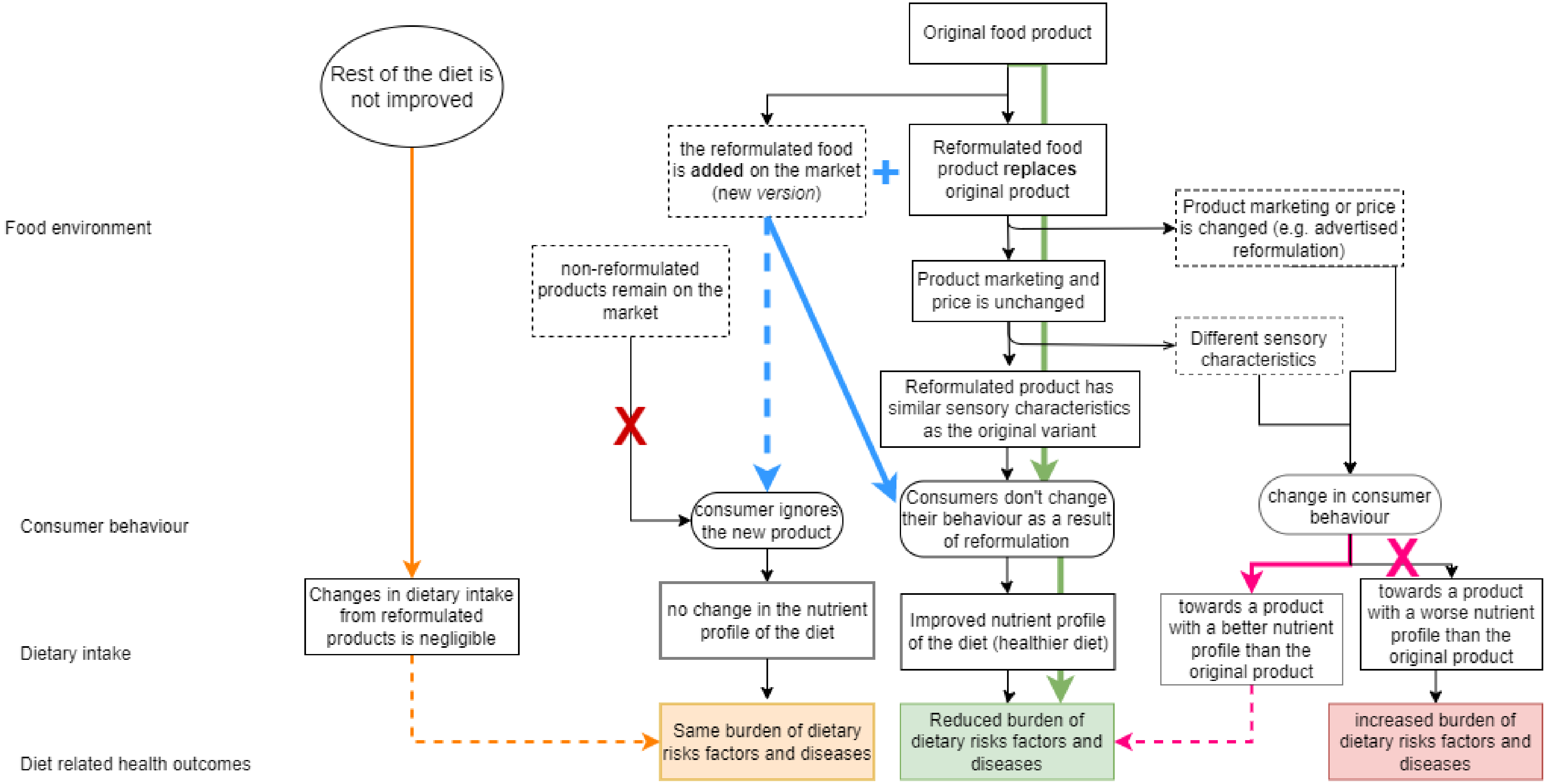
8.1.2 Summary of learnings on the logic model (drawn in Chapter 2)

The different chapters of this thesis can be used to confirm and invalidate, in this study context, some of the pathways of the logic model in Chapter 2 (Figure 2-8). First, the pathway through which reformulation can, if consumers don't change their behaviour, influence dietary intake and dietary risk factors was observed in the case of salt reformulation in the UK (Chapter 5). This pathway was also found in the systematic review (chapter 3) and has been highlighted in green in Figure 8-1. This pathway seems also to be the one valid in the case of the UK sugar reduction programme. We found that when there was reformulation, there were limited changes in consumer choices, and the decrease in sugar purchased from reformulated products was not compensated by switches to non-reformulated products (Chapter 5 and 6). This absence of compensation with non-reformulated products is shown as the red cross in Figure 8-1. In chapter 7, we found that most consumers of soft drinks decreased their purchase of sugar from beverages, including the consumers of reformulated products. The reformulation of soft drinks, in the context of the SDIL, was often advertised and/or linked with a change in taste of the product. This context could have created a health halo around beverages and made taste-oriented consumers switch to higher sugar products. However, we observed an improvement in the quantity of sugar purchased from beverages. Here, the advertised reformulation did not seem to have provoked a consumer shift to products with a worse nutrient profile. This pathway is highlighted in pink in Figure 8-1. We found in the systematic review that sometimes reformulated products were added to the market, instead of replacing the previous version. The results of the studies of such examples showed that the addition of new products still resulted in improved dietary intake. This pathway, highlighted in blue was also found in the soft drink reformulation analysis. While high consumers of reformulated products preferred new drinks with more sugar than low consumers of reformulated drinks, we still observed a similar reduction in sugar purchases for the two groups.

Nonetheless, there were also several instances where reformulation did not lead to improved nutrient intake, purchase, or health status. Some reformulation policies included in the systematic review did not lead to improved dietary intake, often when the reformulation was not intense enough. Consumers had still access to non-reformulated products, and the change in intake for some people was limited. This was also observed in the case of fibre reformulation in the UK. The reformulation of only a subset of the products resulted in no clear improvement of the diet. This pathway has been added on the left of the logic model, in orange (Figure 8-1).

It was not always possible to assess the impact of reformulation dietary risk factors, or even on total dietary intake. The missing evidence on the effect of reformulation on health status has been added to the logic model as dotted (orange and pink) lines.

Figure 8-1: Expanded logic model of the effect of reformulation including possible changes in consumer choices resulting from a change in the food environment other than reformulation; updated model based on the findings of this thesis



Notes: Dotted boxes are deviations from "silent" reformulation policies. Blue arrows and 'plus' signs are learnings from the systematic review of the literature and the analysis of the soft drink reformulation, where reformulation policies that included product diversification led to improved dietary intake (and thereby acceptance of reformulated products). Green arrows show the pathway that was found in the literature review and in the UK sugar or salt reformulation analysis: reformulated products were consumed and there was no compensation, resulting in improved dietary intake and health (in the case of the systematic review). The pathway in pink shows the learning from the analysis of the soft drink reformulation in the UK. Even when reformulation was advertised or linked to a change in marketing, consumers accepted the products and the shifts to newer products did not outweigh the improvements from reformulation. The pathway in orange (left) shows that, when reformulation is isolated or too limited, it results in no improvement in the diet. Crosses show invalidated pathways. Dotted lines showed pathways that were not validated.

All analyses of this thesis did not use causal inferences, and as such the pathways cannot be proved as causal pathways.

8.2. Strengths and limitations

8.2.1 Two complementary data sources used

The novelty of this thesis is to have studied the impact of reformulation on consumer habits through different lenses. The two types of dataset used (dietary surveys with the NDNS and household purchases with the UK Kantar panel and the Lumina Intelligence datasets) are representative of the UK population and have been used extensively to evaluate the impact of food policies in the UK. The NDNS is cross-sectional but covers the whole diet, while the Kantar panel is longitudinal, but only covers the purchases brought home.

Studies were done at the population and individual levels. This allowed us understanding the impact of reformulation policies on the population and on individual consumers. At a population level, we observed the effect of reformulation for the whole or subgroups of the population. This type of analysis give understanding on the effect of reformulation for the population, but not individuals composing the population. The drawback of this analysis is that a global improvement of population intake can hide disparities between individuals. A strength of this thesis is to have combined the analyses at the population level with individual-level analyses, which allowed us to study in more details disparities in dietary intakes.

We observed that reformulation often led to an overall improvement in population intake. For example, after salt reformulation, the average salt intake of the population decreased. After sugar reformulation, the average sugar density of purchases decreased, as well as the average quantity of sugar purchased. In addition, we were able to analyse the dynamics at the household level. We saw that after the sugar reformulation of soft drinks, a majority of households purchased drinks of a decreased sugar content. Also, a majority of households purchased a smaller quantity of sugar from beverages in 2018 than in 2015. Analysing household response to reformulation allowed us to investigate the role of socio-demographic characteristics in explaining the different response to reformulated foods. In all analyses accounting for socio-demographic characteristics, we found that there was no specific pattern of different response to reformulation across different groups.

Another original element of this thesis is to have investigated the consequences of reformulation at different levels of the diet. Changes were investigated at the product, food category and whole diet levels. Although the different levels were not explored for the same examples of reformulation, these different levels informed us about how reformulation impacted populations and consumers. In addition, in chapter 6 on sugar reformulation, we compared the reformulation of foods purchased for at-home vs. out-of-home consumption.

There were also limitations linked to the use of these two types of datasets. The NDNS was not precise in its evaluation of the reformulation of food products. As generic foods were used to record consumption, the reformulation of foods was captured in the nutrient content of these generic foods. Hence, the reformulation of a product could have been diluted if other foods matching the definition of the generic food product were not reformulated. If reformulation was isolated and was not done for all products matching a generic food product definition, nutrient intake from the reformulated food but estimated using the generic food could be biased. For example, the NDNS had one code for all colas consumed in the UK. But as a consequence of the SDIL, retailers' own brand colas were reformulated while national brand colas were not. In the NDNS, a consumer of a branded cola or a retailer brand cola would be attributed the same sugar intake from the same generic cola. This did not limit the validity of the NDNS to analyse population averages, as the nutrient compositions of generic products are averages of products sold. But the NDNS is not the best dataset to evaluate the impact of reformulation.

The Kantar dataset had details on individual product nutrition information and purchase, so was more appropriate to study reformulation. But these data also had their limitations. The fact that only purchases for at-home consumption were registered made it inadequate to estimate total sugar intake from the whole diet. This was especially true for products that were often consumed out-of-home. This was the case for soft drinks or snacks which are often consumed on the go. Nonetheless, our analyses may not be impacted by this possible bias. Indeed, in chapter 6 we focused on the sugar density of purchases, and we complemented the Kantar data analysis with an analysis of a similar database for out-of-home purchases. In chapter 7, we studied changes in consumption for the same households. We hypothesized that the patterns of purchasing products on the go did not change much between 2015 and 2018. As such, there should not be specific transfers of purchases from at-home to out-of-home sources.

8.2.2 The use of established and exploratory analyses

The analyses in this thesis used both methods commonly used to study food policies, and methods that were refined to analyse new aspects of the impact of food policies on consumers. An example of a method that was refined is the decomposition analysis. The decomposition method was first used in food studies in 2017, and has been used by different research groups (Griffith, O'Connell & Smith, 2017; Spiteri & Soler, 2018; Cengiz, Rojas & Wang, 2019). This method was previously used to evaluate the role of demand and supply drivers of a change in the nutrient composition of purchases. In this thesis, in addition to using the decomposition method to analyse changes in the sugar density of purchases in the

UK (Chapter 6), it was also used to evaluate the change in salt *intake* in the UK (Chapter 5). This was, as far as our knowledge, the first time this method was applied to dietary intake data (and not purchase). Nonetheless, it should be noted that this method is algebraic, and not probabilistic. As such, it does not produce standard errors for the estimation of the three effects (reformulation, switches between products and product renewal). Technically, producing these standards errors would need to estimate the standard errors of a sum, with the number of objects summed equalling the number of foods consumed. That requires calculating the covariance matrix of the quantities consumed of all foods, which was not technically feasible. The consequence of the absence of standard error is that it is difficult to judge if one of the effects is larger than the others.

To be able to estimate with more details (and including a measure of variability) the three effects, we refined the decomposition method to study longitudinally the purchases of the same households. It was, as far as our knowledge, the first time the decomposition was applied on individual household purchases, and not total sales of products. This method allows us to understand differences across households, and how reformulation affected them differently. We were then able to estimate the standard error of the three effects and compare them.

Chapter 7 used adjusted regressions. Regressions were adjusted for known factors that influence the consumption of soft drinks, and that we thought could equally influence the changes in their consumption. These factors were demographic characteristics, preference for high-sugar drinks (proxied with the sugar density of purchases at baseline), consumption levels of sugary drinks at baseline, and diversity of soft drinks purchased (estimated using the HHI). Unfortunately, we could not adjust for social norms. Literature showed that social norms can influence food choices, but these variables are difficult to measure. The datasets we used did not include a questionnaire that could inform us of the social norms of households.

8.2.3 Challenges is applying causal inference methods

The analyses in this thesis could not rely on robust causal inference approaches. Causal inference would have required a control group, but this was not possible given we studied policies that applied at the population level. Instead, we used methods to come as close as possible to an assessment of causal effects.

The analyses based on NDNS could not use a causal framework. There was no possible control group, and it was not possible to build pre-existing trends because of the duration of the survey and the timing of the interventions. The analyses were adjusted for changes in the composition of the panel, and possible changes in energy intake. Nonetheless, the analyses of the trend in the population average intake in the context of a reformulation policy informed us about the overall trends that happen concurrently to this type of policy. These trends are important to consider as reformulation policies are often implemented together with other policies. Despite showing us the impact of reformulation alone (i.e., causally), these analyses informed us about the likely effect of the implementation of a reformulation policy in a complex context.

The analysis of the household response to the reformulation of beverages was done using OLS. More robust methods such as random effects were tested but were not relevant in our study (see section 7.3.3). The OLS were adjusted for confounders, including preferences for beverages at baseline. Despite the adjustment factors used in all analyses, bias can exist, in the case when consumers of reformulated products and consumers of non-reformulated products had different preferences. Reformulation was widespread across product categories (and manufacturers), hence we assumed that there is no specific preference underlying the choice for reformulated products (as consumers can't know what products are going to be reformulated).

The fact that the analyses did not show causal inference should not limit the learnings from this thesis. Indeed, taken together the analyses showed that reformulating foods and drinks was not linked to adverse reactions, but was linked to improvements in the diet. Hence, policy makers should encourage manufacturers to improve their products. Secular trends cannot be controlled for, but some factors driving trends in food choice can be. For example, restricting the marketing of less healthy foods could limit the switch for these products.

8.2.4 Generalisability of the findings

A limitation of this thesis is that most findings may not be generalisable to other reformulation policies. The different chapters of this thesis suggest that a reformulation policy, if designed with caution and monitored carefully, is likely to make manufacturers reformulate their products. As a result, dietary intake from the reformulated food categories is likely to be improved. But shifts can happen, at a magnitude that could offset the benefits from reformulation. That also highlights the importance of other policies changing food environments, for example, education campaigns or restricting advertisement.

This thesis focused on the UK population. Although reformulation policies are implemented in other countries, and that the food supply has some globalized components, the effect of reformulation should be considered together with the cultural context.

8.3. Implications for policy

8.3.1 Promoting food product reformulation had beneficial outcomes

(1) Reformulation is a strong driver of improvement in intake and purchases

The launch of reformulation initiatives was very often followed by improvements in the composition of foods (section 1.7.2). Chapters 5 and 6 showed that the UK reformulation programmes to reduce salt and sugar in foods strongly contributed to the decrease in the intakes of these nutrients in the UK population. Although the sugar reductions were limited to some food categories, reformulation was the only force acting towards a reduction in sugar intake in these categories. Hence, reformulation policies contributed to improving the purchases and intake of populations.

Few published studies evaluated the change in the whole nutrient profile of products after reformulation. Although this was not one of the objectives of the studies in this thesis, some learnings can be derived from this thesis research. Chapter 3 and 4 both used NDNS data to investigate salt and fibre reformulation. While in chapter 4 we found important reformulation that reduced the salt content of foods, in chapter 3 we found negligible changes in the fibre content of food categories. The analysis of the different nutrient intake showed that the reduction in sodium intake was linked to a decrease in energy and sugar intakes (although not statistically significant for all age groups). This suggested that the reformulation to decrease salt in foods was linked to an improvement in the nutrient profile of these foods. The reports by PHE on the progress by industry to reach the sugar reduction objectives included the assessment of the nutrient content of nutrients other than sugar (Public Health England, 2020e). In the first year of the evaluation, only 4% of the 20 top brands from each category had a decrease in sugar, SFA and energy. 16% of products had decreases in sugar and no change in SFA and energy, meaning that their nutrient profile improved. But in 17% of the products, SFA and/or energy increased while sugar decreased (Tedstone et al., 2018). In the third-year report, PHE reported that amongst brands that reduced their sugar by more than 2%, 17% of brands decreased also their SFA content (by more than 10%) while 10% increased SFA. After three years, the compensation of sugar reduction by SFA increase seemed limited, and of a smaller extent than reformulation that improved the nutrient profile of products (Public Health England, 2020e).

(2) The importance of policies in harmonizing reformulation

The effectiveness of strong incentives such as mandatory targets in promoting reformulation may come from the level-playing field they create. Manufacturers need to know that the constraints they are facing are also faced by competitors. That is why manufacturers may prefer mandatory policies to voluntary ones (Kaldor, 2018; Antman et al., 2014). With mandatory policies, manufacturers know that their competitors, including small manufacturers, will need to comply with the rules set by the policy. In addition, it is believed that this level playing field with help consumers get used to the changed taste of products (Antman et al., 2014).

Isolated reformulation was sometimes a failure, in which manufacturers had to change back the recipe of their products to the initial one. For example, Campbell soup was reformulated with lower sodium contents in 2011. But because of a decline in consumer purchase, the manufacturer chose to restore the initial levels of sodium (Antman et al., 2014; Regan et al., 2017). Similarly, the manufacturer of the McVities Digestive biscuits also came back to the initial recipe, after seeing that consumers did not like the taste of the new reformulated product with no palm oil (Stone, 2013). The study in chapter 7 showed that in the case of soft drink reformulation, consumers did not buy smaller quantities of reformulated products. One explanation is that reformulation happened simultaneously in many drinks. Also, the reformulation was coupled to a tax, making reformulated products cheaper than non-reformulated ones.

Nonetheless, a voluntary reformulation programme (possibly incentivised by a tax) does not guarantee a full harmonization of products. The implementation of the SDIL showed that most manufacturers of high-sugar drinks reformulated them. But the two market leaders did not reformulate their high-sugar products. Instead, they changed the size of their bottles to keep similar pricing between high and lower sugar versions of their drinks. A similar process has been observed in the case of a reformulation (but not to improve the nutrient profile of the product). Nutella, which also benefits from a unique taste and brand image for consumers, had its recipe reformulated. Despite consumer protests, the powerful manufacturer did not change back its recipe (Ducharme, 2017).

(3) Reformulation does not widen inequalities

The studies done in Chapters 5, 6 and 7 showed that the effect of reformulation was similar across socio-demographic groups, irrespective of the type of reformulation performed.

All studies in this thesis focused on the UK population, but the relationship between reformulation and inequalities has been investigated in other regions too. A study done on the French population simulating the potential effect of reformulation on multiple diseases found that reformulation did not change the disparity already existing in the French population (Leroy et al., 2016). In this study, lowest-income populations experienced a higher decrease in mortality with reformulation than highest-income populations. But as baseline deaths were higher for lowest-income populations, reformulation resulted in no change in disparities. A few studies estimating possible changes in intake resulting from the reformulation of foods found higher reduction for lower SES groups, for salt reformulation in Australia (Coyle et al., 2021); or sugar in France and the US (Gressier et al., 2017). The role of reformulation in the modulation of health disparities should be investigated for each reformulation initiative launched.

At a larger scale, reformulation policies should not only be applied in the most developed countries. The systematic review in chapter 3 showed that only a few reformulation initiatives were launched in developing countries, despite having an important part of daily calories coming from processed foods. A study from 2014 highlighted that, amongst the countries in the WHO Europe region, the ones with mature policies to reduce salt in the diet (including reformulation and/or education campaigns) were the ones with the highest development index (Rodriguez-Fernandez et al., 2014). The article cautioned about the possible widening of inequalities if lower-development countries don't act to reduce the salt intake of their populations.

8.3.2 But, to happen, reformulation needs strong incentives

(1) Limitations of voluntary initiatives

The review in the background section (section 1.7.2 chapter 1) showed that the success rate of voluntary reformulation initiatives was lower than the one of mandatory reformulation initiatives. The studies in this thesis tend to reinforce this finding. Indeed, the different reformulation initiatives studied in this thesis had varying levels of incentives. The initiative with the lowest incentive was the fibre reformulation (chapter 4), followed by the salt (chapter 5) and sugar (chapter 6) reformulation programmes that had a medium incentive level, while the SDIL created a strong incentive for soft drink manufacturers to reformulate. And the results of the studies showed that the effectiveness of these initiatives to improve intake or purchase was linked with the level of incentive. The voluntary fibre reformulation was the initiative linked to the lower level of success. Reformulation of foods was minimal and linked to a marginal increase in fibre intake in adults, probably caused more likely by a change in food choices. The salt reduction campaign may have only been effective to drive reformulation because of the threat to make the thresholds mandatory. Lastly, the sugar reduction programme showed that, in the absence of taxation, the reformulation of foods to reduce sugar contents was limited.

Although the SDIL and the sugar reduction programme were launched at the same time, they did not benefit the same publicity. Indeed, the SDIL was debated in the media, creating a high awareness for consumers. Conversely, the sugar reduction programme was not so much discussed, and it is possible that the population was less aware of the reformulation in foods. We observed that consumers switched to lower sugar drinks, but this effect was not visible for foods. This suggested that the debate on the SDIL created a signalling effect that played a critical role in making consumers change their purchase habits.

Manufacturers reacted differently to the voluntary commitment they made about salt and sugar reductions. Although there were important salt reductions in foods, sugar reductions were limited to almost two food categories. On the other hand, sugar reformulation happened for soft drinks, especially to avoid the higher tax tier. The fact that strong incentives provoke more reformulation has already been highlighted in several papers (Hyseni et al., 2017b; Magnusson & Reeve, 2015). The different reformulation rates following the implementation of the salt and sugar reduction programmes show that the type of incentive does not determine alone the efforts that manufacturers will make.

(2) The importance of monitoring reformulation

The monitoring of the UK sugar reduction programme by PHE is an example of a thorough evaluation of a reformulation programme. First, the monitoring is done by a government's body, but in collaboration with manufacturers. As outlined previously, the data collected and monitored is complex and includes the evaluation of the nutrient profile of products (reported as the change in the content of SFA, sugar, salt, and energy content in the top 20 brands in all categories). The change in the top brand nutrient content is presented together with the name of the brands (after approval by the manufacturers). This approach belongs to the "name and shame/blame" approach that consists in praising the efforts of some manufacturers while blaming the ones who don't improve their products. Nonetheless, the disclosure of manufacturers' efforts or absence of action could be more transparent. First, some manufacturers can choose not to approve the disclosure of data on their products in the reports. Secondly, the measure reported is the change in nutrient content, not the actual content before and after. This measure allows evaluating manufacturers who make effort to improve their products by reformulating them but can be in disfavour of brands that had a better nutrient profile from the start.

Nonetheless, this detailed reporting does not guarantee effectiveness. As reported, sugar reformulation has been limited in some categories. In the absence of fiscal incentives, only the sugar content of breakfast cereals and yoghurts was reduced by approximately 10% (and not to the 20% objective) (Public Health England, 2020e). Strong monitoring appears necessary to incentivise manufacturers to reformulate, but not enough.

