Does a Spoonful of Sugar Levy Help the Calories Go Down? An Analysis of the UK Soft Drinks Industry Levy*

Alex Dickson[†], Markus Gehrsitz[*‡], Jonathan Kemp[*§]

April 17, 2022

Abstract

This study evaluates the effects of the 2018 UK Soft Drinks Industry Levy on soft drinks prices, sales, reformulation activities, and consequently calories consumed. We combine novel electronic point of sale data that cover most of the UK soft drinks market with longitudinal nutritional information and a variety of event-study specifications. We document that all but a few global soft drinks brands reduced sugar content and hence avoided the tiered levy. For brands that maintained their original sugar content, the levy was on average over-shifted resulting in substantial retail price increases. Consumers responded by reducing their consumption of levied drinks by around 18% which is indicative of an inelastic demand response, especially in the drink-now and energy drink segments of the market. We also document substitution into diet drinks in response to the tax. In total, the levy is responsible for a reduction in intake of about 6,600 calories from soft drinks per annum per UK resident. More than 80% of reductions were due to manufacturers' reformulation activities and occurred in the two years between the announcement of the levy and its implementation.

Keywords: sugar tax; soda tax; reformulation; tax pass-through; sin taxes
JEL Codes: H21; H23; H51; I12; I18

*We are grateful to Hunt Allcott, Ana Balsa, Nano Barahona, John Cawley, Fabrice Etilé, David Frisvold, Michael Grossman, Emilio Gutierrez, David Jaeger, Tinna Laufey Ásgeirsdóttir, Jan Marcus, Jonathan Norris, Agnese Romiti, Mark Schaffer, Renke Schmacker, Hans van Kippersluis, Tanya Wilson, Ian Wooton, and the participants of the University of St. Andrews and the University of Strathclyde's applied microeconomics seminars as well as participants of Cornell University's Virtual Seminar on the Economics of Risky Health Behaviors for their helpful comments.

†Department of Economics and Fraser of Allander Institute, University of Strathclyde, Glasgow, UK. Corresponding author: Markus Gehrsitz, e-mail: markus.gehrsitz@strath.ac.uk.

‡Institute for the Study of Labor (IZA), Bonn, Germany

§AG Barr, plc. All views expressed in this paper are personal and not those of AG Barr plc.

1 Introduction

In March 2016 the UK Government announced the implementation of a UK-wide Soft Drinks Industry Levy (SDIL) to take effect some two years later in April 2018. The responsibility to pay the levy lies with manufacturers of soft drinks and is tiered: if the sugar content exceeds a threshold of 5g per 100ml a tax of 18 pence per litre (ppl) is imposed; while if it exceeds 8g per 100ml the tax is 24ppl. Effectively, the levy substantially increases the cost of sugar as an input for manufacturers of sugar sweetened beverages (SSBs) which, crucially, can be completely avoided if manufacturers ensure the sugar content of their drinks falls below the lower 5g per 100ml threshold.

'Sugar taxes', in various forms, have been introduced globally—in line with World Health Organisation (WHO) recommendations (WHO, 2017)—with the aim of reducing consumption of high-sugar foods, which are linked to the problem of obesity. The specific objective of the UK SDIL was to "contribute to the government's plans to reduce childhood obesity by removing added sugar from soft drinks...[by encouraging producers to] reformulate their products to reduce the sugar content [and] reduce portion sizes..." (UK Government, 2016). While the effect of sugar taxes around the world has seen close scholarly attention, evaluation of their efficacy has (due to their nature) focused on the demand-side channel of consumers responding to tax-induced higher prices. The features of the UK SDIL (substantial delay between announcement and implementation; and ability to completely avoid the levy if the soft drink contains only a teaspoonful of sugar per 100ml) adds scope for a supply-side channel of reformulating products to avoid the levy, which has been largely under-studied.

In this article, we study and quantify the overall effect of the UK SDIL on calorific intake from soft drinks, and answer three related questions to understand the effect of the policy. First, what contribution has product reformulation made to levy-induced calorie reductions; and how have pricing, calorie intake, and sales of reformulated beverages developed over time? Second, what has been the pass-through of the levy? In the UK soft drinks market manufacturers, who in some segments have substantial market share, sell their products to the retail market, some segments of which are also highly concentrated; moreover, it is manufacturers who are liable for the levy. As such, the extent of pass through within this layered market structure is an interesting area of investigation that we carefully study, along with whether there is any price response in products that do not attract the levy. Third, consumers are likely to respond to higher prices as a result of the levy being passed through by reducing their consumption of levied goods and by shifting towards non-levied substitutes; we therefore ask: does a large sugar levy lower the consumption of levied goods and do close substitutes, such as diet versions of levied brands, see increased sales volumes?