(3) (Perceived) barriers to reformulate

Manufacturers are often raising concerns about the challenges to reformulate their products. Often, reformulation targets are set after a discussion between different parties including manufacturers. The mandatory salt targets implemented in Argentina and South Africa were released after a consultative phase with the industry (Kaldor, Thow & Schönfeldt, 2019; Allemandi et al., 2015). These consultations allowed manufacturers to say what reformulation was feasible for the different types of products to be targeted by the policy. But there seemed to be an upward bias in the targets suggested by manufacturers. In Argentina, targets were set at the level of an existing voluntary agreement in place, to ensure compliance. But the targets were assessed not challenging enough and became stricter a few years after implementation (Allemandi et al., 2019). In the UK, soft drinks manufacturers were opposed to the implementation of the SDIL. The British Soft Drinks Association (BSDA) justified this opposition saying that the drink sector was already acting to reduce sugar intake and that sugar intake from soft drinks was reduced by 16.2% between 2012 and 2016 (The British Soft Drinks Association, 2016). Nonetheless, the BSDA reported that sugar intake from soft drinks decreased by 30.3% between 2015 and 2019 (The British Soft Drinks Association, 2021), suggesting that the implementation of the tax accelerated manufacturers actions. Chile's law restricting advertisement and requiring foods high in sugar, salt, or fat to add a warning sign label on their packages is another example of a policy that was likely to have accelerated the speed of reformulation. Substantial reformulation was observed after the implementation of the law, resulting in fewer products being "high in" a nutrient (Reyes et al., 2020). The reformulations were around the cut-off values (products that were above the cut-off were reformulated to get just below, with no change in the nutrient content distribution otherwise). Reformulation around the cut-off is likely to have been incentivized by the law (Reyes et al., 2020).

In addition, manufacturers often express concern about declining revenues as a result of reformulation. If reformulation leads to smaller revenue for the manufacturing companies, manufacturers will not reformulate their products. Manufacturers often claim that mandatory reformulation policies would result in lower revenue, and hence job cuts. This argument was also used in South Africa and the UK before the respective taxes on sugar-sweetened beverages were implemented (Bridge, Flint & Tench, 2020; Popkin et al., 2021). In response to manufacturers concerns, research is growing about the impact of reformulation policies on business and employment, including manufacturer revenue. Studies have found that the implementation of a tax on unhealthy products did not have negative consequences on employment (Popkin et al., 2021) or manufacturer sales (Bíró, 2021), or that the UK SDIL did not decrease turnover in the long term (Law et al., 2020). Adding to this body of evidence, we found in chapter 7 that there was no decrease in purchases of reformulated products while non-reformulated products were purchased in smaller quantities. It is possible that manufacturers directed more advertisement budget to reformulated products, as some of those were subject to a lower rate tax. Whatever solution manufacturers used, it was effective to mitigate any adverse effect that the change in recipes could have on consumers. These different examples show that a reformulation policy is unlikely to affect the economy, as manufacturers find ways to limit the impact of the policy on their revenues.

8.3.3 The limitations of reformulation policies

(1) The limitations of reformulation in reducing energy intake

A finding of the systematic review in chapter 3 is that reformulation is unlikely to be a relevant policy to decrease the energy intake of populations. Except for soft drinks, for which sugar reformulation is expected to result in a reduction in energy content, the reformulation of solid foods is less likely to result in energy decreases. For example, the PHE monitoring of the first three years of the sugar reduction programme in foods found that, while sugar in yoghurts decreased by 13%, energy per serving decreased by only 8% (Public Health England, 2020e). In soft drinks, the sugar content decreased by 44% and calorie (per serving) by 35%.

This is a major limitation to be added to simulation models estimating the impact of reformulation on health outcomes. For example, the estimation of the impact of the tax on salt and sugar proposed by the National Food Strategy assumes that the reduction in sugar will be translated into reductions in calories in foods (Griffith et al., 2021). Such approximations are likely to overestimate the health impact of policies involving reformulation. Such models should take into consideration that the energy reduction rate is much lower than the sugar reduction rate. The substitution of an ingredient with another one in the reformulation process was mentioned in a study evaluating fat reductions in foods (Alessandrini et al., 2021). Nonetheless, this approach was not tested in the paper as it would need a thorough evaluation of the reformulation options for each food category.

From a policy perspective, it means that reducing the energy intake of the population should not be only tackled with reformulation policies. The UK has launched in 2018 a calorie reduction programme, part of the childhood obesity plan (Public Health England, 2018). It aimed at reducing the calorie content of some categories by 20%, using both reformulation and portion size reduction. After discussion with the industry to define the category targets, the aim was lowered to a 10% reduction, this reduction being more realistic (Public Health England, 2020a). The impact of this policy is still to be seen. First, the sugar reduction was not achieved for all categories. Second, as energy reformulation is challenging, manufacturers may prefer reducing their portion size. But the effect of downsizing portions on energy intake is unclear. To reduce the energy intake of the UK population, other policies are probably needed.

(2) The evaluation of reformulation, and its reliance on labels

Some key elements of the effectiveness of reformulation policies are linked to labels. First, the monitoring of reformulation efforts often uses product labels that are available to public authorities and researchers. Also, one incentive for reformulation is the competitive advantage created by a better nutrient content compared to the competition (and sometimes highlighted with claims). As a result, most reformulation policies launched until now focused on nutrients that are labelled in most labelling systems in the world. Nonetheless, it could also be relevant to improve the composition of products according to other criteria for which a scientific basis on its relevance to the improvement of diets exists. For example, some researchers recommended the use of a measure of carbohydrate quality (such as the carbohydrate to fibre ratio, or the glycaemic index) or fat quality (e.g., unsaturated to saturated fat ratio) in labels (Mozaffarian et al., 2018). The obstacle to using more complicated metrics such as the carbohydrate and fat quality indexes is that all components are not often labelled. Unsaturated fats and fibre are not mandatorily labelled in the US and the EU, for example. As for glycaemic index, this metric needs to be measured in foods and cannot be easily calculated. Hence, a reformulation policy based on these metrics would be more expensive to monitor, either for the manufacturers or the governments.

Also, recent research has highlighted the high exposition of populations to food additives, coming mostly from processed foods (Chazelas et al., 2021; Monteiro et al., 2018). Research pieces discuss the possibility to reformulate processed foods to reduce the number or amount of additive, and change their degree of processing (Baker et al., 2020; Tobias & Hall, 2021b). Although additives are listed on labels (in the ingredient list), labels contain no information on the level of processing done to a food product.

8.3.4 The small overall effects of reformulation call for wider strategies including complementary measures

(1) To obtain an overall improvement of the diet

Food reformulation policies implemented so far focused almost exclusively on one nutrient at a time. For example, the UK, despite having one of the most advanced reformulation programmes in the world, has its reformulation programme based on several nutrients separately. The salt reduction programme is a separate programme from the sugar or calorie reduction programmes. Some food categories have targets in two or three of the programmes, but the UK reformulation strategy was not built as a strategy to improve the overall quality of foods. Focusing on one nutrient at a time makes reformulation easier, as manufacturers are guided towards which nutrient should be of concern for a given type of food. But the possible caveat of this approach is that the nutrient profile of reformulated foods doesn’t improve if the reduction of the nutrient under focus is compensated by nutrients that are not under scrutiny.

A solution to that caveat is to use nutrient profiling systems (NPS) in the design of reformulation policies. The NPS can be either used to define the reformulation strategy or be used in other policies that would create enough incentive to control reformulation. For example, the use of an NPS in an FOP label could incentivize a reformulation that does not degrade the nutrient profile of products. France implemented in 2017 the voluntary Nutri-Score, a summary indicator of the nutrient profile of a food. France has also a set of voluntary reformulation commitments by food manufacturers. So far, the two policies are not linked to each other. There has not been yet evaluations of the effect of the Nutri-Score on the reformulation of products, but the media reported several examples of manufacturers adopting the Nutri-Score and reformulating their products to obtain better grades (Dumonteil, 2021; Haverland, 2021, 2019). In most of the cases, only one nutrient was mentioned to have been reduced to improve the nutrient profile of the product. Nonetheless, the improvement of the Nutri-Score rating (defined per 100g of product) guarantees that the reformulation did not increase the content of other nutrients to limit. Australia and New Zealand also have such FOP labelling in force, but no specific reformulation programme. In Australia and New Zealand, the adoption of the Health Star Rating label was associated with further reformulation than products that did not adopt the label (Morrison, Meloncelli & Pelly, 2018; Bablani et al., 2020).

The use of an NPS in guiding reformulation would also ensure that all food products are improved. While current reformulation policies focus very often on a limited number of categories, a reformulation policy based on NPS could have a wide scope. Indeed, single-nutrient reformulation policies often focus on the categories that are the most important sources of that nutrient. For example, some countries have mandatory salt targets only for bread (see Chapter 3), while the UK has studied sugar sources in the population to define the categories included in the sugar reduction programme (Public Health England, 2015). As long as the NPS used in reformulation policies can be applied to all products, the reformulation policy could also apply to all products (taking into consideration that raw products cannot be reformulated).

The use of the same basis in different nutrition policies, such as reformulation policies, FOP labelling, or food procurement offers several advantages. First, it can help consumers to understand what foods are to be preferred to others. If the same system is used across policies, the same foods will be promoted in different settings, for example, fruits would be offered as snacks in schools, and would have a better label than chocolate bars. In the case where different systems are used in different policies, confusion can be created if consumers face different messages. That is why NPS are proposed as one system that could guide different policies. The country the most advanced in using an NPS to guide different nutrition policies is Chile. Chile is using the same set of nutrient targets to restrict advertisement, sales in schools and define which foods should have a warning label (Taillie et al., 2021). There are currently discussions about using the same system as the basis of a tax on unhealthy foods (Agencia UNO, 2021).

(2) Other policies to shift consumer demand

Given the poor quality of current diets and the high number of people having an excess intake of energy, sugar, saturated fats or salt, it appears needed to find solutions to improve food choice patterns. Chapter 3 showed that fibre intake did not change much between 2008/09 and 2016/17, because of a balance between reformulation and change in consumption patterns. While in adults there were some improvements in the average fibre intake, that was not the case in children and adolescents. In chapter 6, we saw that shifts towards lower-sugar products only happened for soft drinks that were subject to the SDIL. The learnings from chapters 3 and 6 tend to suggest that reformulation alone is not enough to improve dietary intake or nutrient purchase. The decrease in sugar purchased from soft drinks in chapters 6 and 7 was influenced by the SDIL: the tax made consumers shift their purchases towards lower sugar products. Taxes on soft drinks have been implemented in many countries and have shown to be effective in shifting purchases towards lower sugar drinks (Teng et al., 2019). Two countries have implemented taxation on unhealthy foods: Hungary and Mexico. The results about the effectiveness of those taxes to improve dietary intake are mixed. In Hungary, the volume of taxed products decreased after implementation but came back to its initial levels after a few years (Bíró, 2021). In Mexico, the volume of taxed products decreased, but evaluations have produced conflicting results on the effect of the tax on total energy purchased (Aguilar, Gutierrez & Seira, 2021; Hernández-F et al., 2019; Batis et al., 2016; Taillie et al., 2017).

8.4. Future research

This thesis investigated how populations reacted to the reformulation of foods. In Chapter 6 we found that there were important shifts in purchases, resulting in both purchases with higher and lower sugar across households. A higher proportion of these shifts were towards products with lower sugar for soft drinks, probably due to the SDIL. But in the case of soft drinks too, shifts were varied across households. The reasons for these shifts remain unknown. Chapter 7 suggested that part of the explanation relied on household preference, but there remained a large unexplained part. An effective policy should ensure that all households improve their purchase. To fulfil this objective, future research should investigate what determine consumer shifts between products.

In addition, most of the research on the effect of reformulation policies (coupled or not with taxation) did not cover total dietary intake. The reason why most studies (including the ones in chapters 6 and 7) focussed on partial purchases instead is to be able to track reformulation at the level of branded products; the level at which reformulation is done. Most current dietary surveys record the consumption of generic products. Hence, using those in evaluating the effect of reformulation is inappropriate because can inadequately reflect reformulation that happened for some products only. To accurately measure the effect of reformulation policies, research should also evaluate the change in dietary intake. Future research should be done to analyse dietary surveys that correctly account for the reformulation of some products.

A question that this thesis did not answer is about consumer reaction to silent reformulation. In this thesis, consumer reactions were analysed in the context of the reformulation of soft drinks in the UK. Such reformulation was not silent. Indeed, some manufacturers advertised their reformulation as a way to tell consumers they care about their health. Also, there was a lot of awareness campaigns about the sugar content of soft drinks, so it is likely that consumers paid attention to the sugar content of drinks. Even when reformulation was done in the absence of a claim, the media or consumer association picked up products that were reformulated. This awareness may have changed consumers perception of the product, differently from what would have happened with silent reformulation. Understanding consumer reaction to silent reformulation is important as manufacturers may choose silent reformulation in the case of a gradual reformulation. Indeed, the possibility to advertise on-pack the reformulation of a food depends on the regulation. In the EU for example, a claim on 'reduced sugar' content can only be made for reductions higher than 30%. The magnitude of reformulation measured in this thesis was often much below 30%, meaning that manufacturers were unlikely to have advertised their reformulation. Understanding consumer reaction towards silent versus advertised reformulation could ensure the reformulation is viable for manufacturers (meaning they don't lose market shares) while it improves consumer health.

8.5. Conclusions

The aim of this thesis was to study how populations and consumers reacted to the reformulation of foods and beverages; and what was the consequence on their dietary intake and health status. The reformulation of foods was linked to improvement in the dietary intake or nutrient purchases of populations. Substitution mechanisms and secular trends may mitigate the effectiveness of reformulation to improve purchases and intake. The use of the decomposition approach, including at the household level, revealed that reformulation had a stronger effect than changes in behaviours, even in the presence of price incentives. In addition, reformulation seemed to have a similar effect in all socio-economic groups. This also meant that reformulation is unlikely to reduce existing nutrition disparities in the UK population, which should be addressed by other means.

Regarding the incentives to make manufacturers reformulate their products, this thesis also confirms the findings of previous studies, that reformulation is unlikely to lead to major improvements in dietary intake if it is not closely regulated by the governments.

Reformulation policies should be enforced by governments but should not be the only policy to tackle nutrition-related issues. Reformulation only targets manufactured foods. Given their high consumption rates, reformulation appears needed to improve current manufactured foods. But given the high divergence between recommended and current food intakes, other actions are needed to help people choose a better diet.

REFERENCES

Access to Nutrition Foundation (2018) *Access to nutrition index. Global Index 2018*. 2018. https://www.accesstonutrition.org/sites/gl18.atnindex.org/files/resources/atni_report_global_index_2018.pdf [Accessed: 17 October 2018].

Action on Sugar (2016) *Shocking amount of sugar found in many hot flavoured drinks*. 2016. http://www.actiononsugar.org/news-centre/surveys-/2016/shocking-amount-of-sugar-found-in-many-hot-flavoured-drinks.html [Accessed: 1 October 2020].

Adams, J., Pell, D., Penney, T.L., Hammond, D., Vanderlee, L. & White, M. (2021) Public acceptability of the UK Soft Drinks Industry Levy: repeat cross-sectional analysis of the International Food Policy Study (2017–2019). *BMJ Open*. 11 (9), e051677. doi:10.1136/bmjopen-2021-051677.

Addison, A. (2010) *Voluntary - salt reduction strategy reformulation targets*. www.bis.gov.uk/alternatives.

Afshin, A., Sur, P.J., Fay, K.A., Cornaby, L., Ferrara, G., Salama, J.S. & et al. (2019) Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet*. 393 (10184), 1958–1972. doi:10.1016/S0140-6736(19)30041-8.

Agencia UNO (2021) *Realizan positiva evaluación de Ley de Etiquetado a 5 años de su promulgación*. 7 May 2021. CNN Chile. https://web.archive.org/web/20210521011854/https://www.cnnchile.com/pais/positiva-evaluacion-ley-etiquetado-promulgacion_20210507/ [Accessed: 26 July 2021].

Aguilar, A., Gutierrez, E. & Seira, E. (2021) The effectiveness of sin food taxes: Evidence from Mexico. *Journal of Health Economics*. 77, 102455. doi:10.1016/J.JHEALECO.2021.102455.

Ahuja, J.K.C.C., Pehrsson, P.R., Haytowitz, D.B., Wasswa-Kintu, S., Nickle, M., et al. (2015) Sodium monitoring in commercially processed and restaurant foods. *The American journal of clinical nutrition*. 101 (3), 622–631. doi:https://dx.doi.org/10.3945/ajcn.114.084954.

Albani, V., Butler, L.T., Traill, W.B. & Kennedy, O.B. (2017) Fruit and vegetable intake: Change with age across childhood and adolescence. *British Journal of Nutrition*. 117 (5), 759–765. doi:10.1017/S0007114517000599.

Albuquerque, T.G., Nunes, M.A., Oliveira, M.B.P.P. & Costa, H.S. (2020) Compliance of declared vs. analysed values with EU tolerance limits for mandatory nutrients in prepacked foods. *Food Chemistry*. 302, 125330. doi:10.1016/J.FOODCHEM.2019.125330.

Alessandrini, R., He, F.J., Ma, Y., Scrutinio, V., Wald, D.S. & MacGregor, G.A. (2021) Potential impact of gradual reduction of fat content in manufactured and out-of-home food on obesity in the United Kingdom: a modeling study. *The American Journal of Clinical Nutrition*. 113 (5), 1312–1321. doi:10.1093/AJCN/NQAA396.

Allemandi, L., Tiscornia, M.V., Guarnieri, L., Castronuovo, L. & Martins, E. (2019) Monitoring Sodium Content in Processed Foods in Argentina 2017–2018: Compliance with National Legislation and Regional Targets. *Nutrients*. 11 (7), 1474. doi:10.3390/nu11071474.

Allemandi, L., Tiscornia, M.V., Ponce, M., Castronuovo, L., Dunford, E. & Schoj, V. (2015) Sodium content in processed foods in Argentina: compliance with the national law. *Cardiovascular Diagnosis and Therapy*. 5 (3), 197–206. doi:10.3978/j.issn.2223-3652.2015.04.01.

Allen, L., De Benoist, B., Dary, O. & Hurrell, R. (2006) *Guidelines on food fortification with* *micronutrients*. http://apps.who.int/iris/bitstream/handle/10665/43412/9241594012_eng.pdf?sequence=1.

Álvarez-Sánchez, C., Contento, I., Jiménez-Aguilar, A., Koch, P., Gray, H.L., Guerra, L.A., Rivera-Dommarco, J., Uribe-Carvajal, R. & Shamah-Levy, T. (2018) Does the Mexican sugar-sweetened beverage tax have a signaling effect? ENSANUT 2016. *PLOS ONE*. 13 (8), e0199337. doi:10.1371/JOURNAL.PONE.0199337.

Angell, S.Y., Cobb, L.K., Curtis, C.J., Konty, K.J. & Lynn D. Silver (2012) Change in Trans Fatty Acid Content of Fast-Food Purchases Associated With New York City ' s Restaurant Regulation. *Ann Intern Med*. 157, 81–86.

Angell, S.Y., Silver, L.D., Goldstein, G.P., Johnson, C.M., Deitcher, D.R., Frieden, T.R. & Bassett, M.T. (2009) Cholesterol Control Beyond the Clinic: New York City's Trans Fat Restriction. *Annals of Internal Medicine*. 151 (2), 129. doi:10.7326/0003-4819-151-2-200907210-00010.

Antman, E.M., Appel, L.J., Balentine, D., Johnson, R.K., Steffen, L.M., Miller, E.A., Pappas, A., Stitzel, K.F., Vafiadis, D.K. & Whitsel, L. (2014) Stakeholder discussion to reduce population-wide sodium intake and decrease sodium in the food supply a conference report from the American Heart Association sodium conference 2013 planning group. In: *Circulation*. 2014 p. doi:10.1161/CIR.0000000000000051.

Ares, G., Aschemann-Witzel, J., Curutchet, M.R., Antúnez, L., Machín, L., Vidal, L. & Giménez, A. (2018a) Product reformulation in the context of nutritional warning labels: Exploration of consumer preferences towards food concepts in three food categories. *Food Research International*. 107, 669–674. doi:10.1016/j.foodres.2018.03.021.

Ares, G., Varela, F., Machin, L., Antúnez, L., Giménez, A., Curutchet, M.R. & Aschemann-Witzel, J. (2018b) Comparative performance of three interpretative front-of-pack nutrition labelling schemes: Insights for policy making. *Food Quality and Preference*. 68 (January), 215–225. doi:10.1016/j.foodqual.2018.03.007.

Bablani, L., Mhurchu, C.N., Neal, B., Skeels, C.L., Staub, K.E. & Blakely, T. (2020) The impact of voluntary front-of-pack nutrition labelling on packaged food reformulation: A difference-in-differences analysis of the Australasian Health Star Rating scheme M. Reyes (ed.). *PLoS Medicine*. 17 (11), e1003427. doi:10.1371/journal.pmed.1003427.

Baker, P., Machado, P., Santos, T., Sievert, K., Backholer, K., Hadjikakou, M., Russell, C., Huse, O., Bell, C., Scrinis, G., Worsley, A., Friel, S. & Lawrence, M. (2020) Ultra-processed foods and the nutrition transition: Global, regional and national trends, food systems transformations and political economy drivers. *Obesity Reviews*.p.obr.13126. doi:10.1111/obr.13126.

Ball, J. (2009) *FSA unveils first participants in voluntary additive ban*. 2009. The Grocer. https://www.thegrocer.co.uk/fsa-unveils-first-participants-in-voluntary-additive-ban/197035.article [Accessed: 20 April 2020].

Bandy, L., Adhikari, V., Jebb, S. & Rayner, M. (2019) The use of commercial food purchase data for public health nutrition research: A systematic review R.J. de Souza (ed.). *PLOS ONE*. 14 (1), e0210192. doi:10.1371/journal.pone.0210192.

Bandy, L.K., Scarborough, P., Harrington, R.A., Rayner, M. & Jebb, S.A. (2020) Reductions in sugar sales from soft drinks in the UK from 2015 to 2018. *BMC Medicine*. 18 (1), 20. doi:10.1186/s12916-019-1477-4.

Bandy, L.K., Scarborough, P., Harrington, R.A., Rayner, M. & Jebb, S.A. (2021) The sugar content of foods in the UK by category and company: A repeated cross-sectional study, 2015-2018. *PLoS Medicine*. 18 (5). doi:10.1371/journal.pmed.1003647.

Batis, C., Rivera, J.A., Popkin, B.M. & Taillie, L.S. (2016) First-Year Evaluation of Mexico's Tax on Nonessential Energy-Dense Foods: An Observational Study. *PLoS Med*. 13 (7), e1002057. doi:10.1371/journal.pmed.1002057.

Berger, N., Cummins, S., Allen, A., Smith, R.D. & Cornelsen, L. (2020a) Patterns of beverage purchases amongst British households: A latent class analysis S. Basu (ed.). *PLoS Medicine*. 17 (9), e1003245. doi:10.1371/JOURNAL.PMED.1003245.

Berger, N., Cummins, S., Smith, R.D. & Cornelsen, L. (2020b) Have socio-economic inequalities in sugar purchasing widened? A longitudinal analysis of food and beverage consumer data from British households, 2014-2017. *Public Health Nutrition*. 1–27. doi:10.1017/S1368980020005029.

Bíró, A. (2015) Did the junk food tax make the Hungarians eat healthier? *Food Policy*. 54, 107–115. doi:10.1016/j.foodpol.2015.05.003.

Bíró, A. (2021) The impact of sweet food tax on producers and household spending—Evidence from Hungary. *Agricultural Economics (United Kingdom)*. agec.12634. doi:10.1111/agec.12634.

Blatt, A.D., Williams, R.A., Roe, L.S. & Rolls, B.J. (2012) Effects of Energy Content and Energy Density of Pre-Portioned Entrées on Energy Intake. *Obesity*. 20 (10), 2010–2018. doi:10.1038/oby.2011.391.

Bleich, S.N., Wolfson, J.A. & Jarlenski, M.P. (2017) Calorie changes in large chain restaurants from 2008 to 2015. *Preventive Medicine*. 100, 112–116. doi:10.1016/j.ypmed.2017.04.004.

Bloks, S.A. (2019) The Regulation of Trans Fats in Food Products in the US and the EU. *Utrecht Law Review*. 15 (3), 121–141. doi:10.36633/ulr.465.

Bobowski, N., Rendahl, A. & Vickers, Z. (2015) A longitudinal comparison of two salt reduction strategies: Acceptability of a low sodium food depends on the consumer. *Food Quality and Preference*. 40 (PB), 270–278. doi:10.1016/j.foodqual.2014.07.019.

Bourlakis, M.A. & Weightman, P.W.H. (2008) *Food supply chain management*. John Wiley & Sons.

Brandt, E.J., Myerson, R., Perraillon, M.C. & Polonsky, T.S. (2017) Hospital admissions for myocardial infarction and stroke before and after the trans-fatty acid restrictions in New York. *JAMA Cardiology*. 2 (6), 627–634. doi:10.1001/jamacardio.2017.0491.

Breen, M., James, H., Rangan, A. & Gemming, L. (2020) Prevalence of Product Claims and Marketing Buzzwords Found on Health Food Snack Products Does Not Relate to Nutrient Profile. *Nutrients*. 12 (5), 1513. doi:10.3390/nu12051513.

Bridge, G., Flint, S.W. & Tench, R. (2020) An exploration of the portrayal of the UK soft drinks industry levy in UK national newspapers. *Public Health Nutrition*. 1–9. doi:10.1017/S1368980020000208.

Briggs, A.D.M., Mytton, O.T., Kehlbacher, A., Tiffin, R., Elhussein, A., Rayner, M., Jebb, S.A., Blakely, T. & Scarborough, P. (2017) Health impact assessment of the UK soft drinks industry levy: a comparative risk assessment modelling study. *The Lancet Public Health*. 2 (1), e15–e22. doi:10.1016/S2468-2667(16)30037-8.

Briggs, A.D.M., Mytton, O.T., Kehlbacher, A., Tiffin, R., Rayner, M. & Scarborough, P. (2013) Overall and income specific effect on prevalence of overweight and obesity of 20% sugar sweetened drink tax in UK: Econometric and comparative risk assessment modelling study. *BMJ*. 347. doi:10.1136/bmj.f6189.

British Heart Foundation (2019) *7 easy ways to add more fibre to your diet - Heart Matters*. 2019. Heart Matters. https://www.bhf.org.uk/informationsupport/heart-matters-magazine/nutrition/fibre/fibre-swaps [Accessed: 31 August 2020].

British Nutrition Foundation (2020) *Dietary fibre*. 2020. https://www.nutrition.org.uk/healthyliving/basics/fibre.html [Accessed: 31 August 2020].

Buttriss, J.L. (2013) Food reformulation: the challenges to the food industry. *Proc Nutr Soc*. 72 (1), 61–69. doi:10.1017/S0029665112002868.

Bysted, A., Mikkelsen, A.A. & Leth, T. (2009) Substitution of trans fatty acids in foods on the Danish market. *European Journal of Lipid Science and Technology*. 111 (6), 574–583. http://www.ejlst.com.

Van Camp, D., De Souza Monteiro, D.M. & Hooker, N.H. (2012) Stop or go? How is the UK food industry responding to front-of-pack nutrition labels? *European Review of Agricultural Economics*. 39 (5), 821–842. doi:10.1093/erae/jbr063.

Capacci, S., Allais, O., Bonnet, C. & Mazzocchi, M. (2019) The impact of the French soda tax on prices and purchases. An ex post evaluation B. Shankar (ed.). *PLOS ONE*. 14 (10), e0223196. doi:10.1371/journal.pone.0223196.

Capacci, S. & Mazzocchi, M. (2011) Five-a-day, a price to pay: An evaluation of the UK program impact accounting for market forces. *Journal of Health Economics*. 30 (1), 87–98. doi:10.1016/j.jhealeco.2010.10.006.

Capewell, S. & Kypridemos, C. (2017) Socioeconomic inequalities in dietary sodium intake: Upstream versus downstream interventions. *American Journal of Public Health*. 107 (4), 499–500. doi:10.2105/AJPH.2017.303673.

Cengiz, E., Rojas, C. & Wang, E. (2019) *The Evolution of Diet Quality in the U . S .: Firms ' Actions and Consumers ' Reactions*.

Chawner, L.R., Blundell-Birtill, P. & Hetherington, M.M. (2021) Predictors of vegetable consumption in children and adolescents: Analyses of the UK National Diet and Nutrition Survey (2008-2017). *British Journal of Nutrition*.126 (2) pp.295–306. doi:10.1017/S0007114520004109.

Chazelas, E., Druesne-Pecollo, N., Esseddik, Y., de Edelenyi, F.S., Agaesse, C., et al. (2021) Exposure to food additive mixtures in 106,000 French adults from the NutriNet-Santé cohort. *Scientific Reports*. 11 (1), 1–21. doi:10.1038/s41598-021-98496-6.

Christoforou, A.K., Dunford, E.K. & Neal, B.C. (2013) Changes in the sodium content of australian ready meals between 2008 and 2011. *Asia Pacific Journal of Clinical Nutrition*. 22 (1), 138–143. doi:10.6133/apjcn.2013.22.1.10.

Clapp, J.E., Niederman, S.A., Leonard, E. & Curtis, C.J. (2018) Changes in Serving Size, Calories, and Sodium Content in Processed Foods From 2009 to 2015. *Preventing Chronic Disease*. 15 (33), 1–9. doi:https://dx.doi.org/10.5888/pcd15.170265.

Cleeren, K., Geyskens, K., Verhoef, P.C. & Pennings, J.M.E. (2016) Regular or low-fat? An investigation of the long-run impact of the first low-fat purchase on subsequent purchase volumes and calories. *International Journal of Research in Marketing*. 33 (4), 896–906. doi:10.1016/j.ijresmar.2016.04.001.

Cobiac, L., Irz, X., Leroy, P., Réquillart, V., Scarborough, P. & Soler, L.-G. (2019) Accounting for consumers' preferences in the analysis of dietary recommendations. *European Journal of Clinical Nutrition*. 73 (7), 1033–1039. doi:10.1038/s41430-018-0317-5.

Cohen, D.A. & Babey, S.H. (2012) Contextual influences on eating behaviours: Heuristic processing and dietary choices. *Obesity Reviews*. 13 (9), 766–779. doi:10.1111/j.1467-789X.2012.01001.x.

Colón-Ramos, U., Baylin, A. & Campos, H. (2006) The Relation between Trans Fatty Acid Levels and Increased Risk of Myocardial Infarction Does Not Hold at Lower Levels of Trans Fatty Acids in the Costa Rican Food Supply. *The Journal of Nutrition*. 136 (11), 2887–2892. doi:10.1093/jn/136.11.2887.

Combris, P., Goglia, R., Henini, M., Soler, L.-G. & Spiteri, M. (2011) Improvement of the nutritional quality of foods as a public health tool. *Public Health*. 125 (10), 717–724. doi:10.1016/j.puhe.2011.07.004.

Corvalán, C., Garmendia, M.L., Jones-Smith, J., Lutter, C.K., Miranda, J.J., Pedraza, L.S., Popkin, B.M., Ramirez-Zea, M., Salvo, D. & Stein, A.D. (2017) Nutrition status of children in Latin America. *Obesity Reviews*. 18, 7–18. doi:10.1111/obr.12571.

Da Costa Louzada, M.L., Ricardo, C.Z., Steele, E.M., Levy, R.B., Cannon, G. & Monteiro, C.A. (2018) The share of ultra-processed foods determines the overall nutritional quality of diets in Brazil. *Public Health Nutrition*. 21 (1), 94–102. doi:10.1017/S1368980017001434.

Coyle, D., Shahid, M., Dunford, E., Ni Mhurchu, C., McKee, S., Santos, M., Popkin, B., Trieu, K., Marklund, M., Neal, B. & Wu, J. (2021) Estimating the potential impact of Australia's reformulation programme on households' sodium purchases. *BMJ Nutrition, Prevention and Health*. 4 (1), 49–58. doi:10.1136/bmjnph-2020-000173.

Crino, M., Herrera, A.M.M., Ananthapavan, J., Wu, J.H.Y., Neal, B., Lee, Y.Y., Zheng, M., Lal, A. & Sacks, G. (2017) Modelled cost-effectiveness of a package size cap and a kilojoule reduction intervention to reduce energy intake from sugar-sweetened beverages in Australia. *Nutrients*. 9 (9), 1–17. doi:10.3390/nu9090983.

Curtis, C.J., Clapp, J., Niederman, S.A., Ng, S.W. & Angell, S.Y. (2016) US food industry progress during the National Salt Reduction Initiative: 2009-2014. *American Journal of Public Health*. 106 (10), 1815–1819. doi:http://dx.doi.org/10.2105/AJPH.2016.303397.

Darmon, N. & Drewnowski, A. (2015) Contribution of food prices and diet cost to socioeconomic disparities in diet quality and health: A systematic review and analysis. *Nutrition Reviews*. 73 (10), 643–660. doi:10.1093/nutrit/nuv027.

Deierlein, A.L., Peat, K. & Claudio, L. (2015) Comparison of the nutrient content of children's menu items at US restaurant chains, 2010-2014. *Nutrition Journal*. 14 (1), 1–7. doi:10.1186/s12937-015-0066-4.

Department for Digital, C.M. and S. & Department of Health & Social Care (2021) *Consultation outcome - Evidence note*. 2021. https://www.gov.uk/government/consultations/total-restriction-of-online-advertising-for-products-high-in-fat-sugar-and-salt-hfss/evidence-note [Accessed: 20 July 2021].

Dicken, S.J. & Batterham, R.L. (2021) The Role of Diet Quality in Mediating the Association between Ultra-Processed Food Intake, Obesity and Health-Related Outcomes: A Review of Prospective Cohort Studies. *Nutrients*. 14 (1), 23. doi:10.3390/nu14010023.

Dickson, A., Gehrsitz, M. & Kemp, J. (2021) *Does a Spoonful of Sugar Levy Help the Calories Go Down ? An Analysis of the UK Soft Drinks Industry Levy*. (IZA DP No. 14528). https://www.iza.org/de/publications/dp/14528/does-a-spoonful-of-sugar-levy-help-the-calories-go-down-an-analysis-of-the-uk-soft-drinks-industry-levy.

Downs, S.M., Bloem, M.Z., Zheng, M., Catterall, E., Thomas, B., Veerman, L. & Wu, J.H. (2017) The Impact of Policies to Reduce trans Fat Consumption: A Systematic Review of the Evidence. *Current Developments in Nutrition*. 1 (12). doi:10.3945/cdn.117.000778.

Downs, S.M., Thow, A.M. & Leeder, S.R. (2013) The effectiveness of policies for reducing dietary trans fat: a systematic review of the evidence. *Bull World Health Organ*. 91 (4), 262-9H. doi:10.2471/BLT.12.111468.

Dubois, P., Albuquerque, P., Allais, O., Bonnet, C., Bertail, P., Combris, P., Lahlou, S., Rigal, N., Ruffieux, B. & Chandon, P. (2020) Effects of front-of-pack labels on the nutritional quality of supermarket food purchases: evidence from a large-scale randomized controlled trial. *Journal of the Academy of Marketing Science*. 1–20. doi:10.1007/s11747-020-00723-5.

Ducharme, J. (2017) *Nutella Admits It Changed Its Recipe and Fans Are Not Happy | Time*. 9 November 2017. Time. https://time.com/5016830/nutella-recipe-change/ [Accessed: 29 November 2021].

Ducrot, P., Julia, C., Méjean, C., Kesse-Guyot, E., Touvier, M., Fezeu, L.K., Hercberg, S. & Péneau, S. (2016) Impact of different front-of-pack nutrition labels on consumer purchasing intentions: A randomized controlled trial. *American Journal of Preventive Medicine*. 50 (5), 627–636. doi:10.1016/j.amepre.2015.10.020.

Dumonteil, P. (2021) *Gâteaux, céréales, yaourts... Pourquoi sont-ils toujours aussi sucrés?* 2021. BFM Business. https://www.bfmtv.com/economie/consommation/gateaux-cereales-yaourts-pourquoi-sont-ils-toujours-aussi-sucres_AN-202110030161.html [Accessed: 29 November 2021].

Dunford, E.K., Wu, J.H.Y., Wellard-Cole, L., Watson, W., Crino, M., Petersen, K. & Neal, B. (2017) A comparison of the Health Star Rating system when used for restaurant fast foods and packaged foods. *Appetite*. 117, 1–8. doi:10.1016/j.appet.2017.06.005.

Elizabeth, L., Machado, P., Zinöcker, M., Baker, P. & Lawrence, M. (2020) Ultra-processed foods and health outcomes: A narrative review. *Nutrients*.12 (7) pp.1–36. doi:10.3390/nu12071955.

EU Platform on Diet Physical Activity and Health (2009) *Annual Report 2009*. http://ec.europa.eu/health/ph_determinants/life_style/nutrition/platform/docs/eu_platform_2009frep_en.pdf.

European Commission (2017) *Health equity pilot project (HEPP): the impact of taxes on 'junk food' in Hungary*. https://ec.europa.eu/health/sites/health/files/social_determinants/docs/hepp_case-studies_02_en.pdf.

European Parliament (2008) *Modernising the rules on food additives and labelling of azo dyes*. 3 July 2008. https://www.europarl.europa.eu/sides/getDoc.do?language=EN&type=IM-PRESS&reference=20080624BRI32584&secondRef=ITEM-004-EN [Accessed: 20 April 2020].

Eyles, H., Webster, J., Jebb, S., Capelin, C., Neal, B. & Ni Mhurchu, C. (2013) Impact of the UK voluntary sodium reduction targets on the sodium content of processed foods from 2006 to 2011: analysis of household consumer panel data. *Preventive medicine*. 57 (5), 555–560. doi:10.1016/j.ypmed.2013.07.024.

FAO (2018) *Sustainable food systems Concept and framework*.

FAO (2017) *The future of food and agriculture*. https://www.fao.org/3/i6583e/i6583e.pdf.

FAO, IFAD, UNICEF, WFP & WHO (2020) *The State of Food Security and Nutrition in the World 2020*. doi:10.4060/ca9692en.

FAO & WHO (2018) *The nutrition challenge and food system solutions*. http://www.fao.org/3/ca2024en/CA2024EN.pdf.

Fearne, A., Borzino, N., Iglesia, B.D. La, Moffatt, P. & Robbins, M. (2021) Using supermarket loyalty card data to measure the differential impact of the UK soft drink sugar tax on buyer behaviour. *Journal of Agricultural Economics*. doi:10.1111/1477-9552.12462.

Federici, C., Detzel, P., Petracca, F., Dainelli, L. & Fattore, G. (2019) The impact of food reformulation on nutrient intakes and health, a systematic review of modelling studies. *BMC Nutrition*. 5 (1), 2. doi:10.1186/s40795-018-0263-6.

Foschia, M., Peressini, D., Sensidoni, A. & Brennan, C.S. (2013) The effects of dietary fibre addition on the quality of common cereal products. *Journal of Cereal Science*.58 (2) pp.216–227. doi:10.1016/j.jcs.2013.05.010.

Foster, H.M.E., Celis-Morales, C.A., Nicholl, B.I., Petermann-Rocha, F., Pell, J.P., Gill, J.M.R., O'Donnell, C.A. & Mair, F.S. (2018) The effect of socioeconomic deprivation on the association between an extended measurement of unhealthy lifestyle factors and health outcomes: a prospective analysis of the UK Biobank cohort. *The Lancet Public Health*. 3 (12), e576–e585. doi:10.1016/S2468-2667(18)30200-7.

Friesen, R. & Innis, S.M. (2006) Trans Fatty Acids in Human Milk in Canada Declined with the Introduction of Trans Fat Food Labeling. *The Journal of Nutrition*. 136 (10), 2558–2561. doi:10.1093/jn/136.10.2558.

GBD 2017 Risk Factor Collaborators, Stanaway, J.D., Afshin, A., Gakidou, E., Lim, S.S., et al. (2018) Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Stu. *The Lancet*. 392 (10159), 1923–1994. doi:10.1016/S0140-6736(18)32225-6.

Gibson, R., Eriksen, R., Chambers, E., Gao, H., Aresu, M., Heard, A., Chan, Q., Elliott, P. & Frost, G. (2019) Intakes and food sources of dietary fibre and their associations with measures of body composition and inflammation in UK adults: Cross-sectional analysis of the airwave health monitoring study. *Nutrients*. 11 (8), 1839. doi:10.3390/nu11081839.

Global Panel on Agriculture and Food Systems for Nutrition (2016) *Food systems and diets: facing the challenges of the 21st century*. (February). http://glopan.org/sites/default/files/ForesightReport.pdf.

Grabovac, I., Hochfellner, L., Rieger, M., Jewell, J., Snell, A., Weber, A., Stüger, H.P., Schindler, K.E., Mikkelsen, B. & Dorner, T.E. (2018) Impact of Austria's 2009 trans fatty acids regulation on all-cause, cardiovascular and coronary heart disease mortality. *European journal of public health*. 28 (2), 4–9. doi:10.1093/eurpub/cky147.

Gressier, M., Privet, L., Mathias, K.C., Vlassopoulos, A., Vieux, F. & Masset, G. (2017) Modeled dietary impact of industry-wide food and beverage reformulations in the United States and France. *American Journal of Clinical Nutrition*. 106 (1), 225–232. doi:10.3945/ajcn.117.153361.

Gressier, M., Segal, A., Swinburn, B.A. & Gary Frost, F.S. (2019) What is the impact of food reformulation on individual's behaviour, nutrient intakes and health status? A systematic review of empirical evidence. *PROSPERO 2019 CRD42019127624*. https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=127624.

Gressier, M., Swinburn, B., Frost, G., Segal, A.B. & Sassi, F. (2021) What is the impact of food reformulation on individuals' behaviour, nutrient intakes and health status? A systematic review of empirical evidence. *Obesity Reviews*. 22 (2), 1–23. doi:10.1111/obr.13139.

Greve, C. & Neess, R.I. (2014) *The Evolution of the Whole Grain Partnership in Denmark*. https://research.cbs.dk/en/publications/the-evolution-of-the-whole-grain-partnership-in-denmark.

Grieger, J.A., Johnson, B.J., Wycherley, T.P. & Golley, R.K. (2017) Evaluation of Simulation Models that Estimate the Effect of Dietary Strategies on Nutritional Intake: A Systematic Review. *The Journal of nutrition*. 147 (5), 908–931. doi:https://dx.doi.org/10.3945/jn.116.245027.

Griffith, R., Jenneson, V., James, J. & Taylor, A. (2021) *Working paper The impact of a tax on added sugar and salt The impact of a tax on added sugar and salt*.

Griffith, R., O'Connell, M. & Smith, K. (2015) Relative prices, consumer preferences, and the demand for food. *Oxford Review of Economic Policy*. 31 (1), 116–130. doi:10.1093/oxrep/grv004.

Griffith, R., O'Connell, M. & Smith, K. (2017) The Importance of Product Reformulation Versus Consumer Choice in Improving Diet Quality. *Economica*. 84 (333), 34–53. doi:10.1111/ecca.12192.

Guadagni, P.M. & Little, J.D.C. (2008) A logit model of brand choice calibrated on scanner data. *Marketing Science*. 27 (1), 29–48. doi:10.1287/mksc.1070.0331.

Van Gunst, A., Roodenburg, A.J.C. & Steenhuis, I.H.M. (2018) Reformulation as an integrated approach of four disciplines: A qualitative study with food companies. *Foods*. 7 (4), 64. doi:10.3390/foods7040064.

Guttmann, A. (2021) *Advertising spending by media in the UK 1999-2019*. 2021. Statista.com. https://www.statista.com/statistics/248766/advertising-spending-in-the-uk-by-media/ [Accessed: 13 August 2020].

Hall, K.D., Ayuketah, A., Brychta, R., Cai, H., Cassimatis, T., et al. (2019) Ultra-Processed Diets Cause Excess Calorie Intake and Weight Gain: An Inpatient Randomized Controlled Trial of Ad Libitum Food Intake. *Cell metabolism*. 0 (0). doi:10.1016/j.cmet.2019.05.008.

Harel, C. (2016) *Intermarché réitère son opération Sucres Detox - Ultra frais*. 12 September 2016. https://www.lsa-conso.fr/intermarche-reitere-son-operation-sucres-detox,244518 [Accessed: 3 September 2020].

Hartmann, C., Dohle, S. & Siegrist, M. (2013) Importance of cooking skills for balanced food choices. *Appetite*. 65, 125–131. doi:10.1016/j.appet.2013.01.016.

Hashem, K.M., He, F.J. & MacGregor, G.A. (2017) Cross-sectional surveys of the amount of sugar, energy and caffeine in sugar-sweetened drinks marketed and consumed as energy drinks in the UK between 2015 and 2017: monitoring reformulation progress. *BMJ Open*. 7 (12), e018136. doi:http://dx.doi.org/10.1136/bmjopen-2017-018136.

Hashem, K.M., He, F.J. & MacGregor, G.A. (2019) Effects of product reformulation on sugar intake and health—a systematic review and meta-analysis. *Nutrition Reviews*. 77 (3), 181–196. doi:10.1093/nutrit/nuy015.

Hashem, K.M., He, F.J. & MacGregor, G.A. (2016) Systematic review of the literature on the effectiveness of product reformulation measures to reduce the sugar content of food and drink on the population's sugar consumption and health: a study protocol. *BMJ Open*. 6 (6), e011052. doi:10.1136/bmjopen-2016-011052.

Haverland, A. (2019) *Comment Intermarché va modifier 900 recettes pour augmenter ses scores Yuka*. 12 September 2019. L'Usine Nouv. https://www.usinenouvelle.com/article/comment-intermarche-va-modifier-900-recettes-pour-augmenter-ses-scores-yuka.N883175 [Accessed: 29 November 2021].

Haverland, A. (2021) *Kellogg's reformule ses recettes pour améliorer le Nutri-Score*. 13 May 2021. L'Usine Nouvelle. https://www.usinenouvelle.com/article/kellogg-s-reformule-ses-recettes-pour-ameliorer-le-nutri-score.N1092004 [Accessed: 29 November 2021].

Hawkes, C., Smith, T.G., Jewell, J., Wardle, J., Hammond, R.A., Friel, S., Thow, A.M. & Kain, J. (2015) Smart food policies for obesity prevention. *The Lancet*. 385 (9985), 2410–2421. doi:10.1016/s0140-6736(14)61745-1.

He, F.J., Brinsden, H.C. & MacGregor, G.A. (2014) Salt reduction in the United Kingdom: a successful experiment in public health. *J Hum Hypertens*. 28 (6), 345–352. doi:10.1038/jhh.2013.105.

He, F.J., Pombo-Rodrigues, S. & MacGregor, G.A. (2014) Salt reduction in England from 2003 to 2011: Its relationship to blood pressure, stroke and ischaemic heart disease mortality. *BMJ Open*. 4 (4), e004549. doi:10.1136/bmjopen-2013-004549.

Hendriksen, M.A.H., Geleijnse, J.M., Van Raaij, J.M.A., Cappuccio, F.P., Cobiac, L.C., Scarborough, P., Nusselder, W.J., Jaccard, A. & Boshuizen, H.C. (2017) Identification of differences in health impact modelling of salt reduction. *PLoS ONE*. 12 (11), 1–14. doi:10.1371/journal.pone.0186760.

Henninger, M. & Ulberth, F. (1996) Trans fatty acids in margarines and shortenings marketed in Austria. *Zeitschrift fur Lebensmittel-Untersuchung und -Forschung*. 203 (3), 210–215. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med4&NEWS=N&AN=8873458.

Herforth, A., Arimond, M., Álvarez-Sánchez, C., Coates, J., Christianson, K. & Muehlhoff, E. (2019) A Global Review of Food-Based Dietary Guidelines. *Advances in Nutrition*.10 (4) pp.590–605. doi:10.1093/advances/nmy130.

Hernández-F, M., Batis, C., Rivera, J.A. & Colchero, M.A. (2019) Reduction in purchases of energy-dense nutrient-poor foods in Mexico associated with the introduction of a tax in 2014. *Preventive Medicine*. 118, 16–22. doi:10.1016/j.ypmed.2018.09.019.

J.P.T. Higgins & S. Green (eds.) (2011) *Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 [updated March 2011]*. 2011. The Cochrane Collaboration. http://handbook.cochrane.org.

High Level Panel of Experts on Food Security (2017) *Nutrition and food systems*. www.fao.org/cfs/cfs-hlpe.

HM Government (2016) *Childhood obesity: a plan for action*. 2016. https://www.gov.uk/government/publications/childhood-obesity-a-plan-for-action/childhood-obesity-a-plan-for-action [Accessed: 1 December 2020].

S. Holger, J. Brożek, G. Guyatt, & A. Oxman (eds.) (2013) *GRADE Handbook: Handbook for grading the quality of evidence and the strength of recommendations using the GRADE approach.* October 20. https://gdt.gradepro.org/app/handbook/handbook.html.

Hollands, G.J., Shemilt, I., Marteau, T.M., Jebb, S.A., Lewis, H.B., Wei, Y., Higgins, J. & Ogilvie, D. (2015) Portion , package or tableware size for changing selection and consumption of food , alcohol and tobacco (Review). *Cochrane Database of Systematic Reviews*. (9). doi:10.1002/14651858.CD011045.pub2.Copyright.

Hutchinson, J., Rippin, H.L., Jewell, J., Breda, J.J. & Cade, J.E. (2018) Comparison of high and low trans-fatty acid consumers: Analyses of UK National Diet and Nutrition Surveys before and after product reformulation. *Public Health Nutrition*. 21 (3), 465–479. doi:10.1017/S1368980017002877.

Hyseni, L., Bromley, H., Kypridemos, C., O'Flaherty, M., Lloyd-Williams, F., Guzman-Castillo, M., Pearson-Stuttard, J., Capewell, S. & O'Flaherty, M. (2017a) Systematic review of dietary trans-fat reduction interventions. *Bulletin of the World Health Organization*. 95 (12), 821-830G. doi:10.2471/BLT.16.189795.

Hyseni, L., Elliot-Green, A., Lloyd-Williams, F., Kypridemos, C., O'Flaherty, M., McGill, R., Orton, L., Bromley, H., Cappuccio, F.P. & Capewell, S. (2017b) Systematic review of dietary salt reduction policies: Evidence for an effectiveness hierarchy? *PLoS One*. 12 (5), e0177535. doi:10.1371/journal.pone.0177535.

Jahn, J.L., Cohen, J.F.F.W., Gorski-Findling, M.T., Hoffman, J.A., Rosenfeld, L., Chaffee, R., Smith, L. & Rimm, E.B. (2018) Product reformulation and nutritional improvements after new competitive food standards in schools. *Public Health Nutrition*. 21 (5), 1011–1018. doi:10.1017/S1368980017003445.

Janssen, H.G., Davies, I.G., Richardson, L.D. & Stevenson, L. (2017) Determinants of takeaway and fast food consumption: a narrative review. *Nutrition Research Reviews*. 1–19. doi:10.1017/S0954422417000178.

Jarlenski, M.P., Wolfson, J.A. & Bleich, S.N. (2016) Macronutrient Composition of Menu Offerings in Fast Food Restaurants in the U.S. *American Journal of Preventive Medicine*. 51 (4), e91–e97. doi:10.1016/j.amepre.2016.03.023.

Jensen, J.D. & Sommer, I. (2017) Reducing calorie sales from supermarkets – 'silent' reformulation of retailer-brand food products. *International Journal of Behavioral Nutrition and Physical Activity*. 14 (1), 104. doi:10.1186/s12966-017-0559-y.

Jones-Smith, J.C., Gordon-Larsen, P., Siddiqi, A. & Popkin, B.M. (2011) Cross-national comparisons of time trends in overweight inequality by socioeconomic status among women using repeated cross-sectional surveys from 37 developing countries, 1989-2007. *American Journal of Epidemiology*. 173 (6), 667–675. doi:10.1093/aje/kwq428.

Kaldor, J.C. (2018) Food Reformulation for NCD-Prevention: Regulatory Options and Potential Barriers. *QUT Law Review*. 18 (1), 76. doi:10.5204/qutlr.v18i1.729.

Kaldor, J.C., Thow, A.M. & Schönfeldt, H. (2019) Using regulation to limit salt intake and prevent non-communicable diseases: Lessons from South Africa's experience. *Public Health Nutrition*. 22 (7), 1316–1325. doi:10.1017/S1368980018003166.

Kantar (n.d.) *Consumer Panels*. https://www.kantar.com/expertise/consumer-shopper-retail/consumer-panels [Accessed: 13 December 2021].

Kanter, R., Reyes, M., Vandevijvere, S., Swinburn, B. & Corvalán, C. (2019) Anticipatory effects of the implementation of the Chilean Law of Food Labeling and Advertising on food and beverage product reformulation. *Obesity Reviews*. 20 (S2), 129–140. doi:10.1111/obr.12870.

Kleef, E. Van & Dagevos, H. (2015) The Growing Role of Front-of-Pack Nutrition Profile Labeling: A Consumer Perspective on Key Issues and Controversies. *Critical Reviews in Food Science and Nutrition*. 55 (3), 291–303. doi:10.1080/10408398.2011.653018.

Knai, C., James, L., Petticrew, M., Eastmure, E., Durand, M.A. & Mays, N. (2017) An evaluation of a public-private partnership to reduce artificial trans fatty acids in England, 2011-16. *European Journal of Public Health*. 27 (4), 605–608. doi:10.1093/eurpub/ckx002.

Knai, C., Petticrew, M., Durand, M.A., Eastmure, E., James, L., Mehrotra, A., Scott, C. & Mays, N. (2015) Has a public-private partnership resulted in action on healthier diets in England? An analysis of the Public Health Responsibility Deal food pledges. *Food Policy*. 54, 1–10. doi:10.1016/j.foodpol.2015.04.002.

Koutoukidis, D.A., Jebb, S.A., Ordóñez-mena, J.M., Noreik, M., Tsiountsioura, M., Kennedy, S., Payne-riches, S., Aveyard, P., Ordonez-mena, J., Noreik, M., Tsiountsioura, M., Kennedy, S., Riches, S.P., Aveyard, P. & Piernas, C. (2019) Effectiveness of interventions to reduce the saturated fat content of food purchases: a factorial randomised controlled trial in an experimental online supermarket. *International Journal of Behavioural Nutrition and Physical Activity*. 1–14.

Kuhns, A. & Saksena, M. (2017) Food purchase decisions of millennial households compared to other generations. *U.S. Department of Agriculture, Economic Research Service*. (186), 1–51. https://www.ers.usda.gov/webdocs/publications/86401/eib-186.pdf?v=43097.

Lachat, C., Nago, E., Verstraeten, R., Roberfroid, D., Van Camp, J. & Kolsteren, P. (2012) Eating out of home and its association with dietary intake: A systematic review of the evidence. *Obesity Reviews*.13 (4) pp.329–346. doi:10.1111/j.1467-789X.2011.00953.x.

Lappi, V.-M., Mottas, A., Sundström, J., Neal, B., Löf, M. & Rådholm, K. (2020) A Comparison of the Nutritional Qualities of Supermarket's Own and Regular Brands of Bread in Sweden. *Nutrients*. 12 (4), 1162. doi:10.3390/nu12041162.

Laverty, A.A., Kypridemos, C., Seferidi, P., Vamos, E.P., Pearson-Stuttard, J., Collins, B., Capewell, S., Mwatsama, M., Cairney, P., Fleming, K., O'flaherty, M. & Millett, C. (2019) Quantifying the impact of the Public Health Responsibility Deal on salt intake, cardiovascular disease and gastric cancer burdens: Interrupted time series and microsimulation study. *Journal of Epidemiology and Community Health*. 73 (9), 881–887. doi:10.1136/jech-2018-211749.

Law, C., Cornelsen, L., Adams, J., Pell, D., Rutter, H., White, M. & Smith, R. (2020) The impact of UK Soft Drinks Industry Levy on manufacturers' domestic turnover. *Economics & Human Biology*. 37, 100866. doi:10.1016/j.ehb.2020.100866.

Leahy, K.E., Birch, L.L. & Rolls, B.J. (2008) Reducing the Energy Density of an Entrée Decreases Children's Energy Intake at Lunch. *Journal of the American Dietetic Association*. 108 (1), 41–48. doi:10.1016/j.jada.2007.10.015.

Ledikwe, J.H., Ello-Martin, J.A. & Rolls, B.J. (2005) Portion sizes and the obesity epidemic. In: *Journal of Nutrition*. 1 April 2005 American Institute of Nutrition. pp. 905–909. doi:10.1093/jn/135.4.905.

Lemmerer, A. (2016) Modeling the correct level of analysis in non-aggregated household panel data: A simulation approach. *Marketing Letters*. 27 (2), 247–257. doi:10.1007/s11002-014-9330-1.

Leroy, P., Requillart, V., Soler, L.-G. & Enderli, G. (2016) An assessment of the potential health impacts of food reformulation. *European Journal of Clinical Nutrition*. 70 (6), 694–699. doi:10.1038/ejcn.2015.201.

Li, M., Ho, K.K.H.Y., Hayes, M. & Ferruzzi, M.G. (2019) The Roles of Food Processing in Translation of Dietary Guidance for Whole Grains, Fruits, and Vegetables. *Annual Review of Food Science and Technology*. 10 (1), 569–596. doi:10.1146/annurev-food-032818-121330.

Lim, S.S., Vos, T., Flaxman, A.D., Danaei, G., Shibuya, K., et al. (2012) A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: A systematic analysis for the Global Burden of Disease Study 2010. *The Lancet*. 380 (9859), 2224–2260. doi:10.1016/S0140-6736(12)61766-8.

Lockyer, S. & Nugent, A.P. (2017) Health effects of resistant starch. *Nutrition Bulletin*.42 (1) pp.10–41. doi:10.1111/nbu.12244.

Lockyer, S. & Spiro, A. (2020) The role of bread in the UK diet: An update. *Nutrition Bulletin*.45 (2) pp.133–164. doi:10.1111/nbu.12435.

Lourenço, S., Hansen, G.L., Stærk, B., Frank, P. & Petersen, C.T. (2019) The Whole Grain

Partnership—How a Public–Private Partnership Helped Increase Whole Grain Intake in Denmark. *Cereal Foods World*. 64 (3), 1–9. doi:10.1094/cfw-64-3-0027.

Luger, M., Winzer, E., Schätzer, M., Dämon, S., Moser, N., et al. (2018) Gradual reduction of free sugars in beverages on sale by implementing the beverage checklist as a public health strategy. *European Journal of Public Health*. 1–6. doi:10.1093/eurpub/cky039.

Lumina Intelligence (n.d.) *Food, drink and nutrition market insight solutions*. https://www.lumina-intelligence.com/ [Accessed: 13 December 2021].

Magnusson, R. & Reeve, B. (2015) Food reformulation, responsive regulation, and "Regulatory Scaffolding": Strengthening performance of salt reduction programs in Australia and the United Kingdom. *Nutrients*. 7 (7), 5281–5308. doi:10.3390/nu7075221.

Maguire, E.R. & Monsivais, P. (2014) Socio-economic dietary inequalities in UK adults: An updated picture of key food groups and nutrients from national surveillance data. *British Journal of Nutrition*. 57 (2). doi:10.1017/S0007114514002621.

Mak, T.N., Prynne, C.J., Cole, D., Fitt, E., Bates, B. & Stephen, A.M. (2013) Patterns of sociodemographic and food practice characteristics in relation to fruit and vegetable consumption in children: Results from the UK National Diet and Nutrition Survey Rolling Programme (2008-2010). *Public Health Nutrition*. 16 (11), 1912–1923. doi:10.1017/S1368980013001912.

Mancino, L., Kuchler, F. & Leibtag, E. (2008) Getting consumers to eat more whole-grains: The role of policy, information, and food manufacturers. *Food Policy*. 33 (6), 489–496. doi:10.1016/j.foodpol.2008.05.005.

Mancino, L., Todd, J. & Lin, B.H. (2009) Separating what we eat from where: Measuring the effect of food away from home on diet quality. *Food Policy*. 34 (6), 557–562. doi:10.1016/j.foodpol.2009.09.003.

Markey, O., Le Jeune, J. & Lovegrove, J.A. (2016) Energy compensation following consumption of sugar-reduced products: a randomized controlled trial. *European Journal of Nutrition*. 55 (6), 2137–2149. doi:5.

Marotta, G., Simeone, M. & Nazzaro, C. (2014) Product reformulation in the food system to improve food safety. Evaluation of policy interventions. *Appetite*. 74 (health is a LATENT demand because consumers lack of information, and there is "information asymmetry" between producers and consumers), 107–115. doi:10.1016/j.appet.2013.12.003.

McGill, C.R., Fulgoni, V.L. & Devareddy, L. (2015) Ten-year trends in fiber and whole grain intakes and food sources for the united states population: National health and nutrition examination survey 2001-2010. *Nutrients*. 7 (2), 1119–1130. doi:10.3390/nu7021119.

McLaren, L., McIntyre, L. & Kirkpatrick, S. (2010) Rose's population strategy of prevention need not increase social inequalities in health. *International Journal of Epidemiology*. 39 (2), 372–377. doi:10.1093/ije/dyp315.

McLaren, L., Sumar, N., Barberio, A.M., Trieu, K., Lorenzetti, D.L., Tarasuk, V., Webster, J. & Campbell, N.R. (2016) Population-level interventions in government jurisdictions for dietary sodium reduction. *Cochrane Database of Systematic Reviews*. 2016 (9), CD010166. doi:10.1002/14651858.CD010166.pub2.

McMahon, E., Webster, J. & Brimblecombe, J. (2017) Effect of 25% sodium reduction on sales of a top-selling bread in remote indigenous australian community stores: A controlled intervention trial. *Nutrients*. 9 (3), 214. doi:http://dx.doi.org/10.3390/nu9030214.

McMichael, A.J., Powles, J.W., Butler, C.D. & Uauy, R. (2007) Food, livestock production, energy, climate change, and health. *Lancet*.370 (9594) pp.1253–1263. doi:10.1016/S0140-6736(07)61256-2.

Millett, C., Laverty, A.A., Stylianou, N., Bibbins-Domingo, K. & Pape, U.J. (2012) Impacts of a national strategy to reduce population salt intake in England: serial cross sectional study. *PLoS One*. 7 (1), e29836. doi:10.1371/journal.pone.0029836.

Mintel Press Team (2015) *Mintel serves up 5 key food and drink trends for 2015*. 2015. https://www.mintel.com/press-centre/food-and-drink/mintel-serves-up-5-key-food-and-drink-trends-for-2015 [Accessed: 20 April 2020].

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Altman, D., et al. (2009) Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine*.6 (7) p.e1000097. doi:10.1371/journal.pmed.1000097.

Monge-Rojas, R., Aragón, M.C., Chinnock, A., Campos, H. & Colón-Ramos, U. (2013) Changes in dietary intake and food sources of saturated and cis and trans unsaturated fatty acids in Costa Rican adolescents: 1996 versus 2006. *Nutrition*. 29 (4), 641–645. doi:10.1016/j.nut.2012.10.004.

Monge-Rojas, R., Colon-Ramos, U., Jacoby, E., Alfaro, T., Carmo, M. das G.T. do, Villalpando, S. & Bernal, C. (2017) Progress towards elimination of trans-fatty acids in foods commonly consumed in four Latin American cities. *Public Health Nutrition*. 20 (13), 2440–2449. doi:http://dx.doi.org/10.1017/s1368980017001227.

Monsivais, P., Aggarwal, A. & Drewnowski, A. (2014) Time spent on home food preparation and indicators of healthy eating. *American Journal of Preventive Medicine*. 47 (6), 796–802. doi:10.1016/j.amepre.2014.07.033.

Monteiro, C.A., Moubarac, J.-C., Levy, R.B., Canella, D.S., Da Costa Louzada, M.L. & Cannon, G. (2018) Household availability of ultra-processed foods and obesity in nineteen European countries. *Public Health Nutrition*. 21 (1), 18–26. doi:10.1017/S1368980017001379.

Morley, B.C., Niven, P.H., Dixon, H.G., Swanson, M.G., Mcaleese, A.B. & Wakefield, M.A. (2018) Controlled cohort evaluation of the LiveLighter mass media campaign's impact on adults' reported consumption of sugar-sweetened beverages. *BMJ Open*. 8, 19574. doi:10.1136/bmjopen-2017-019574.

Morrison, H., Meloncelli, N. & Pelly, F.E. (2018) Nutritional quality and reformulation of a selection of children's packaged foods available in Australian supermarkets: Has the Health Star Rating had an impact? *Nutrition & Dietetics*. doi:10.1111/1747-0080.12486.

Mozaffarian, D., Angell, S.Y., Lang, T. & Rivera, J.A. (2018) Role of government policy in nutrition—barriers to and opportunities for healthier eating. *BMJ*. 361, k2426. doi:10.1136/bmj.k2426.

Mozaffarian, D., Jacobson, M.F. & Greenstein, J.S. (2010) Food Reformulations to Reduce Trans Fatty Acids. *New England Journal of Medicine*. 362 (21), 2037–2039. doi:10.1056/NEJMc1001841.

Mozaffarian, D., Katan, M.B., Ascherio, A., Stampfer, M.J., Willett, W.C., Jacobson, M.F. & Greenstein, J.S. (2006) Trans Fatty Acids and Cardiovascular Disease. *New England Journal of Medicine*. 354 (15), 1601–1613. doi:10.1056/NEJMra054035.

Mozaffarian, D., Rosenberg, I. & Uauy, R. (2018) History of modern nutrition science-implications for current research, dietary guidelines, and food policy. *BMJ*. 361, k2392. doi:10.1136/bmj.k2392.

Murphy, S., Ruel, M. & Carriquiry, A. (2012) Should Household Consumption and

Expenditures Surveys (HCES) be used for nutritional assessment and planning? *Food and nutrition bulletin*.33 (3 Suppl) pp.S235–S241. doi:10.1177/15648265120333s213.

Namba, A., Auchincloss, A., Leonberg, B.L. & Wootan, M.G. (2013) Exploratory analysis of fast-food chain restaurant menus before and after implementation of local calorie-labeling policies, 2005-2011. *Preventing chronic disease*. 10, E101. doi:https://dx.doi.org/10.5888/pcd10.120224.

NatCen Social Research & MRC Elsie Widdowson Laboratory (2019) *National Diet and Nutrition Survey Years 1-9, 2008/09-2016/17*. doi:10.5255/UKDA-SN-6533-15.

National Heart Foundation of Australia (2012) *Effectiveness of food reformulation as a strategy to improve population health*.

NCD Risk Factor Collaboration (2019) Rising rural body-mass index is the main driver of the global obesity epidemic in adults. *Nature*. 569 (7755), 260–264. doi:10.1038/s41586-019-1171-x.

NCD Risk Factor Collaboration (NCD-RisC) (2020) Repositioning of the global epicentre of non-optimal cholesterol. *Nature*. 582 (7810), 73–77. doi:10.1038/s41586-020-2338-1.

Ng, S.W. & Popkin, B.M. (2014) The healthy weight commitment foundation pledge: Calories purchased by U.S. households with children, 2000-2012. *American Journal of Preventive Medicine*. 47 (4), 520–530. doi:http://dx.doi.org/10.1016/j.amepre.2014.05.030.

Ng, S.W., Slining, M.M. & Popkin, B.M. (2014) The healthy weight commitment foundation pledge: Calories sold from U.S. consumer packaged goods, 2007-2012. *American Journal of Preventive Medicine*. 47 (4), 508–519. doi:http://dx.doi.org/10.1016/j.amepre.2014.05.029.

NHS (2019) *How to get more fibre into your diet*. 2019. https://www.nhs.uk/live-well/eat-well/how-to-get-more-fibre-into-your-diet/ [Accessed: 31 August 2020].

Ni Mhurchu, C., Eyles, H. & Choi, Y.H. (2017) Effects of a voluntary front-of-pack nutrition labelling system on packaged food reformulation: The health star rating system in New Zealand. *Nutrients*. 9 (8), 918. doi:10.3390/nu9080918.

Niblett, P., Coyle, N., Little, E., Beaton, C., Burton, J., Chisholm, S., Tedstone, A., Targett, V., Nicholas, J., Montel, S., Knowles, B., Pyne, V., Jennifer Lynas, J. & Fitzpatrick, U. (2019) *Sugar reduction : report on progress between 2015 and 2018*. https://www.gov.uk/government/publications/sugar-reduction-progress-between-2015-and-2018.

Ning, S.X., Mainvil, L.A., Thomson, R.K. & McLean, R.M. (2017) Dietary sodium reduction in New Zealand: influence of the Tick label. *Asia Pacific Journal of Clinical Nutrition*. 26 (6), 1133–1138. doi:10.6133/apjcn.032017.06.

Nutrition and Food Systems Division (2016) Influencing food environments for healthy diets through the production of diversified foods. *Influencing food environments for healthy diets*.

Office for National Statistics (2021) *Total deaths in the UK in 2020 and deaths from heart attacks, heart disease, cancer, and Alzheimer's and dementia, 2016 to 2020*. 2021. https://www.ons.gov.uk/aboutus/transparencyandgovernance/freedomofinformationfoi/totaldeathsintheukin2020anddeathsfromheartattacksheartdiseasecancerandalzheimersanddementia2016to2020 [Accessed: 5 October 2021].

Oqali (2016) *Bilan des premiers résultats des suivis des évolutions - Etude de l'évolution des produits transformés disponibles sur le marché français par secteur entre 2008-2010 et 2010-2013*. https://www.oqali.fr/content/download/3452/33055/file/Oqali 2016_Rapport_Bilan des premiers resultats des suivis des evolutions.pdf.

Otten, J.J., Hekler, E.B., Krukowski, R.A., Buman, M.P., Saelens, B.E., Gardner, C.D. & King, A.C. (2012) Food marketing to children through toys: Response of restaurants to the first U.S. toy ordinance. *American Journal of Preventive Medicine*. 42 (1), 56–60. doi:10.1016/j.amepre.2011.08.020.

Otten, J.J., Saelens, B.E., Kapphahn, K.I., Hekler, E.B., Buman, M.P., Goldstein, B.A., Krukowski, R.A., O'Donohue, L.S., Gardner, C.D. & King, A.C. (2014) Impact of San Francisco's toy ordinance on restaurants and children's food purchases, 2011-2012. *Preventing Chronic Disease*. 11 (7), E122. internal-pdf://62.2.218.141/Otten_San Francisco standards free toys.pdf.

Ouzzani, M., Hammady, H., Fedorowicz, Z. & Elmagarmid, A. (2016) Rayyan—a web and mobile app for systematic reviews. *Systematic Reviews 2016 5:1*. 5 (1), 1–10. doi:10.1186/S13643-016-0384-4.

Panjwani, C. & Caraher, M. (2014) The Public Health Responsibility Deal: brokering a deal for public health, but on whose terms? *Health policy (Amsterdam, Netherlands)*. 114 (2–3), 163–173. doi:10.1016/J.HEALTHPOL.2013.11.002.

Payne Riches, S., Aveyard, P., Piernas, C., Rayner, M. & Jebb, S.A. (2019) Optimising swaps to reduce the salt content of food purchases in a virtual online supermarket: A randomised controlled trial. *Appetite*. 133, 378–386. doi:10.1016/j.appet.2018.11.028.

Pechey, R., Jebb, S.A., Kelly, M.P., Almiron-Roig, E., Conde, S., Nakamura, R., Shemilt, I., Suhrcke, M. & Marteau, T.M. (2013) Socioeconomic differences in purchases of more vs. less healthy foods and beverages: Analysis of over 25,000 British households in 2010. *Social Science & Medicine (1982)*. 92, 22. doi:10.1016/J.SOCSCIMED.2013.05.012.

Pell, D., Mytton, O., Penney, T.L., Briggs, A., Cummins, S., Penn-Jones, C., Rayner, M., Rutter, H., Scarborough, P., Sharp, S.J., Smith, R.D., White, M. & Adams, J. (2021) Changes in soft drinks purchased by British households associated with the UK soft drinks industry levy: controlled interrupted time series analysis. *BMJ*. 372, n254. doi:10.1136/bmj.n254.

Pell, D., Penney, T.L., Mytton, O., Briggs, A., Cummins, S., Rayner, M., Rutter, H., Scarborough, P., Sharp, S.J., Smith, R.D., White, M. & Adams, J. (2020) Anticipatory changes in British household purchases of soft drinks associated with the announcement of the Soft Drinks Industry Levy: A controlled interrupted time series analysis B.M. Popkin (ed.). *PLOS Medicine*. 17 (11), e1003269. doi:10.1371/journal.pmed.1003269.

Pereira, M.A., O'Reilly, E., Augustsson, K., Fraser, G.E., Goldbourt, U., Heitmann, B.L., Hallmans, G., Knekt, P., Liu, S., Pietinen, P., Spiegelman, D., Stevens, J., Virtamo, J., Willett, W.C. & Ascherio, A. (2004) Dietary Fiber and Risk of Coronary Heart Disease: A Pooled Analysis of Cohort Studies. *Archives of Internal Medicine*. 164 (4), 370–376. doi:10.1001/archinte.164.4.370.

Perrin, C., Battisti, C., Chambefort, A., Digaud, O., Duplessis, B., Volatier, J.L., Gauvreau-Béziat, J. & Ménard, C. (2018) A comparison of the nutritional content of processed foods available on the French market, according to the type of brand, and potential impact on nutrient intakes—An Oqali study. *Food Science and Nutrition*. 6 (6), 1410–1421. doi:10.1002/fsn3.655.

von Philipsborn, P., Stratil, J.M., Burns, J., Busert, L.K., Pfadenhauer, L.M., Polus, S., Holzapfel, C., Hauner, H. & Rehfuess, E. (2019) Environmental interventions to reduce the consumption of sugar-sweetened beverages and their effects on health. *Cochrane Database of Systematic Reviews*. 2019 (6). doi:10.1002/14651858.CD012292.pub2.

Pigat, S., Connolly, A., Cushen, M., Cullen, M. & O'Mahony, C. (2018) A probabilistic intake model to estimate the impact of reformulation by the food industry among Irish consumers.

International journal of food sciences and nutrition. 1–8. doi:https://dx.doi.org/10.1080/09637486.2018.1438375.

Plessz, M. & Étilé, F. (2019) Is Cooking Still a Part of Our Eating Practices? Analysing the Decline of a Practice with Time-Use Surveys. *Cultural Sociology*. 13 (1), 93–118. doi:10.1177/1749975518791431.

Popkin, B.M. (2017) Relationship between shifts in food system dynamics and acceleration of the global nutrition transition. *Nutrition Reviews*. 75 (2), 73–82. doi:10.1093/nutrit/nuw064.

Popkin, B.M., Adair, L.S. & Ng, S.W. (2012) Global nutrition transition and the pandemic of obesity in developing countries. *Nutrition Reviews*. 70 (1), 3–21. doi:10.1111/j.1753-4887.2011.00456.x.

Popkin, B.M., Barquera, S., Corvalan, C., Hofman, K.J., Monteiro, C., Ng, S.W., Swart, E.C. & Taillie, L.S. (2021) Towards unified and impactful policies to reduce ultra-processed food consumption and promote healthier eating. *The Lancet Diabetes & Endocrinology*. 9 (7), 462–470. doi:10.1016/S2213-8587(21)00078-4.

Popkin, B.M., Corvalan, C. & Grummer-Strawn, L.M. (2020) Dynamics of the double burden of malnutrition and the changing nutrition reality. *The Lancet*.395 (10217) pp.65–74. doi:10.1016/S0140-6736(19)32497-3.

Popkin, B.M. & Kenan, W.R. (2016) Preventing type 2 diabetes: Changing the food industry. *Best Practice and Research: Clinical Endocrinology and Metabolism*. 30 (3), 373–383. doi:10.1016/j.beem.2016.05.001.

Poti, J.M., Dunford, E.K. & Popkin, B.M. (2017) Sodium reduction in US households' packaged food and beverage purchases, 2000 to 2014. *JAMA Internal Medicine*. 177 (7), 986–994. doi:10.1001/jamainternmed.2017.1407.

Poti, J.M., Mendez, M.A., Ng, S.W. & Popkin, B.M. (2015) Is the degree of food processing and convenience linked with the nutritional quality of foods purchased by US households? *American Journal of Clinical Nutrition*. 101 (6), 1251–1262. doi:10.3945/ajcn.114.100925.

Poti, J.M., Yoon, E., Hollingsworth, B., Ostrowski, J., Wandell, J., Miles, D.R. & Dunford, E. (2017) Monitoring changes in sodium intake for the US population between 2007 and 2012: A novel approach using a crosswalk between nutrition label data and dietary recalls. *FASEB Journal*. 31 (1 Supplement 1). http://www.fasebj.org/content/31/1_Supplement/302.3.abstract?sid=fa96af40-450e-4507-95bf-8ad32f1591a.

Public Health England (2018) *Calorie reduction: The scope and ambition for action*. https://www.gov.uk/government/publications/calorie-reduction-the-scope-and-ambition-for-action.

Public Health England (2020a) *Calorie reduction - Technical report: guidelines for industry, 2017 baseline calorie levels and the next steps*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/915367/Calorie_reduction_guidelines-Technical_report_070920-FINAL.pdf.

Public Health England (2017a) *Health matters: combating high blood pressure*. https://www.gov.uk/government/publications/health-matters-combating-high-blood-pressure/health-matters-combating-high-blood-pressure.

Public Health England (2020b) *National Diet and Nutrition Survey, Assessment of salt intake from urinary sodium in adults (aged 19 to 64 years) in England, 2018 to 2019*. https://www.gov.uk/government/statistics/national-diet-and-nutrition-survey-assessment-of-salt-intake-from-urinary-sodium-in-adults-aged-19-to-64-years-in-england-2018-to-2019.

Public Health England (2020c) *Salt reduction targets for 2024*. https://www.gov.uk/government/publications/salt-reduction-targets-for-2024.

Public Health England (2020d) *Salt targets 2017: Second progress report*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/915371/Salt_targets_2017_Second_progress_report_031020.pdf.

Public Health England (2017b) *Sugar Reduction: Achieving the 20%*. https://www.gov.uk/government/publications/sugar-reduction-achieving-the-20.

Public Health England (2015) *Sugar Reduction: The evidence for action*. (October). https://www.gov.uk/government/publications/sugar-reduction-from-evidence-into-action.

Public Health England (2020e) *Sugar reduction Report on progress between 2015 and 2019*. (October). https://www.gov.uk/government/publications/sugar-reduction-report-on-progress-between-2015-and-2019.

Public Health England & Food Standards Agency (2019) *Years 1 to 9 of the Rolling Programme (2008/2009 – 2016/2017): Time trend and income analyses*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/772434/NDNS_UK_Y1-9_report.pdf.

Quilez, J. & Salas-Salvado, J. (2016) The feasibility and acceptability of reducing salt in partially baked bread: A Spanish case study. *Public Health Nutrition*. 19 (6), 983–987. doi:10.1017/S1368980015000944.

Van Raaij, J., Hendriksen, M. & Verhagen, H. (2009) Potential for improvement of population diet through reformulation of commonly eaten foods. *Public Health Nutrition*. 12 (3), 325–330. doi:10.1017/S1368980008003376.

Ratnayake, W.M.N., L'Abbé, M.R. & Mozaffarian, D. (2009) Nationwide product reformulations to reduce trans fatty acids in Canada: When trans fat goes out, what goes in? *European Journal of Clinical Nutrition*. 63 (6), 808–811. doi:10.1038/ejcn.2008.39.

Ratnayake, W.M.N., Swist, E., Zoka, R., Gagnon, C., Lillycrop, W. & Pantazapoulos, P. (2014) Mandatory trans fat labeling regulations and nationwide product reformulations to reduce trans fatty acid content in foods contributed to lowered concentrations of trans fat in Canadian women's breast milk samples collected in 2009-2011. *American Journal of Clinical Nutrition*. 100 (4), 1036–1040. doi:10.3945/ajcn.113.078352.

Rauber, F., Louzada, M.L. da C., Steele, E.M., Millett, C., Monteiro, C.A. & Levy, R.B. (2018) Ultra-processed food consumption and chronic non-communicable diseases-related dietary nutrient profile in the UK (2008–2014). *Nutrients*. 10 (5). doi:10.3390/nu10050587.

Rayner, M. (2017) Nutrient profiling for regulatory purposes. *Proc Nutr Soc*. 76 (3), 230–236. doi:10.1017/S0029665117000362.

Reardon, T., Timmer, C.P. & Minten, B. (2012) Supermarket revolution in Asia and emerging development strategies to include small farmers. *Proceedings of the National Academy of Sciences of the United States of America*.109 (31) pp.12332–12337. doi:10.1073/pnas.1003160108.

Regan, Á., Kent, M.P., Raats, M.M., McConnon, Á., Wall, P. & Dubois, L. (2017) Applying a consumer behavior lens to salt reduction initiatives. *Nutrients*. 9 (8), 1–9. doi:10.3390/nu9080901.

Rekhy, R. & McConchie, R. (2014) Promoting consumption of fruit and vegetables for better health. Have campaigns delivered on the goals? *Appetite*.79 pp.113–123. doi:10.1016/j.appet.2014.04.012.

Requillart, V. & Soler, L.-G. (2014) Is the reduction of chronic diseases related to food consumption in the hands of the food industry? *European Review of Agricultural Economics*. 41 (3), 375–403. doi:10.1093/erae/jbu010.

Restrepo, B.J. & Rieger, M. (2016a) Denmark's policy on artificial trans fat and cardiovascular disease. *American Journal of Preventive Medicine*. 50 (1), 69–76. doi:http://dx.doi.org/10.1016/j.amepre.2015.06.018.

Restrepo, B.J. & Rieger, M. (2016b) Trans fat and cardiovascular disease mortality: Evidence from bans in restaurants in New York. *Journal of Health Economics*. 45, 176–196. doi:http://dx.doi.org/10.1016/j.jhealeco.2015.09.005.

Reyes, M., Taillie, L.S., Popkin, B., Kanter, R., Vandevijvere, S. & Corvalán, C. (2020) Changes in the amount of nutrient of packaged foods and beverages after the initial implementation of the Chilean Law of Food Labelling and Advertising: A nonexperimental prospective study. *PLOS Medicine*. 17 (7), e1003220. doi:10.1371/journal.pmed.1003220.

Riis, N.L., Bjoernsbo, K.S., Toft, U., Trolle, E., Hyldig, G., Hartley, I.E., Keast, R. & Lassen, A.D. (2021) Impact of salt reduction interventions on salt taste sensitivity and liking, a cluster randomized controlled trial. *Food Quality and Preference*. 87, 104059. doi:10.1016/j.foodqual.2020.104059.

RIVM National institute for Public Health and the Environment (2016) *Food Reformulation - RIVM*. 2016. https://www.rivm.nl/en/Topics/F/Food_Reformulation [Accessed: 30 May 2018].

Robinson, E., Blake, M.R. & Sacks, G. (2020) Benchmarking Food and Beverage Companies on Obesity Prevention and Nutrition Policies: Evaluation of the BIA-Obesity Australia Initiative, 2017-2019. *International Journal of Health Policy and Management*. 2020, 1–14. doi:10.34172/ijhpm.2020.147.

Rodgers, A., Woodward, A., Swinburn, B. & Dietz, W.H. (2018) Prevalence trends tell us what did not precipitate the US obesity epidemic. *The Lancet Public Health*.3 (4) pp.e162–e163. doi:10.1016/S2468-2667(18)30021-5.

Rodrigues, V.M., Rayner, M., Fernandes, A.C., De Oliveira, R.C., Da Costa Proença, R.P. & Fiates, G.M.R. (2016) Comparison of the nutritional content of products, with and without nutrient claims, targeted at children in Brazil. *British Journal of Nutrition*. 115 (11), 2047–2056. doi:10.1017/S0007114516001021.

Rodriguez-Fernandez, R., Siopa, M., Simpson, S.J., Amiya, R.M., Breda, J. & Cappuccio, F.P. (2014) Review articlecurrent salt reduction policies across gradients of inequality-adjusted human development in the WHO european region: Minding the gaps. *Public Health Nutrition*. 17 (8), 1894–1904. doi:10.1017/S136898001300195X.

Rose, G. (1992) notion of superficial to radical approach page 134. *The strategy of preventive medicine*. Oxford University Press. https://books.google.co.uk/books?hl=en&lr=&id=BQDXQI8n7qQC&oi=fnd&pg=PR17&dq=The+Strategy+of+Preventive+Medicine&ots=Rp1pOH-P9K&sig=5iJI8g0V4HzFhu7I1UVP12V7XyE#v=snippet&q=superficial&f=false.

Sacerdote, C., Ricceri, F., Rolandsson, O., Baldi, I., Chirlaque, M.-D., et al. (2012) Lower educational level is a predictor of incident type 2 diabetes in European countries: The EPIC-InterAct study. *International Journal of Epidemiology*. 41 (4), 1162–1173. doi:10.1093/IJE/DYS091.

Salgado Hernández, J.C. & Ng, S.W. (2021) Simulating international tax designs on sugar-sweetened beverages in Mexico G. Paraje (ed.). *PLOS ONE*. 16 (8), e0253748. doi:10.1371/journal.pone.0253748.

Salles, C., Kerjean, J.R., Veiseth-Kent, E., Stieger, M., Wilde, P. & Cotillon, C. (2017) The TeRiFiQ project: Combining technologies to achieve significant binary reductions in sodium, fat and sugar content in everyday foods whilst optimising their nutritional quality. *Nutrition Bulletin*. 42 (4), 361–368. doi:10.1111/nbu.12297.

Sallis, J.F. & Glanz, K. (2009) Physical activity and food environments: Solutions to the obesity epidemic. *Milbank Quarterly*. 87 (1), 123–154. doi:10.1111/j.1468-0009.2009.00550.x.

Savio, S., Mehta, K., Udell, T. & Coveney, J. (2013) A survey of the reformulation of Australian child-oriented food products. *BMC Public Health*. 13 (1). doi:10.1186/1471-2458-13-836.

Scarborough, P., Adhikari, V., Harrington, R.A., Elhussein, A., Briggs, A., Rayner, M., Adams, J., Cummins, S., Penney, T. & White, M. (2020) Impact of the announcement and implementation of the UK Soft Drinks Industry Levy on sugar content, price, product size and number of available soft drinks in the UK, 2015-19: A controlled interrupted time series analysis B.M. Popkin (ed.). *PLoS medicine*. 17 (2), e1003025. doi:10.1371/journal.pmed.1003025.

Scheelbeek, P.F.D., Cornelsen, L., Marteau, T.M., Jebb, S.A. & Smith, R.D. (2019) Potential impact on prevalence of obesity in the UK of a 20% price increase in high sugar snacks: Modelling study. *The BMJ*. 366, l4786. doi:10.1136/bmj.l4786.

Schouten, A.P., Janssen, L. & Verspaget, M. (2020) Celebrity vs. Influencer endorsements in advertising: the role of identification, credibility, and Product-Endorser fit. *International Journal of Advertising*. 39 (2), 258–281. doi:10.1080/02650487.2019.1634898.

Scientific Advisory Committee on Nutrition (2015) Carbohydrates and Health. *TSO The Stationary Office*. (August). www.tsoshop.co.uk.

Scientific Advisory Committee on Nutrition (2011) *Dietary Reference Values for Energy Scientific Advisory Committee on Nutrition 2011*. www.sacn.gov.uk.

Scott, C., Hawkins, B. & Knai, C. (2017) Food and beverage product reformulation as a corporate political strategy. *Social Science and Medicine*. 172, 37–45. doi:10.1016/j.socscimed.2016.11.020.

Shangguan, S., Afshin, A., Shulkin, M., Ma, W., Marsden, D., Smith, J., Saheb-Kashaf, M., Shi, P., Micha, R., Imamura, F. & Mozaffarian, D. (2019) A Meta-Analysis of Food Labeling Effects on Consumer Diet Behaviors and Industry Practices. *American Journal of Preventive Medicine*. 56 (2), 300–314. doi:10.1016/j.amepre.2018.09.024.

Shankar, B., Brambila-Macias, J., Traill, B., Mazzocchi, M. & Capacci, S. (2013) An evaluation of the UK Food Standards Agency's salt campaign. *Health Economics*. 22 (2), 243–250. doi:10.1002/hec.2772.

Singh, J., Ehrenberg, A. & Goodhardt, G. (2008) Measuring customer loyalty to product variants. *International Journal of Market Research*. 50 (4), 513–532. doi:10.1177/147078530805000408.

Slimani, N., Deharveng, G., Southgate, D.A.T., Biessy, C., Chajès, V., et al. (2009) Contribution of highly industrially processed foods to the nutrient intakes and patterns of middle-aged populations in the European Prospective Investigation into Cancer and Nutrition study. *European Journal of Clinical Nutrition*. 63 (S4), S206–S225. doi:10.1038/ejcn.2009.82.

Sloan, A.E. (2015) *The Top Ten Food Trends*. 2015. IFT.org. https://www.ift.org/news-and-publications/food-technology-magazine/issues/2015/april/features/the-top-ten-food-trends

[Accessed: 13 August 2020].

Smed, S., Scarborough, P., Rayner, M. & Jensen, J.D. (2016) The effects of the Danish saturated fat tax on food and nutrient intake and modelled health outcomes: An econometric and comparative risk assessment evaluation. *European Journal of Clinical Nutrition*. 70 (6), 681–686. doi:10.1038/ejcn.2016.6.

Smith, E., Scarborough, P., Rayner, M. & Briggs, A.D.M. (2018a) Should we tax unhealthy food and drink? *Proceedings of the Nutrition Society*. 77 (3), 314–320. doi:10.1017/S0029665117004165.

Smith, R.D., Cornelsen, L., Quirmbach, D., Jebb, S.A. & Marteau, T.M. (2018b) Are sweet snacks more sensitive to price increases than sugar-sweetened beverages: Analysis of British food purchase data. *BMJ Open*. 8 (4), e019788. doi:10.1136/bmjopen-2017-019788.

Spiteri, M. & Soler, L.-G. (2018) Food reformulation and nutritional quality of food consumption: an analysis based on households panel data in France. *European Journal of Clinical Nutrition*. 72 (2), 228–235. doi:10.1038/s41430-017-0044-3.

Srour, B., Fezeu, L.K., Kesse-Guyot, E., Allès, B., Méjean, C., Andrianasolo, R.M., Chazelas, E., Deschasaux, M., Hercberg, S., Galan, P., Monteiro, C.A., Julia, C. & Touvier, M. (2019) Ultra-processed food intake and risk of cardiovascular disease: Prospective cohort study (NutriNet-Santé). *The BMJ*. 365, l1451. doi:10.1136/bmj.l1451.

Stacey, N., Edoka, I., Hofman, K., Swart, E.C., Popkin, B. & Ng, S.W. (2021) Changes in beverage purchases following the announcement and implementation of South Africa's Health Promotion Levy: an observational study. *The Lancet Planetary Health*. 5 (4), e200–e208. doi:10.1016/S2542-5196(20)30304-1.

Staudigel, M. & Anders, S. (2018) EFFECTS OF NUTRIENTS, BRAND, AND FLAVOR TYPE ON DEMAND FOR DIFFERENTIATED CHIPS PRODUCTS IN THE U.S. In: *Food-Health-Economics-Workshop, Manufacture des tabacs, Toulouse, June 7–8, 2018*. 2018 Toulouse School of Economics. p. https://www.tse-fr.eu/sites/default/files/TSE/documents/conf/food/staudigel.pdf.

Staudigel, M. & Anders, S. (2020) Effects of the FDA's sodium reduction strategy in the U.S. market for chip products. *Journal of Economic Behavior and Organization*. 173, 216–238. doi:10.1016/j.jebo.2020.03.006.

Steel, N., Ford, J.A., Newton, J.N., Davis, A.C.J., Vos, T., et al. (2018) Changes in health in the countries of the UK and 150 English Local Authority areas 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *The Lancet*. 392 (10158), 1647–1661. doi:10.1016/S0140-6736(18)32207-4.

Stephen, A.M., Champ, M.M.-J., Cloran, S.J., Fleith, M., Van Lieshout, L., Mejborn, H. & Burley, V.J. (2017) Dietary fibre in Europe: Current state of knowledge on definitions, sources, recommendations, intakes and relationships to health. *Nutrition Research Reviews*. 30 (2), 149–190. doi:10.1017/S095442241700004X.

Stone, M. (2007) *Fundamentals of Marketing*. Routledge. doi:10.4324/9780203030783.

Stone, M. (2013) *United Biscuits reverts to old McVitie's Digestives recipe*. 2013. Food Manufacture. https://www.foodmanufacture.co.uk/Article/2013/12/24/United-Biscuits-reverts-to-old-McVitie-s-Digestives-recipe [Accessed: 29 November 2021].

Suthers, R., Broom, M. & Beck, E. (2018) Key Characteristics of Public Health Interventions Aimed at Increasing Whole Grain Intake: A Systematic Review. *Journal of Nutrition Education and Behavior*. 50 (8), 813–823. doi:10.1016/j.jneb.2018.05.013.

Swinburn, B., Sacks, G., Vandevijvere, S., Kumanyika, S., Lobstein, T., et al. (2013)

INFORMAS (International Network for Food and Obesity/non-communicable diseases Research, Monitoring and Action Support): overview and key principles. *Obesity Reviews*. 14 (S1), 1–12. doi:10.1111/obr.12087.

Swinburn, B.A., Kraak, V.I., Allender, S., Atkins, V.J., Baker, P.I., et al. (2019) The Global Syndemic of Obesity, Undernutrition, and Climate Change: The Lancet Commission report. *The Lancet*. 393 (10173), 791–846. doi:10.1016/S0140-6736(18)32822-8.

Taillie, L.S., Bercholz, M., Popkin, B., Reyes, M., Colchero, M.A. & Corvalán, C. (2021) Changes in food purchases after the Chilean policies on food labelling, marketing, and sales in schools: a before and after study. *The Lancet Planetary Health*. 5 (8), e526–e533. doi:10.1016/s2542-5196(21)00172-8.

Taillie, L.S., Ng, S.W. & Popkin, B.M. (2015) Gains Made By Walmart's Healthier Food Initiative Mirror Preexisting Trends. *Health Affairs*. 34 (11), 1869–1876. doi:10.1377/hlthaff.2015.0072.

Taillie, L.S., Rivera, J.A., Popkin, B.M. & Batis, C. (2017) Do high vs. low purchasers respond differently to a nonessential energy-dense food tax? Two-year evaluation of Mexico's 8% nonessential food tax. *Preventive Medicine*. 105, S37–S42. doi:10.1016/J.YPMED.2017.07.009.

Tedstone, A., Coulton, V., Targett, V., Bennett, A., Sweeney, K., Morgan, K., Clegg, E., Robinson, M., Dowd, L., Knowles, B., Owtram, G. & Perkins, C. (2018) *Sugar reduction and wider reformulation programme: Report on progress towards the first 5% reduction and next steps*. https://www.gov.uk/government/publications/sugar-reduction-report-on-first-year-progress.

Temme, E.H.M., Hendriksen, M.A.H., Milder, I.E.J., Toxopeus, I.B., Westenbrink, S., Brants, H.A.M. & A, D. van der L. van der (2017) Salt reductions in some foods in the Netherlands: monitoring of food composition and salt intake. *Nutrients*. 9 (7), 791. doi:http://dx.doi.org/10.3390/nu9070791.

Teng, A.M., Jones, A.C., Mizdrak, A., Signal, L., Genç, M. & Wilson, N. (2019) Impact of sugar-sweetened beverage taxes on purchases and dietary intake: Systematic review and meta-analysis. *Obesity Reviews*.20 (9) pp.1187–1204. doi:10.1111/obr.12868.

Tester, J.M., Leung, C.W., Leak, T.M. & Laraia, B.A. (2017) Recent uptrend in whole-grain intake is absent for low-income adolescents, national health and nutrition examination survey, 2005-2012. *Preventing Chronic Disease*. 14 (7). doi:10.5888/pcd14.160540.

The British Soft Drinks Association (2020) *2020 Annual Report - Meeting the challenge*. 2020. Annual report.

The British Soft Drinks Association (2016) *BSDA's response to the Soft Drinks Tax Consultation and the Childhood Obesity Strategy*. 2016. Press Release. https://www.britishsoftdrinks.com/Press-releases-/its-a-sad-irony-that-the-one-category-that-has-led-the-way-in-reducing-consumers-sugar-intake-is-being-targeted-for-a-punitive-tax [Accessed: 26 November 2021].

The British Soft Drinks Association (2015) Changing Tastes: The UK Soft Drinks Anuual Report 2015. *Annual Report*. 1–20. http://www.britishsoftdrinks.com/write/mediauploads/publications/bsda_annual_report_2015.pdf%0Ahttp://www.britishsoftdrinks.com/write/MediaUploads/Publications/BSDA_Annual_Report_2015.pdf.

The British Soft Drinks Association (2021) *Helping our consumers reduce their calorie and sugar intake*. 2021. Initiatives. https://www.britishsoftdrinks.com/initiatives [Accessed: 26 November 2021].

Thomson, R.K., McLean, R.M., Ning, S.X. & Mainvil, L.A. (2016) Tick front-of-pack label has a positive nutritional impact on foods sold in New Zealand. *Public Health Nutrition*. 19 (16), 2949–2958. doi:http://dx.doi.org/10.1017/S1368980016001208.

Tobias, D. & Hall, K. (2021a) Eliminate or reformulate ultra-processed foods? Biological mechanisms matter. *Cell Metabolism*. 33 (12), 2314–2315. doi:10.1016/J.CMET.2021.10.005.

Tobias, D.K. & Hall, K.D. (2021b) Eliminate or reformulate ultra-processed foods? Biological mechanisms matter. *Cell Metabolism*. 33 (12), 2314–2315. doi:10.1016/j.cmet.2021.10.005.

Todd, J.E. (2017) Changes in consumption of food away from home and intakes of energy and other nutrients among US working-age adults, 2005-2014. *Public Health Nutrition*. 20 (18), 3238–3246. doi:10.1017/S1368980017002403.

Traka, M.H., Plumb, J., Berry, R., Pinchen, H. & Finglas, P.M. (2020) Maintaining and updating food composition datasets for multiple users and novel technologies: Current challenges from a UK perspective. *Nutrition Bulletin*. 45 (2), 230–240. doi:10.1111/nbu.12433.

Trieu, K., Neal, B., Hawkes, C., Dunford, E., Campbell, N., Rodriguez-Fernandez, R., Legetic, B., McLaren, L., Barberio, A. & Webster, J. (2015) Salt Reduction Initiatives around the World - A Systematic Review of Progress towards the Global Target. M.M. DeAngelis (ed.). *PloS one*. 10 (7), e0130247. doi:10.1371/journal.pone.0130247.

University of Southampton (2007) *Major study indicates a link between hyperactivity in children and certain food additives*. 2007.

Utter, J., Fay, A.P. & Denny, S. (2017) Child and Youth Cooking Programs: More Than Good Nutrition? *Journal of Hunger & Environmental Nutrition*. 12 (4), 554–580. doi:10.1080/19320248.2015.1112758.

Veroniki, A.A., Jackson, D., Viechtbauer, W., Bender, R., Bowden, J., Knapp, G., Kuss, O., Higgins, J.P., Langan, D. & Salanti, G. (2016) Methods to estimate the between-study variance and its uncertainty in meta-analysis. *Research Synthesis Methods*. 7 (1), 55–79. doi:10.1002/jrsm.1164.

Vesper, H.W., Caudill, S.P., Kuiper, H.C., Yang, Q., Ahluwalia, N., Lacher, D.A. & Pirkle, J.L. (2017) Plasma trans-fatty acid concentrations in fasting adults declined from NHANES 1999-2000 to 2009-2010. *American Journal of Clinical Nutrition*. 105 (5), 1063–1069. doi:10.3945/ajcn.116.141622.

Vin, K., Beziat, J., Seper, K., Wolf, A., Sidor, A., Chereches, R., Luc Volatier, J. & Ménard, C. (2020) Nutritional composition of the food supply: a comparison of soft drinks and breakfast cereals between three European countries based on labels. *European Journal of Clinical Nutrition*. 74 (1), 17–27. doi:10.1038/s41430-019-0442-9.

Watson, K.E. (2019) *Creating Demand for Healthier Behaviour An Innovative Approach to Social Marketing for Public Health Campaigns*.

Weaver, C.M., Dwyer, J., Fulgoni, V.L., King, J.C., Leveille, G.A., MacDonald, R.S., Ordovas, J. & Schnakenberg, D. (2014) Processed foods: contributions to nutrition. *The American Journal of Clinical Nutrition*. 99 (6), 1525–1542. doi:10.3945/ajcn.114.089284.

Wells, G., Shea, B., O'Connell, D., Robertson, J., Peterson, J., Welch, V., Losos, M. & Tugwell, P. (2009) *The Newcastle-Ottawa Scale (NOS) for assessing quality of nonrandomised studies*. http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp.

White, M., Aguirre, E., Finegood, D.T., Holmes, C., Sacks, G. & Smith, R. (2020) What role should the commercial food system play in promoting health through better diet? *BMJ*. 368, m545. doi:10.1136/bmj.m545.

WHO global co-ordination mechanism on the prevention and control of noncommunicable diseases (GCM/NCD) (2014) *Policy brief: producing and promoting more food products consistent with a healthy diet*. http://www.who.int/nmh/ncd-coordination-mechanism/Policybrief32.pdf.

World Cancer Research Fund International (2018) *NOURISHING database*. 2018. https://www.wcrf.org/int/policy/nourishing-database [Accessed: 30 May 2018].

World Health Organization (2007) *Reducing salt intake in populations : report of a WHO forum and technical meeting*.53 (9).

World Health Organization (2002) *The World health report : 2002 : reducing risks, promoting healthy life : overview*. https://apps.who.int/iris/handle/10665/67454.

Wyness, L.A., Butriss, J.L. & Stanner, S.A. (2012) Reducing the population's sodium intake: The UK Food Standards Agency's salt reduction programme. *Public Health Nutrition*. 15 (2), 254–261. doi:10.1017/S1368980011000966.

Young, L. & Swinburn, B.A. (2002) Impact of the Pick the Tick food information programme on the salt content of food in New Zealand. *Health Promotion International*. 17 (1), 13–19. doi:http://dx.doi.org/10.1093/heapro/17.1.13.

Ziauddeen, N., Fitt, E., Edney, L., Dunford, E., Neal, B. & Jebb, S.A. (2015) Variability in the reported energy, total fat and saturated fat contents in fast-food products across ten countries. *Public Health Nutrition*. 18 (16), 2962–2969. doi:10.1017/S1368980015000336.

Zimmerman, F.J. & Shimoga, S. V. (2014) The effects of food advertising and cognitive load on food choices. *BMC Public Health*. 14 (1), 1–10. doi:10.1186/1471-2458-14-342/TABLES/4.

Zupanič, N., Hribar, M., Kupirovič, U.P., Kušar, A., Žmitek, K., Pravst, I., Zupanic, N., Hribar, M., Kupirovic, U.P., Kusar, A., Zmitek, K. & Pravst, I. (2018) Limiting trans fats in foods: Use of partially hydrogenated vegetable oils in prepacked foods in Slovenia. *Nutrients*. 10 (3), 355. doi:http://dx.doi.org/10.3390/nu10030355.

Appendix I. ADDITIONAL TABLES AND FIGURES

Appendix to Chapter 3

Appendix Table i: Search strategy on Medline for the systematic review

1	sodium, dietary/ or Sodium Chloride/ or sodium chloride, dietary/ or exp ENERGY INTAKE/ or dietary fats/ or Fats, Unsaturated/ or Fatty Acids, Unsaturated/ or Dietary Sugars/ or Dietary fiber/ or exp Nutritive value/ or whole grains/ or dietary carbohydrates/ or dietary proteins/
2	(salt or sodium or sugar* or energy or calori* or saturated fat* or "trans fat*" or trans?fat* or fibre* or fiber* or whole?grain* or wholegrain* or "whole grain*" or carbohydrate* or protein* or fatty acid* or nutrient*).ab.
3	1 or 2
4	reformulat*.ab.
5	3 and 4
6	((salt or sodium or sugar* or saturated fat* or "trans fat*" or trans?fat or TFA) adj5 (target* or limit* or restrict* or regulat* or reduc*)).ab.
7	((fibre* or fiber* or whole?grain* or wholegrain* or whole grain*) adj5 (improv* or increas* or promot* or favo?r*)).ab.
8	((energy or calori*) adj5 (reduc* or limit* or target*)).ab.
9	(((improve* or better or enhance* or health*) adj5 (composition* or profile*)) and (nutrition or food or nutrient)).ab.
10	5 or 6 or 7 or 8 or 9
11	(sold or sales or intake* or purchase* or consumption or diet* or overweight or diabetes or bmi or cholesterol or "coronary heart disease" or cardiovascular or "dietary habit*" or "heart disease risk" or "consumer behaviour" or "consumer behavior" or "blood pressure" or hyperglyc?emia or "glucose tolerance" or "insulin resistance" or hypertension or hyperlipidemia or dyslipidemia).ab.
12	(grocery or groceries or store or stores or supermarket or supermarkets or retailer or retailers or market or markets or food industry or food dispensers or vending or point-of-purchase or point-of-selection or package* or packages or front-of-pack).ab.
13	((regulat* or polic* or legislation* pledge* or ban or bans or standard or standards or strategy or strategies or intervention* or restriction*) and food*).ab.

14	12 or 13
15	exp animals/ not humans.sh.
16	(restaurant* or fast-food* or "fast food*" or fastfood* or takeaway* or take-away* or "take-away*").ab.
17	14 or 16
18	10 and 11 and 17
19	18 not 15

Appendix Table ii: Summary of results for studies reporting the effect of reformulation on intakes.

	Studies reporting a measure of intakes					
			Biomarkers		**Reported measures**	
	Total N studies	**% positive results**	**N studies**	**% positive results**	**N studies**	**% positive results**
Total	26	70%	13	77%	13	69%
Nutrient studied						
sodium	20	65%	10	70%	10	60%
TFA	5	100%	3	100%	2	100%
whole grains	1	100%			1	100%

Notes: Biomarker measures include spot or 24h urine for sodium measures, or TFA concentration in blood or breastmilk. Reported measures include data from dietary surveys (food frequency questionnaires, 24h-dietary recalls) and from total purchases or sales.

Appendix Table iii: Meta-regression of the change in salt intake, using method of salt intake estimation to explain heterogeneity

	estimate	95% CI	P-value
Intercept	-0.46	[-0.94 ; 0.01]	0.06
Difference with 24-h urinary samples			
Dietary surveys	0.14	[-0.67 ; 0.94]	0.7
Household purchases	-0.58	[-1.49 ; 0.33]	0.2
Spot urine	-0.28	[-1.49 ; 0.93]	0.6

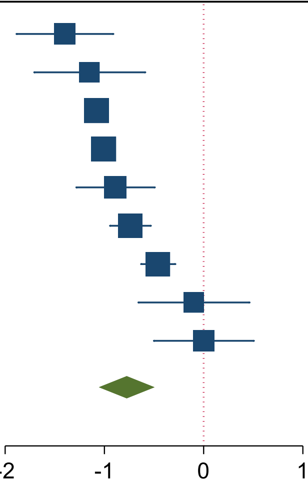
Appendix Table iv: Meta-regression of the change in salt intake, using timeframe between baseline and follow-up to explain heterogeneity

	estimate	95% CI	P-value
Intercept	-0.31	[-1.01 ; 0.38]	0.4
Difference with studies measuring a change <5y			
[5y-10y]	-0.29	[-1.28 ; 0.69]	0.6
>10y	-0.36	[-1.20 ; 0.49]	0.4

Appendix Figure i: Sensitivity analysis of the pooled estimate of the effect of initiatives including salt reformulation on populations' salt intake (in g/day). Only studies with a NOS Score >2 were selected

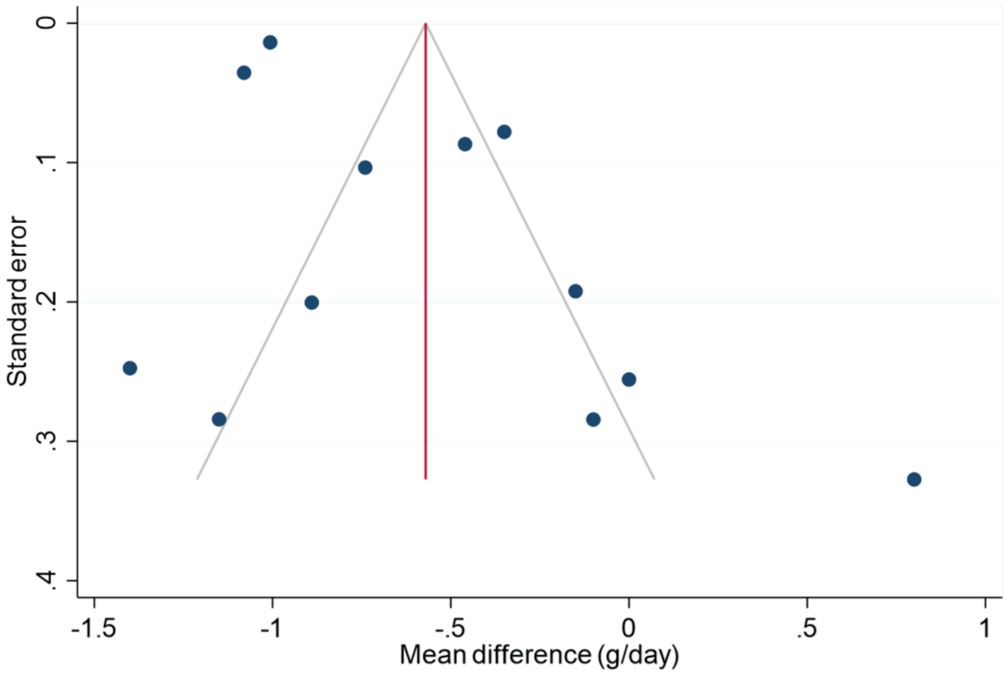
Study	Before intervention N	Before intervention Mean	Before intervention SD	After intervention N	After intervention Mean	After intervention SD	Mean Diff. with 95% CI
He, 2014 [33]	1,147	9.5	4.7	692	8.1	5.8	-1.40 [-1.89, -0.91]
McLaren, 2016 (Finland)	670	11.8	4.7	400	10.6	4.1	-1.15 [-1.71, -0.59]
Griffith, 2017	16,664	6.5	4.0	28,767	5.5	3.5	-1.08 [-1.15, -1.01]
Poti, 2017 [26]	33,706	6.0	0.8	58,138	5.0	2.5	-1.01 [-1.03, -0.98]
McLaren, 2016 (UK)	1,724	9.5	4.5	692	8.6	4.4	-0.89 [-1.28, -0.50]
Millett, 2012	1,668	5.3	4.2	4,269	4.6	3.3	-0.74 [-0.94, -0.54]
McLaren, 2016 (France)	1,345	8.0	2.6	1,922	7.5	2.3	-0.46 [-0.63, -0.29]
Temme, 2017	317	9.1	3.4	289	9.0	3.6	-0.10 [-0.66, 0.46]
McLaren, 2016 (Netherlands)	317	8.6	3.2	342	8.6	3.4	0.00 [-0.50, 0.50]
Overall							-0.78 [-1.06, -0.49]

Heterogeneity: $\tau^2 = 0.15$, $I^2 = 97.30\%$, $H^2 = 37.05$



Appendix Figure ii: Sensitivity analysis of the pooled estimate of the effect of initiatives including TFA reformulation on populations' TFA intake (the effect size is the standardized mean difference given by the Hedge’s g statistic). Only studies with a NOS Score >2 were selected

Appendix Figure iii: Funnel plot of studies reporting changes in salt intake and included in the meta-analysis



Appendix to Chapter 4

Appendix Table v: Regression results: estimated fibre intake by survey year

	estimate	SE	statistic	p.value
(Intercept)	3.69	0.56	6.61	7.05E-11
Survey year (1y increment)	0.06	0.03	2.14	3.23E-02
age group 1.5-3 y	-2.23	0.21	-10.39	9.15E-24
age group 4-10 y	-1.37	0.19	-7.20	1.46E-12
age group 11-18 y	-1.61	0.15	-10.50	3.39E-24
age group >=65 y	0.95	0.20	4.73	2.69E-06
Sex Male	-0.31	0.13	-2.39	1.69E-02
Energy (in kcal/day)	0.01	0.00	23.52	1.06E-92
BMI	-0.02	0.01	-1.37	1.71E-01
Ethnic group Non-white	1.04	0.26	3.95	8.66E-05
Equivalised income	0.00	0.00	3.78	1.72E-04

Appendix to Chapter 5

Appendix Table vi: Table of descriptive statistics for the full adult sample of NDNS and the selected sample

	Year 1			Year 9		
	full sample	selected sample	p-value	full sample	selected sample	p-value
n	1195	935.9		1173.3	906.4	
Highest qualification (%)			**0.031**			**0.161**
GCE, A level or equivalent	195.2 (16.3)	170.6 (18.2)		189.4 (16.1)	151.8 (16.8)	
GCSE	263.2 (22.0)	219.0 (23.4)		215.3 (18.4)	169.0 (18.6)	
Higher education	381.7 (31.9)	299.6 (32.0)		481.2 (41.0)	393.0 (43.4)	
missing	74.6 (6.2)	41.6 (4.4)		88.7 (7.6)	62.5 (6.9)	
No qualifications	280.3 (23.5)	205.1 (21.9)		198.6 (16.9)	130.1 (14.4)	
Ethnicity (%)			0.046			0.346
White	1086.1 (90.9)	867.5 (92.97		1008.8 (86.0)	795.8 (87.8)	
Non-white	108.6 (9.1)	68.4 (7.3)		163.2 (13.9)	110.6 (12.2)	
Refusal				1.3 (0.1)	0.0 (0.0)	
Equivalised income (mean (SD))	29656.4 (20682.8)	29461.4 (20449.4)	0.445	37310.8 (24934.4)	37468.1 (24911.9)	0.614
BMI (mean (SD))	27.5 (5.2)	27.6 (5.3)	0.418	27.4 (5.4)	27.4 (5.4)	0.579
Age (mean (SD))	47.8 (18.2)	47.0 (17.6)	0.123	48.8 (17.9)	47.8 (16.9)	0.107
Sex = Female (%)	631.0 (52.8)	492.6 (52.6)	0.888	601.1 (51.2)	451.7 (49.8)	0.4
Country (%)			0.417			0.158
England	1006.8 (84.3)	780.0 (83.3)		985.5 (84.0)	775.4 (85.5)	
Northern Ireland	33.3 (2.8)	28.3 (3.0)		32.3 (2.7)	21.7 (2.4)	
Scotland	105.9 (8.9)	87.6 (9.4)		99.2 (8.5)	63.5 (7.0)	
Wales	49.0 (4.1)	39.9 (4.3)		56.3 (4.8)	45.8 (5.1)	
Energy in kcal/d (mean (SD))	1868.0 (591.6)	1891.5 (598.0)	0.085	1782.4 (597.1)	1797.0 (594.8)	0.393
Sodium in mg/d (mean (SD))	2323.6 (892.4)	2360.9 (911.9)	0.111	1987.8 (804.7)	2005.8 (834.4)	0.327

p-values in bold show a significant difference. Chi square tests were performed for categorical variables, and t-tests for continuous variables

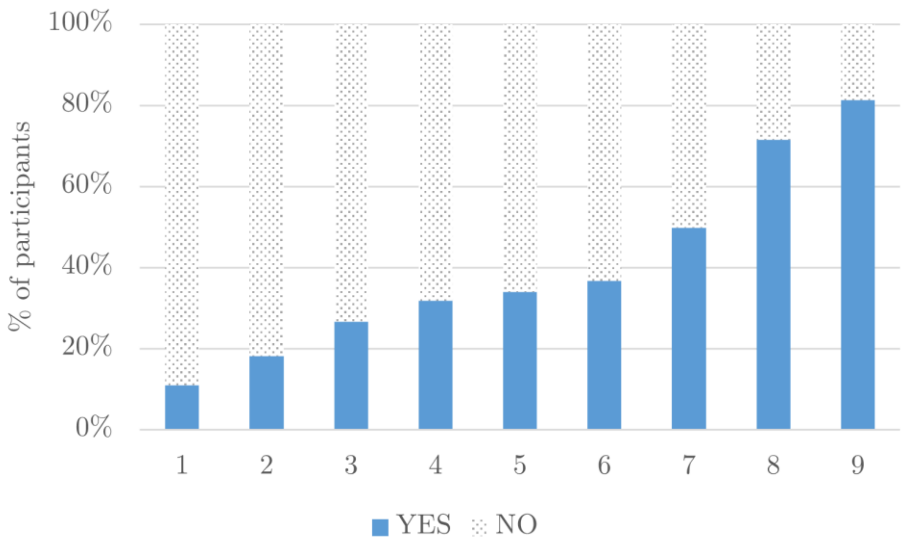
Appendix Table vii: Results of the logistic regression on the use of salt

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.33	0.85	0.39	0.7
Survey year	0.01	0.01	0.76	0.449
Diploma question not asked (<18y)	-0.53	0.84	-0.63	0.531
Degree or equivalent	-0.03	0.85	-0.04	0.97
Higher education, below degree level	-0.48	0.84	-0.57	0.57
GCE, A level or equivalent	-0.24	0.85	-0.29	0.774
GCSE grades A - C or equivalent	-0.42	0.85	-0.50	0.618
GCSE grades D-G/Commercial qualifications/apprenticeship	-0.42	0.85	-0.49	0.62
Foreign or other qualifications	0.05	0.86	0.06	0.951
No qualifications	0.00	0.85	-0.01	0.996
Still in FT education	-0.04	0.84	-0.04	0.965
Equivalised income	0.00	0.00	-0.99	0.321
Sex= Female	-0.01	0.06	-0.15	0.881

Sensitivity analyses carried out to understand the declared use of table salt in NDNS participants:

a) Reports of table salt use (while cooking or eating) from the food diaries

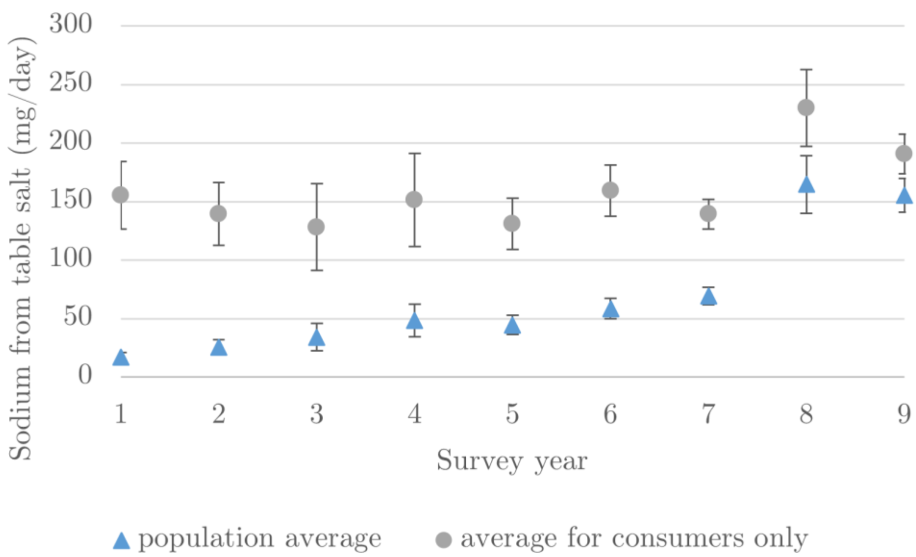
Appendix Figure iv: Proportion of NDNS participants for which 'Table salt' was included in diaries



b) Average population intake of table salt

To test if this increased proportion of participants having table salt in their diaries meant increased intake of table salt, we evaluated the mean intake coming from this ingredient. First, evaluating this metric amongst 'consumers' of table salt (i.e. participants with table salt reported in their diaries) showed a small increase in sodium from table salt (Figure 2.2). This increase in sodium from table salt was stronger when assessed for the whole population: while table salt provided on average 17mg of sodium per day (SE 3.8mg) per day in year 1, it provided 155mg (SE 15g) in year 9.

Appendix Figure v: Average sodium intake from table salt, for the whole population, and for participants with table salt in their dairies



Appendix Table viii: Regression of sodium intake (in mg/year) by survey years

	estimate	std.error	statistic	p.value
(Intercept)	45.1	48.8	0.9	0.356
Survey year	-14.5	5.2	-2.8	0.005
age group 4-10 y	184.8	39.1	4.7	0.000
age group 11-18 y	290.3	45.7	6.4	0.000
age group 19 - 64 y	193.6	45.7	4.2	0.000
age group >=65 y	89.7	55.3	1.6	0.105
Sex=Male	76.3	17.1	4.5	0.000
Energy (kcal/day)	1.0	0.0	44.7	0.000
BMI	9.0	1.7	5.4	0.000
ethnic group= Non-white	-176.2	35.3	-5.0	0.000
Equivalised income	0.0	0.0	-1.2	0.220
Syear:agegroup2	-22.5	6.2	-3.7	0.000
Syear:agegroup3	-28.5	7.0	-4.1	0.000
Syear:agegroup4	-17.4	7.3	-2.4	0.017
Syear:agegroup5	-23.8	8.3	-2.8	0.005

Appendix Table ix: Regression of sodium intake (in mg/day) by survey year, adjusted for qualification and quintile of income (for adults only)

	estimate	std.error	statistic	p.value
(Intercept)	393.5	106.1	3.7	0.000
Syear	-38.6	11.2	-3.5	0.001
SexMale	86.7	22.5	3.9	0.000
agegroup4	-83.3	51.1	-1.6	0.104
agegroup5	-226.3	53.2	-4.3	0.000
Energykcal	1.0	0.0	34.7	0.000
bmival	8.5	1.9	4.4	0.000
ethgrp2Non-white	-187.8	50.0	-3.8	0.000
quantile of equivalised income 2	-44.5	75.0	-0.6	0.553
quantile of equivalised income 3	-93.1	65.6	-1.4	0.157
quantile of equivalised income 4	-106.0	76.8	-1.4	0.168
quantile of equivalised income 5	-169.2	79.0	-2.1	0.033
qualGCSE	32.8	61.3	0.5	0.593
qualGCE, A level or equivalent	102.0	71.5	1.4	0.154
qualHigher education	-3.6	56.2	-0.1	0.949
Syear:quantile2	7.6	13.3	0.6	0.567
Syear:quantile3	15.5	12.7	1.2	0.222
Syear:quantile4	22.3	13.9	1.6	0.108
Syear:quantile5	30.1	14.6	2.1	0.039
Syear:qualGCSE	-12.6	10.8	-1.2	0.245
Syear:qualGCE, A level or equivalent	-23.4	13.3	-1.8	0.078
Syear:qualHigher education	-8.0	9.9	-0.8	0.419

Appendix Table x: Decomposition of the sodium density of the diet (food and beverages), stratified by sex

Sex	Males	Females
Sodium density, Y1	99.2 ± 2.3	90.6 ± 1.9
Sodium density, Y9	82.6 ± 2.3	74.7 ± 1.9
% change in sodium density	-17% (-23%,-10%)	-18% (-23%,-12%)
Change in sodium density	-16.7	-15.9
reformulation effect	-12.8	-11.3
switching effect	-1.1	-2.4
product renewal effect	-2.8	-2.2

Appendix Table xi: Decomposition of the sodium density of the diet (food and beverages), stratified by quintile of income

Quintile of income	1 (lowest income) Y1: n=312 Y9: n=251	2 Y1: n=246 Y9: n=186	3 Y1: n=295 Y9: n=211	4 Y1: n=223 Y9: n=201	5 (highest income) Y1: n=258 Y9: n=146
Sodium density, Y1	97.3 ± 3.1	102.1 ± 3.9	91.8 ± 2.6	94.7 ± 3.3	88.3 ± 2.6
Sodium density, Y9	79.6 ± 2.4	75.6 ± 3.9	85.5 ± 3.8	79.2 ± 3.4	73.2 ± 3.3
% change in sodium density	-18% (-26%,-10%)	-26% (-37%,-15%)	-7% (-17%,3%)	-16% (-26%,-6%)	-17% (-26%,-8%)
Change in sodium density	-17.7	-26.5	-6.3	-15.5	-15.0
reformulation effect	-12.6	-13.5	-11.0	-12.3	-10.9
switching effect	-3.1	-10.3	7.3	-2.0	-0.3
product renewal effect	-2.0	-2.7	-2.5	-1.1	-3.9

Appendix Table xii: Decomposition of the sodium density of the diet (food and beverages), stratified by qualification

Highest qualification	No qualification	GCSE	GCE, A level or equivalent	Higher education
Sodium density, Year 1	85.6 ± 2.6	93.2 ± 3.7	90.7 ± 4.3	85.4 ± 3
Sodium density, Year 9	78.1 ± 5	74.9 ± 4.4	72.7 ± 3.4	71.5 ± 2.9
% change in sodium density	-9% (-22%,4%)	-20% (-32%,-8%)	-20% (-32%,-8%)	-16% (-26%,-7%)
Change in sodium density	-7.5	-18.3	-18	-13.9
reformulation effect	-10.3	-11.7	-10.5	-10.5
switching effect	3.8	-5.2	-3.3	0.3
product renewal effect	-1	-1.4	-4.2	-3.7

Appendix to Chapter 6

Appendix Table xiii: Decomposition of the change in the sugar density of soft drinks and breakfast cereals. Data from household panel from Kantar.

	Sugar density 2015	Reformula-tion effect	switches effect	product renewal effect	Sugar density 2018	% change in sugar density[1]
All drinks	3.9	-9%	-9%	-10%	2.9	-27%
Soft drinks	3.8	-12%	-15%	-6%	2.5	-33%
Breakfast cereal	17.1	-5%	0%	-4%	15.6	-9%

The sugar densities are in g/100g or g/100mL, and the three effects are % change compared to baseline. The sum of the three effects equals the total % change in the sugar density of the category. Data from Kantar panel.

Appendix Table xiv: **Descriptive statistics of the decomposition of the changes in sugar density of household purchases between 2015 and 2018, into the effects of reformulation, product renewal and switches.**

		All drinks (n=18512)				Soft drinks (n=18343)				Breakfast cereals (n=18533)			
		Non-weighted statistics		Weighted statistics		Non-weighted statistics		Weighted statistics		Non-weighted statistics		Weighted statistics	
		value	SE	value	SE	value	SE	value	SE	value	SE	value	SE
change in sugar density	Mean	-1.06	0.02	-1.06	0.02	-1.33	0.03	-1.29	0.03	-1.53	0.05	-1.51	0.07
	Q25	-2.30		-2.34	0.03	-2.87		-2.88	0.05	-5.25		-5.32	0.08
	Median	-0.81		-0.79	0.02	-0.85		-0.82	0.03	-1.37		-1.31	0.06
	Q75	0.26		0.28	0.02	0.30		0.36	0.02	2.14		2.20	0.07
reformulation effect	Mean	-0.40	0.00	-0.41	0.01	-0.60	0.01	-0.62	0.01	-0.76	0.01	-0.75	0.01
	Q25	-0.51		-0.52	0.01	-0.74		-0.75	0.01	-1.14		-1.13	0.01
	Median	-0.22		-0.22	0.00	-0.27		-0.26	0.00	-0.57		-0.52	0.01
	Q75	-0.07		-0.06	0.00	-0.06		-0.05	0.00	-0.12		-0.07	0.01
product renewal effect	Mean	-0.32	0.01	-0.31	0.01	-0.22	0.01	-0.21	0.01	-0.45	0.02	-0.42	0.02
	Q25	-0.59		-0.59	0.01	-0.34		-0.33	0.01	-1.02		-0.97	0.02
	Median	-0.15		-0.14	0.01	-0.01		0.00	0.00	-0.04		0.00	0.00
	Q75	0.05		0.05	0.00	0.03		0.03	0.00	0.15		0.14	0.01
switching effect	Mean	-0.33	0.01	-0.31	0.02	-0.40	0.02	-0.33	0.02	0.01	0.05	0.05	0.05
	Q25	-1.25		-1.25	0.02	-1.51		-1.47	0.03	-2.94		-2.92	0.06
	Median	-0.17		-0.15	0.01	-0.14		-0.09	0.01	0.00		0.00	0.02
	Q75	0.64		0.66	0.02	0.71		0.79	0.02	2.88		2.86	0.06

Appendix Table xv: Regression 6-2 results for <u>all drinks</u>: prediction of decomposition effects with household characteristics and preferences

	reformulation effect			switching effect			product renewal effect		
term	estimate	SE	p.value	estimate	SE	p.value	estimate	SE	p.value
(Intercept)	0.09	0.03	**0.008**	1.30	0.11	**0.000**	0.28	0.05	**0.000**
Volume of purchases in 2015	-8.5E-05	5E-05	0.082	-9.3E-04	2E-04	**0.000**	-3.8E-04	7E-05	**0.000**
Mean sugar density of purchases in 2015	-0.10	0.00	**0.000**	-0.27	0.00	**0.000**	-0.10	0.00	**0.000**
N household members	0.00	0.00	0.361	-0.03	0.02	**0.025**	-0.02	0.01	**0.001**
Household.Income£10,000 - £19,999 pa	-0.01	0.02	0.615	-0.08	0.06	0.192	0.02	0.03	0.612
Household.Income£20,000 - £29,999 pa	0.01	0.02	0.801	-0.10	0.07	0.139	0.04	0.03	0.242
Household.Income£30,000 - £39,999 pa	0.00	0.02	0.951	-0.15	0.07	**0.032**	0.02	0.03	0.649
Household.Income£40,000 - £49,999 pa	0.03	0.02	0.258	-0.24	0.08	**0.002**	0.00	0.04	0.989
Household.Income£50,000 - £59,999 pa	0.01	0.03	0.673	-0.26	0.08	**0.002**	0.00	0.04	0.981
Household.Income£60,000 - £69,999 pa	0.00	0.03	0.947	-0.11	0.10	0.256	0.03	0.05	0.543
Household.Income£70,000 +	0.03	0.03	0.316	-0.16	0.09	0.080	0.04	0.04	0.410
Household.IncomeDid not want to answer	0.00	0.02	0.892	-0.09	0.07	0.173	0.04	0.03	0.234
Social.ClassC1	-0.01	0.01	0.255	-0.04	0.04	0.268	-0.01	0.02	0.549
Social.ClassC2	-0.01	0.01	0.322	-0.14	0.05	**0.002**	-0.05	0.02	**0.018**
Social.ClassD	0.00	0.02	0.839	-0.18	0.05	**0.000**	-0.04	0.02	0.079
Social.ClassE	-0.01	0.02	0.775	-0.22	0.07	**0.001**	-0.01	0.03	0.780
Urban...Rural	0.02	0.05	0.616	0.15	0.15	0.339	0.01	0.07	0.899
Urban...RuralRural	0.03	0.02	0.261	0.21	0.08	**0.005**	0.11	0.04	**0.004**
Urban...RuralSemi-rural	0.04	0.02	**0.027**	0.06	0.06	0.279	0.07	0.03	**0.011**
Urban...RuralSuburban	0.01	0.02	0.403	0.03	0.05	0.550	0.05	0.02	**0.018**
Urban...RuralUrban	0.03	0.02	0.093	-0.07	0.05	0.125	0.01	0.02	0.735
Ethnicityother	-0.03	0.02	0.065	0.21	0.05	**0.000**	0.00	0.02	0.946
Life_stageOlder households	-0.05	0.01	**0.000**	-0.07	0.04	0.083	-0.04	0.02	**0.042**
Life_stagePre-Family	-0.03	0.02	0.164	-0.05	0.06	0.376	-0.03	0.03	0.335
RegionEast	-0.01	0.02	0.734	-0.06	0.07	0.378	-0.02	0.03	0.609
RegionMidlands	0.01	0.02	0.673	-0.06	0.06	0.352	-0.09	0.03	**0.002**
RegionNorth	0.04	0.02	**0.021**	-0.10	0.06	0.078	-0.09	0.03	**0.001**
RegionScotland	-0.04	0.02	0.068	0.04	0.07	0.542	-0.04	0.03	0.211
RegionSouth	0.01	0.02	0.726	0.01	0.06	0.869	-0.03	0.03	0.341
RegionWales	0.09	0.03	**0.001**	-0.02	0.08	0.796	-0.09	0.04	**0.015**
R^2	0.23			0.15			0.11		

Appendix Table xvi: Regression 6-2 results for soft drinks: prediction of decomposition effects with household characteristics and preferences

	reformulation effect			switching effect			product renewal effect		
term	estimate	SE	p.value	estimate	SE	p.value	estimate	SE	p.value
(Intercept)	0.17	0.05	**0.002**	1.86	0.13	**0.000**	0.36	0.06	**0.000**
Volume of purchases in 2015	-4.2E-05	1E-04	0.713	-2.9E-03	3E-04	**0.000**	-5.9E-04	1E-04	**0.000**
Mean sugar density of purchases in 2015	-0.17	0.00	**0.000**	-0.31	0.00	**0.000**	-0.10	0.00	**0.000**
N household members	0.02	0.01	**0.025**	-0.10	0.02	**0.000**	-0.01	0.01	0.105
Household.Income£10,000 - £19,999 pa	0.02	0.03	0.588	-0.13	0.08	0.112	0.00	0.04	0.978
Household.Income£20,000 - £29,999 pa	0.03	0.04	0.434	-0.18	0.09	**0.040**	-0.01	0.04	0.838
Household.Income£30,000 - £39,999 pa	0.04	0.04	0.295	-0.15	0.09	0.105	-0.06	0.04	0.119
Household.Income£40,000 - £49,999 pa	0.05	0.04	0.249	-0.31	0.10	**0.001**	-0.02	0.04	0.674
Household.Income£50,000 - £59,999 pa	0.06	0.04	0.196	-0.50	0.11	**0.000**	0.03	0.05	0.563
Household.Income£60,000 - £69,999 pa	-0.01	0.05	0.912	-0.30	0.13	**0.017**	-0.04	0.06	0.427
Household.Income£70,000 +	0.03	0.05	0.552	-0.23	0.12	**0.050**	-0.07	0.05	0.202
Household.IncomeDid not want to answer	0.02	0.04	0.538	-0.09	0.09	0.291	0.00	0.04	0.970
Social.ClassC1	0.03	0.02	0.114	-0.04	0.05	0.436	-0.01	0.02	0.709
Social.ClassC2	0.06	0.02	**0.021**	-0.09	0.06	0.144	-0.01	0.03	0.846
Social.ClassD	0.08	0.03	**0.002**	0.00	0.07	0.949	-0.03	0.03	0.274
Social.ClassE	0.10	0.03	**0.003**	0.02	0.08	0.828	-0.02	0.04	0.565
Urban...Rural	0.03	0.08	0.724	-0.18	0.19	0.360	-0.01	0.09	0.884
Urban...RuralRural	0.02	0.04	0.627	0.09	0.10	0.350	0.07	0.04	0.102
Urban...RuralSemi-rural	0.03	0.03	0.280	-0.14	0.08	0.069	0.03	0.03	0.348
Urban...RuralSuburban	0.01	0.02	0.688	-0.12	0.06	**0.049**	0.00	0.03	0.929
Urban...RuralUrban	0.05	0.03	0.068	-0.19	0.06	**0.002**	0.01	0.03	0.751
Ethnicityother	-0.01	0.03	0.779	0.32	0.07	**0.000**	0.07	0.03	**0.016**
Life_stageOlder households	-0.09	0.02	**0.000**	-0.04	0.05	0.473	0.01	0.02	0.773
Life_stagePre-Family	-0.06	0.03	0.066	-0.05	0.07	0.480	0.00	0.03	0.923
RegionEast	-0.09	0.03	**0.008**	-0.02	0.09	0.798	-0.04	0.04	0.245
RegionMidlands	-0.08	0.03	**0.010**	-0.12	0.08	0.127	-0.07	0.04	0.060
RegionNorth	-0.03	0.03	0.276	-0.22	0.07	**0.003**	-0.07	0.03	**0.042**
RegionScotland	-0.15	0.04	**0.000**	-0.02	0.09	0.857	-0.07	0.04	0.073
RegionSouth	-0.09	0.03	**0.005**	0.01	0.08	0.938	-0.05	0.03	0.120
RegionWales	0.03	0.04	0.415	-0.05	0.11	0.653	-0.15	0.05	**0.001**
R^2		0.33			0.20			0.11	

Appendix Table xvii: Regression 6-2 results for breakfast cereals: prediction of decomposition effects with household characteristics and preferences

	reformulation effect			switching effect			product renewal effect		
term	estimate	SE	p.value	estimate	SE	p.value	estimate	SE	p.value
(Intercept)	0.09	0.06	0.108	7.16	0.32	**0.000**	1.11	0.14	**0.000**
eq_volume_2015	-7.0E-03	9E-04	**0.000**	-2.8E-02	5E-03	**0.000**	-6.4E-03	2E-03	**0.002**
densityHH15	-0.05	0.00	**0.000**	-0.38	0.01	**0.000**	-0.08	0.00	**0.000**
N_people	-0.02	0.01	**0.034**	0.07	0.05	0.148	0.02	0.02	0.410
Household.Income£10,000 - £19,999 pa	0.03	0.04	0.332	-0.36	0.19	0.062	-0.10	0.08	0.221
Household.Income£20,000 - £29,999 pa	0.06	0.04	0.096	-0.34	0.20	0.087	-0.11	0.09	0.204
Household.Income£30,000 - £39,999 pa	0.06	0.04	0.135	-0.27	0.21	0.206	-0.17	0.09	0.057
Household.Income£40,000 - £49,999 pa	0.05	0.04	0.242	-0.36	0.22	0.110	-0.16	0.10	0.090
Household.Income£50,000 - £59,999 pa	0.03	0.05	0.468	-0.24	0.25	0.330	-0.08	0.11	0.448
Household.Income£60,000 - £69,999 pa	0.12	0.05	**0.031**	-0.45	0.29	0.122	-0.09	0.13	0.478
Household.Income£70,000 +	0.11	0.05	**0.026**	-0.20	0.27	0.460	-0.19	0.12	0.098
Household.IncomeDid not want to answer	0.04	0.04	0.332	-0.43	0.21	**0.039**	-0.15	0.09	0.083
Social.ClassC1	0.00	0.02	0.833	0.15	0.11	0.192	0.02	0.05	0.646
Social.ClassC2	0.03	0.02	0.194	0.15	0.14	0.282	0.10	0.06	0.097
Social.ClassD	0.02	0.03	0.405	0.27	0.15	0.074	0.09	0.07	0.154
Social.ClassE	0.01	0.04	0.676	0.16	0.19	0.409	0.00	0.08	0.989
Urban...Rural	0.11	0.08	0.180	-0.02	0.45	0.965	-0.35	0.19	0.067
Urban...RuralRural	0.01	0.04	0.833	-0.67	0.23	**0.003**	-0.02	0.10	0.865
Urban...RuralSemi-rural	0.01	0.03	0.809	-0.23	0.18	0.201	-0.10	0.08	0.197
Urban...RuralSuburban	0.02	0.03	0.437	-0.27	0.14	0.058	-0.09	0.06	0.140
Urban...RuralUrban	0.03	0.03	0.188	-0.02	0.15	0.868	-0.06	0.06	0.326
Ethnicityother	0.01	0.03	0.752	0.48	0.16	**0.002**	0.18	0.07	**0.007**
Life_stageOlder households	0.00	0.02	0.874	-1.44	0.12	**0.000**	-0.07	0.05	0.208
Life_stagePre-Family	0.01	0.03	0.635	-1.16	0.17	**0.000**	-0.12	0.07	0.114
RegionEast	-0.03	0.04	0.435	0.31	0.20	0.120	-0.07	0.08	0.433
RegionMidlands	0.00	0.03	0.941	0.42	0.18	**0.023**	-0.01	0.08	0.871
RegionNorth	0.02	0.03	0.470	0.43	0.17	**0.014**	-0.01	0.07	0.926
RegionScotland	-0.15	0.04	**0.000**	0.69	0.21	**0.001**	0.11	0.09	0.224
RegionSouth	-0.02	0.03	0.589	0.31	0.18	0.075	-0.08	0.08	0.282
RegionWales	-0.10	0.04	**0.027**	0.61	0.25	**0.012**	0.02	0.10	0.877
R^2		0.13			0.20			0.06	

Appendix to Chapter 7

Appendix Table xviii: Descriptive characteristics of the full Kantar panel and the sample used in Chapter 7

	level	Overall sample in 2015	Selected sample[1] in 2015
n		**32084**	**17337**
Household Size (%)	1 Member HHs	30.1	25.5
	2 Member HHs	35.5	38.4
	3 Member HHs	15.6	16
	4 Member HHs	12.7	13.7
	5+ Member HHs	6.1	6.5
Number of Children (%)	No Children	75.2	75.2
	1 Child HHs	12	11.6
	2 Child HHs	9.4	9.8
	3+ Child HHs	3.4	3.4
Household Income (%)	£0 - £9,999 pa	9.9	8.5
	£10,000 - £19,999 pa	22.9	22.3
	£20,000 - £29,999 pa	18.5	18.8
	£30,000 - £39,999 pa	13	13.6
	£40,000 - £49,999 pa	8.7	9.3
	£50,000 - £59,999 pa	5.3	5.2
	£60,000 - £69,999 pa	2.8	3
	£70,000 +	4.3	4.2
	Did not want to answer	14.6	15.2
Social Class (%)	AB	25.2	25.1
	C1	28.6	28.8
	C2	19.6	20.6
	D	15	15.3
	E	11.7	10.3
Urban / Rural (%)	City	16.2	4.5
	Rural	4.2	11.8
	Semi-rural	10.8	35.3
	Suburban	34.4	33.4
	Urban	33.3	14
Main Shopper Age (%)	28-34	11.1	8.5
	35-44	17.8	17.7
	45-54	19.6	21.7
	55-64	18.4	20.5
	65+	25.6	27.2
	under 28	7.5	4.4
Ethnicity (%)	White	89.3	91.9
	other	10.7	8.1
Life stage (%)	Pre-Family	17.6	13.2

	Empty Nesters	25.2	26.5
	Family 10+ Years	6.5	7.3
	Middle Family 5-9 Years	6.7	7.3
	Older Dependents	8.2	10.1
	Retired	24.2	25.4
	Young Family 0-4 Years	11.7	10.2
Region (%)	East	9.5	9.5
	London	11.9	10.4
	Midlands	16.2	16.3
	North	25.1	25.9
	Scotland	9.4	9.6
	South	22.9	23.2
	Wales	5.1	5.1

HH: household; pa: per annum. The Chi square test for all characteristics showed significant differences
[1]. Selected households were households with at least 10 purchase occasions in at least 2 quarters in 2015 and 2018.

Appendix Table xix: Table of variance for the random effects models (product and household level models from Equation 7-1)

	Clustered at the household level only		Clustered at product level only		Nested products within households		Crossed random effects	
	Variance	SD variance	Variance	SD variance	Variance	SD variance	Variance	SD variance
Panel ID	0.48	0.69			0.48	0.69	0.44	0.66
Product ID			0.70	0.84			0.70	0.84
Product ID nested in Panel ID					0.00	0.00		
Residual	140.46	11.85	140.17	11.84	140.46	11.85	139.76	11.82
intra-cluster correlation	**0.0034**		**0.0050**		**0.0034**		**0.0081**	

Appendix Table xx: Regression 7.1 results, estimated with OLS

	change in volume (L/adult equivalent)			change in sugar (g/adult equivalent)		
	Estimate	**SE**	**Pr(>|t|)**	**Estimate**	**SE**	**Pr(>|t|)**
(Intercept)	-0.21	0.1	0.126	-3.1	6.1	0.614
status_new	2.68	0.1	**0.000**	89.9	2.2	**0.000**
status_not continued	-1.73	0.1	**0.000**	-98.0	2.5	**0.000**
status_reformulated	1.65	0.0	**0.000**	55.8	1.9	**0.000**
% reformulated (HH)	0.02	0.0	**0.000**	0.9	0.0	**0.000**
status_new:% reformulated	-0.03	0.0	**0.000**	-0.5	0.1	**0.000**
status_not continued:%reformulated	0.00	0.0	0.101	0.2	0.1	**0.015**
status_reformulated:%reformulated	-0.06	0.0	**0.000**	-2.6	0.1	**0.000**
Volume of sugary drinks (L/AE)	-0.01	0.0	**0.000**	-0.5	0.0	**0.000**
Sugar density of purchases (g/100mL)	0.03	0.0	**0.000**	-4.6	0.2	**0.000**
% of discontinued purchases	0.00	0.0	**0.000**	0.3	0.0	**0.000**
Average price paid	0.15	0.0	**0.000**	13.4	1.6	**0.000**
HHI	0.00	0.0	**0.000**	0.0	0.0	**0.000**
Household.Size2 Member HHs	-0.30	0.0	**0.000**	-2.4	1.7	0.147
Household.Size3 Member HHs	-0.49	0.1	**0.000**	-4.4	2.9	0.132
Household.Size4 Member HHs	-0.52	0.1	**0.000**	-3.8	3.1	0.221
Household.Size5+ Member HHs	-0.64	0.1	**0.000**	-6.2	3.4	0.071
Number.of.Children1 Child HHs	0.16	0.1	**0.028**	10.1	3.3	**0.002**
Number.of.Children2 Child HHs	0.22	0.1	**0.007**	14.1	3.6	**0.000**
Number.of.Children3+ Child HHs	0.24	0.1	**0.010**	14.9	4.1	**0.000**
Household.Income£10,000 - £19,999 pa	-0.01	0.1	0.888	2.7	2.2	0.221
Household.Income£20,000 - £29,999 pa	-0.03	0.1	0.509	4.3	2.3	0.062
Household.Income£30,000 - £39,999 pa	-0.07	0.1	0.229	0.4	2.4	0.861
Household.Income£40,000 - £49,999 pa	-0.05	0.1	0.414	-0.8	2.5	0.757
Household.Income£50,000 - £59,999 pa	-0.06	0.1	0.352	-1.7	2.8	0.540
Household.Income£60,000 - £69,999 pa	-0.13	0.1	0.073	-0.4	3.2	0.911
Household.Income£70,000 +	-0.07	0.1	0.314	-2.2	3.0	0.466
Household.IncomeDid not want to answer	-0.03	0.1	0.626	1.4	2.4	0.561
Social.ClassC1	0.02	0.0	0.381	1.9	1.3	0.137
Social.ClassC2	0.10	0.0	**0.002**	2.2	1.5	0.129
Social.ClassD	0.01	0.0	0.887	0.6	1.7	0.731
Social.ClassE	0.10	0.0	**0.038**	3.1	2.2	0.150
Urban...RuralCity	0.00	0.1	0.971	-5.6	4.6	0.224
Urban...RuralRural	0.02	0.1	0.837	-3.0	4.9	0.541
Urban...RuralSemi-rural	0.00	0.1	0.993	-2.9	4.6	0.536
Urban...RuralSuburban	-0.01	0.1	0.918	-4.9	4.5	0.272
Urban...RuralUrban	0.03	0.1	0.768	-5.5	4.5	0.223
Main.Shopper.Age 35-44	0.03	0.0	0.472	3.5	1.7	**0.044**
Main.Shopper.Age 45-54	0.01	0.0	0.767	5.2	2.2	**0.017**
Main.Shopper.Age 55-64	-0.01	0.1	0.905	5.7	2.5	**0.025**
Main.Shopper.Age 65+	0.06	0.1	0.507	2.7	3.9	0.487
Main.Shopper.Age under 28	-0.04	0.1	0.609	3.2	3.3	0.323
Ethnicity_non white	-0.04	0.0	0.336	2.4	1.6	0.146
LifestageFamily 10+ Years	-0.07	0.0	0.088	-2.5	1.9	0.194
LifestageMiddle Family 5-9 Years	-0.02	0.0	0.573	-1.4	1.7	0.409
LifestageOlder Dependents	0.00	0.1	0.968	1.6	2.9	0.578
LifestagePre-Family	-0.01	0.1	0.877	9.4	2.6	**0.000**

LifestageRetired	-0.12	0.1	0.146	6.1	3.7	0.101
RegionLondon	-0.03	0.0	0.527	-1.1	2.1	0.591
RegionMidlands	0.04	0.0	0.339	-2.2	1.7	0.196
RegionNorth	0.03	0.0	0.413	-2.8	1.6	0.079
RegionScotland	0.02	0.0	0.596	-1.7	2.0	0.385
RegionSouth	0.00	0.0	0.998	-1.3	1.6	0.419
RegionWales	0.08	0.1	0.145	1.2	2.4	0.615

AE: adult equivalent

All household estimates are calculated at baseline (2015)

Appendix Table xxi: Predicted effects (or marginal means) for the three outcomes, using adjusted OLS at household level (Equation 7-2), estimated for three moderators, at the mean level of all other variables

	moderator (in 2015)	percentile moderator	value moderator	predicted effect	SE	population average at baseline	% change with population average at baseline
Change in volume (L)	Baseline sugar density (g/100mL)	5th	0.43	-5.3	1.0	98.2	-5%
		25th	1.97	-2.6	0.7	98.2	-3%
		50th	4.09	1.3	0.5	98.2	1%
		75th	6.56	5.7	0.7	98.2	6%
		95th	9.4	10.8	1.1	98.2	11%
	volume sugary drinks (L)	5th	2.7	15.2	0.7	98.2	15%
		25th	12.2	11.8	0.6	98.2	12%
		50th	27.2	6.6	0.5	98.2	7%
		75th	53.1	-2.5	0.5	98.2	-3%
		95th	122.7	-27.0	1.1	98.2	-27%
	% reformulated products	5th	2	1.4	0.8	98.2	1%
		25th	10	1.6	0.6	98.2	2%
		50th	20	1.8	0.5	98.2	2%
		75th	35	2.1	0.6	98.2	2%
		95th	66	2.7	1.2	98.2	3%
Change in sugar density (g/100mL)	Baseline sugar density (g/100mL)	5th	0.43	0.9	0.0	4.5	19%
		25th	1.97	0.1	0.0	4.5	3%
		50th	4.09	-0.9	0.0	4.5	-20%
		75th	6.56	-2.1	0.0	4.5	-46%
		95th	9.4	-3.4	0.0	4.5	-77%
	volume sugary drinks (L)	5th	2.7	-1.1	0.0	4.5	-24%
		25th	12.2	-1.1	0.0	4.5	-24%
		50th	27.2	-1.1	0.0	4.5	-24%
		75th	53.1	-1.0	0.0	4.5	-23%
		95th	122.7	-1.0	0.0	4.5	-22%
	% reformulated products	5th	2	-1.1	0.0	4.5	-24%
		25th	10	-1.1	0.0	4.5	-24%
		50th	20	-1.1	0.0	4.5	-24%
		75th	35	-1.0	0.0	4.5	-23%
		95th	66	-1.0	0.0	4.5	-23%
Change in sugar (g)	Baseline sugar density (g/100mL)	5th	0.43	-542	38	3800	-14%
		25th	1.97	-689	28	3800	-18%
		50th	4.09	-892	20	3800	-23%
		75th	6.56	-1129	26	3800	-30%
		95th	9.4	-1401	44	3800	-37%
	volume sugary drinks (L)	5th	2.7	589	27	3800	15%
		25th	12.2	208	24	3800	5%
		50th	27.2	-392	20	3800	-10%
		75th	53.1	-1429	20	3800	-38%
		95th	122.7	-4216	44	3800	-111%
	% reformulated products	5th	2	-977	31	3800	-26%
		25th	10	-960	25	3800	-25%
		50th	20	-936	20	3800	-25%
		75th	35	-902	22	3800	-24%
		95th	66	-834	47	3800	-22%

Appendix II. PUBLICATIONS FROM THIS THESIS

Research presented in chapter 2

nutrients

Communication

Healthy Foods and Healthy Diets. How Government Policies Can Steer Food Reformulation

Mathilde Gressier [1,2,*], Franco Sassi [2] and Gary Frost [1]

1 Section for Nutrition Research, Department of Metabolism, Digestion and Reproduction, Faculty of Medicine, Imperial College London, London W12 0NN, UK; g.frost@imperial.ac.uk
2 Center for Health Economics & Policy Innovation, Department of Economics & Public Policy, Imperial College Business School, Imperial College London, London SW7 2AZ, UK; f.sassi@imperial.ac.uk
* Correspondence: m.gressier18@imperial.ac.uk

Received: 19 May 2020; Accepted: 3 July 2020; Published: 4 July 2020

Abstract: Food reformulation policies aimed at reducing the risk of diet-related non-communicable diseases have been implemented in many countries. The degree of success of reformulation policies in changing the range of food options available to consumers has been a function of the design of these policies. Our objective was to review the different factors making the design and implementation of a food reformulation policy effective at improving populations' diets and health. In this narrative review, we present a logic model of the action of reformulation policies on consumer behaviour, dietary intake and population health. We set out how policy design could drive outcomes, and highlight the role for governments and public health agencies in promoting food reformulation that is effective in improving diet and health. The key drivers of success for reformulation policies include strong incentives, a tight implementation strategy, a focus on the overall nutritional quality of food products, rather than on individual nutrients, and effective monitoring and evaluation. Additionally, policies should mark the distinction between product reformulation and product differentiation, which have different nutrition and health outcomes.

Keywords: public health policy; food reformulation; food policy; policy design

1. Introduction

Twenty-two percent of global deaths amongst adults are attributed to diet-related risks [1]. Many countries have adopted population-wide policies aimed at improving diets and countering a steady rise of obesity and non-communicable diseases, such as type 2 diabetes, cardiovascular disease and cancer. Current diets worldwide are characterised by an increasing intake of manufactured foods, defined by some level of alteration during their production (e.g., heated, refined, milled, or mixed with other ingredients). Packaged foods account for 61% of retail sales in the United Kingdom, 42% in Thailand and 32% in Brazil [2]. Manufacturers constantly review and adjust the formulation of the foods they produce to adapt them to consumer preferences and demand, to lower production costs and increase profits, to better position their products relative to those offered by competitors, or in response to government regulation or guidelines. While food reformulation is and will remain primarily driven by market forces, the idea that reformulation efforts can be steered in the direction of an improved nutritional quality has been gradually developing in the public health policy debate [3,4]. Food reformulation has the potential for generating major public health impacts, but realising this potential will require greater clarity and agreement on the underlying concepts and mechanisms through which reformulation can have an impact on people's diet and health.

Nutrients 2020, *12*, 1992; doi:10.3390/nu12071992 www.mdpi.com/journal/nutrients

Research presented in chapter 3

Received: 3 July 2020 | Revised: 10 August 2020 | Accepted: 17 August 2020
DOI: 10.1111/obr.13139

PUBLIC HEALTH

OBESITY Reviews WILEY

What is the impact of food reformulation on individuals' behaviour, nutrient intakes and health status? A systematic review of empirical evidence

Mathilde Gressier[1,2] | Boyd Swinburn[3] | Gary Frost[1] | Alexa B. Segal[2] | Franco Sassi[2]

[1]Section for Nutrition Research, Department of Metabolism, Digestion and Reproduction, Faculty of Medicine, Imperial College London, London, UK

[2]Centre for Health Economics and Policy Innovation, Department of Economics and Public Policy, Imperial College London, London, UK

[3]The University of Auckland, Auckland, New Zealand

Correspondence
Mathilde Gressier, Section for Nutrition Research, Department of Metabolism, Digestion and Reproduction, Faculty of Medicine, Imperial College London, London, UK.
Email: m.gressier18@imperial.ac.uk

Funding information
Horizon 2020 Framework Programme, Grant/Award Number: 774548; Nestec

Summary

Food reformulation aimed at improving the nutritional properties of food products has long been viewed as a promising public health strategy to tackle poor nutrition and obesity. This paper presents a review of the empirical evidence (i.e., modelling studies were excluded) on the impact of food reformulation on food choices, nutrient intakes and health status, based on a systematic search of Medline, Embase, Global Health and sources of grey literature. Fifty-nine studies (in 35 papers) were included in the review. Most studies examined food choices (n = 27) and dietary intakes (n = 26). The nutrients most frequently studied were sodium (n = 32) and trans fatty acids (TFA, n = 13). Reformulated products were generally accepted and purchased by consumers, which led to improved nutrient intakes in 73% of studies. We also conducted two meta-analyses showing, respectively, a −0.57 g/day (95%CI, −0.89 to −0.25) reduction in salt intake and an effect size for TFA intake reduction of −1.2 (95% CI, −1.79 to −0.61). Only six studies examined effects on health outcomes, with studies on TFA reformulation showing overall improvement in cardiovascular risk factors. For other nutrients, it remains unclear whether observed improvements in food choices or nutrient intakes may have led to an improvement in health outcomes.

KEYWORDS
consumer behaviour, food environments, food policy, food reformulation

1 | INTRODUCTION

Noncommunicable diseases (NCDs) are leading causes of death worldwide. In Europe, a quarter of NCD deaths are attributed to poor diet[1] through an increased risk of diabetes, obesity, cardiovascular disease and other conditions, so improving diets can reduce the burden of NCDs. Exposure to a healthy food environment has been shown to be a stronger driver of healthy eating than health promotion and education efforts.[2,3] Food environment interventions include changes to the availability, price, information or composition of food products. For example, food environments can be changed through reformulation of packaged and processed foods. Reformulation, in the context of the prevention of NCDs, is defined as a change in the nutrient profile of a food with the goal of making it healthier for consumers. If successful, food reformulation strategies will improve

Abbreviations: NCD, Noncommunicable diseases; NOS, Newcastle-Ottawa Scale; PICO, Population, Intervention, Comparator, Outcome; TFA, Industrially produced trans fatty acids.

Research presented in chapter 4

European Journal of Clinical Nutrition
https://doi.org/10.1038/s41430-021-00933-2

BRIEF COMMUNICATION

Minor changes in fibre intake in the UK population between 2008/2009 and 2016/2017

Mathilde Gressier [1,2] · Gary Frost [1]

Received: 18 November 2020 / Revised: 15 April 2021 / Accepted: 21 April 2021

Abstract

The benefits of increasing populations' and individuals' fibre intake on non-communicable disease risk have been known and promoted for decades in the UK and in the world. Public health campaigns, including dietary recommendations, called populations to increase their consumption of whole grains, fruits and vegetables, while manufacturers increased the fibre content of their products. In particular, the SACN report in 2015 highlighted the importance of fibres for the UK population. We analysed trends in fibre consumption for the whole population, by age group and gender using the UK National Diet and Nutrition Survey from 2008/09 to 2016/17. We investigated changes in total fibre intake and calculated the contribution to fibre intake and time trends from each food group. We compared the fibre content of food groups between 2008/09 and 2016/17. We found that fibre intake remained fairly stable. While the fibre content of some cereal-based products increased, it decreased for potato-based products. All age groups derived increasing fibre from pasta and other cereal-based products, and decreasing fibre from potato products. Adults, but not children or adolescents derived more fibre from vegetables. This resulted in an increase in fibre intake in adults, but not in children or adolescents.

Introduction

Dietary fibres are component of plant-based foods that are not digested or absorbed in the small intestine [1] but fermented by micro-organisms in the gut. Their consumption is linked to various health benefits, including reducing the risk of cardiovascular diseases or type 2 diabetes and bowel cancer [2]. Intake of dietary fibres is consistently lower than recommended targets in all regions of the world. Intake is lowest in Asia (~8–10 g/day) and highest in Oceania and western and eastern sub-Saharan Africa (~16–20 g/day) [3]. The inadequate consumption of fibres was estimated to be responsible for about 100,000 deaths in 2017 globally [3]. In the UK, the importance of fibres in the diet was emphasized in the 2015 report of the Scientific Advisory Committee on Nutrition (SACN, [1]). The report recommends a daily fibre intake of 30 g/day or more for adults, a level from which the greatest health benefits were observed [1]. This message was promoted by various organizations promoting healthy diets, which designed new messages and campaigns to raise population awareness about the benefit of an adequate fibre intake. Most of these messages, such as the messages from the NHS, the British Heart Foundation or the British Nutrition Foundation, put emphasis on swapping refined grains to whole grains, as fibre and other healthful minerals are lost during the refinement of grains. The message to eat five fruits and vegetables a day was also reinforced [4–6]. In addition, food manufacturers formulate foods with increasing levels of fibres to improve their nutrient profile [7]. One strategy is to substitute refined grains with whole grains or to launch new products with whole grains. The focus on whole grains started in the 2000s, with the introduction of a whole grain guideline in the US dietary guidelines [8], or the launch of the Danish Whole Grain Partnership in 2007 [9]. This increased focus on whole grains incentivised manufacturers to reformulate and formulate new products with whole grains [8]. There is currently limited evidence on the effect of this increased focus on dietary fibres in public health messages, policies, and food product innovations on fibre intake in the UK. The

✉ Mathilde Gressier
m.gressier18@imperial.ac.uk

1 Section for Nutrition Research, Department of Metabolism, Digestion and Reproduction, Faculty of Medicine, Imperial College London, London, UK

2 Centre for Health Economics & Policy Innovation, Department of Economics & Public Policy, Imperial College Business School, Imperial College London, London, UK

Published online: 12 May 2021

Research presented in chapter 5

Contribution of reformulation, product renewal, and changes in consumer behavior to the reduction of salt intakes in the UK population between 2008/2009 and 2016/2017

Mathilde Gressier,[1,2] Franco Sassi,[2] and Gary Frost[1]

[1]Section for Nutrition Research, Department of Metabolism, Digestion and Reproduction, Faculty of Medicine, Imperial College London, London, United Kingdom; and [2]Centre for Health Economics & Policy Innovation, Department of Economics & Public Policy, Imperial College Business School, Imperial College London, London, United Kingdom

ABSTRACT

Background: The UK salt reduction program started in 2003, consisting of education campaigns to raise awareness about the risks associated with a high-salt diet and of a reformulation strategy for food manufacturers. This program is often cited as an example of a successful public health program.

Objectives: This study aimed to assess: *1*) the impacts of changes in food composition and changes in consumer behavior on sodium intakes; and 2) whether changes were similar across socioeconomic groups.

Methods: Food intakes for the UK population were derived from food diaries in the UK National Diet and Nutrition Survey for 2008/09 (year 1; $n = 1334$) and 2016/17 (year 9; $n = 995$). Year-specific sodium densities of foods were used to calculate the average sodium density of all food and beverage consumed. Changes in sodium density between the 2 years were explained by changes in food composition (change in sodium density of products) and/or changes in behavior (type and quantity of food consumed) using a decomposition approach.

Results: The program was linked to a 16% (95% CI: −21% to −12%) decrease in sodium intake between years 1 and 9, while the sodium density of foods consumed decreased by 17% (95% CI: −21% to −12%). This decrease was largely driven by reformulation (−12.0 mg/100 g). Changes in food choices reinforced the effects of the program, but had a smaller impact (−1.6 mg/100 g). These effects were similar across socioeconomic groups, whether stratified by education or income, with a consistent effect of reformulation across groups and no differences between groups in behavioral responses to the program.

Conclusions: A multi-component sodium reduction strategy deployed in the United Kingdom starting in 2003 corresponded to an important reduction in sodium intakes for the population. This reduction was mostly driven by changes in the food environment (reformulated food products to reduce the sodium density of foods) and, to a smaller extent, by changes in food choices. Impacts were consistent across socioeconomic groups. *Am J Clin Nutr* 2021;114:1092–1099.

Keywords: reformulation, public health, food policies, intervention evaluation, consumer behavior, sodium, salt

Introduction

High blood pressure is the third leading risk factor for premature death in the United Kingdom, affecting more than 25% of adults (1). It is estimated to cost £2.1 billion every year for the UK National Health Services (2). Contributors to high blood pressure risk include both nonmodifiable (e.g., genes, age) and modifiable factors (2). A leading contributor among the latter is

MG is the recipient of an unconditional PhD Studentship grant from Societé des Produits Nestlé, supervised by GF. Societé des Produits Nestlé had no role in the study design, data collection and analysis, or preparation of the protocol and research paper. (Science and Technology in childhood Obesity Policy) project. The STOP project (http://www.stopchildobesity.eu/) received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement No. 774548. The Nutrition Research Group is funded by grants from the Medical Research Council, the Biotechnology and Biological Sciences Research Council, the National Institute for Health Research (NIHR); an Integrative Mammalian Biology Capacity Building Award; and the NIHR Biomedical Research Centre Funding Scheme.

The content of this publication reflects only the views of the authors, and the European Commission is not liable for any use that may be made of the information it contains. The views expressed are those of the author(s) and not necessarily those of the National Health Service, the National Institute for Health Research, or the Department of Health.

Supplemental Tables 1–7, Supplemental Figures 1–4, and Supplemental Equation *1* are available from the "Supplementary data" link in the online posting of the article at https://academic.oup.com/ajcn/.

Address correspondence to MG (e-mail: m.gressier18@imperial.ac.uk).

Abbreviations used: NDNS, National Diet and Nutrition Survey; PHE, Public Health England; SES, socioeconomic status.

Received October 22, 2020. Accepted for publication March 30, 2021.

First published online May 8, 2021; doi: https://doi.org/10.1093/ajcn/nqab130.