To address these questions, we leverage uniquely rich electronic point of sale (EPOS) data. The sample period is the 288 weeks from July 2014 (about 2 years prior to the announcement of the levy) to January 2020 (about 2 years after the levy was implemented). Our data give us a weekly read on the universe of soft drinks transactions in the vast majority of supermarket chains across the UK, as well as thousands of convenience stores. As such, our data cover the majority of UK purchases of soft drinks both for 'at-home' consumption and for 'on-the-go' consumption. For our main analysis we focus on the top 100 brands and brand variants, ranked by value as sold, which collectively account for 73% of consumer spending on soft drinks in our data. We link these brands with longitudinal data on their nutritional content, in particular sugar and calorie content of each product over time. For each brand there are a number of individual products (in different packaging formats and pack sizes), and for each of these we have the weekly volume of that product sold as well as the value of those transactions, that allow us to calculate an average price per litre of product sold in that week.

Crucially, our data allow us to understand the sugar and calorie content of each product, as well as identify changes in these so we can pinpoint the timing of product reformulations and the consequences in terms of calories consumed. It also allows us to disaggregate the soft drinks market into four different categories: *levied* brands that did not reformulate and are subject to the high tier of the levy; *reformulated* brands that adapted their recipes and hence fully or partially avoided the levy by the time of its implementation; *diet* brands that do not attract the levy because they contain no sugar; and *non-levied* brands that cover everything else, including water, brands in categories that are exempt, and those with sugar but where that sugar content has always been less than 5g per 100ml.

We combine these rich data with several event-study techniques. Product reformulations occurred after the announcement of the levy in a staggered fashion. This allows us to assess the effects of reformulation-related sugar reductions on calorific intake, sales volumes, and prices in a differences-in-differences setup. We also document large and obvious structural breaks in prices and sales volumes that align with the date of the implementation of the levy. This allows us to credibly estimate the effect of the levy on both levied and unlevied brands by way of an interrupted time series approach.

Figures 1 and 2 visualise our main results. The sugar levy has arguably been very successful from a public health point of view. As can be seen from the red, dashed line in Figure 1, UK calorie consumption from the 100 leading brands in our data has reduced from around 23bn calories per week on average in the period in our data prior to the announcement of the levy, to roughly 15bn per week at the beginning of 2020: our analysis demonstrates that of this 8bn calories per week reduction, 6.1bn, or approximately three quarters, are attributable to the UK SDIL. Extrapolating to the full market and stripping out the effects of a long-term trend in consumer preferences for low calorie products, we estimate that the levy is directly responsible for a reduction of about 6,600 calories per year per head of current UK population. We show that most of the calorie reductions happened in fact *before* the implementation of the levy (grey shaded area of Figure 1) as a result of a supply-side response where manufacturers reformulated their products to contain less sugar, consequently avoiding the levy entirely. Reformulating brands typically saw no change in either sales volumes or prices. We show that in our data reformulation activities account for more than 80% of the levy-induced calorie reductions from soft drinks consumption since it was announced. The demand-side response to higher prices following the introduction of the levy, through which a tax is typically assumed to work, accounts for the much smaller remainder.

This is despite the substantial increase in the retail price of levied brands that did not reformulate and so were subject to the levy upon its implementation. Figure 2 shows that the levy, that amounts to 28.8ppl (with the addition of UK VAT), was not just passed on to consumers but in fact over-shifted. However when assessed in detail it becomes apparent that the *prima facie* evidence for tax over-shifting actually contains a number of 'mix effects': once unpacked, these reveal that over-shifting only occurs for levied colas and, while substantial, it is lower than the raw, graphical evidence suggests. We nevertheless conclude that the pass-through rate for levied colas is in the region of 140%, with other levied beverages exhibiting full pass-through.

Finally, the blue solid line in Figure 1 illustrates that overall soft drinks consumption has continued its trend, seemingly uninterrupted by either the announcement or subsequent implementation of the levy. We document that this aggregate pattern masks several, often opposing trends. Even prior to the levy announcement and implementation, there had been a decline in sales of high-sugar carbonated drinks, in particular colas, and an increase in volumes for diet variants. Both trends were amplified by the SDIL. In fact, consumption of levied brands dropped by around 18% post levy implementation. In the face of a much larger retail price increase, however, this implies that the demand for levied, high sugar drinks is inelastic. For products where sugar is typically regarded by consumers as a key functional component, such as energy drinks, the elasticity of demand in fact appears to be close to zero. We also find no evidence of substitution into high-calorie but unlevied soft drinks such as fruit juices or dairy, nor into lower cost own-label brands.

Our paper adds to two important strands of the literature. First, there are several studies empirically evaluating sugar taxes (see Allcott et al. (2019b); Griffith et al. (2019), and Section 2 of this article for an overview). Many of these evaluate locally-implemented taxes which operate differently from national levies. In particular, local taxes offer little incentive for brand owners to reformulate their products. In our paper, we show that reformulation is in fact a crucial driver of calorie reductions when a levy with a tiered structure that imposes a substantial tax on high-sugar drinks but allows for the levy to be completely avoided with a moderate amount of sugar, is introduced at the national level. To the best of our knowledge, we are the first to credibly document the importance of these supply-side responses.[1] Our data also allow us to more comprehensively unpack pricing and sales responses. As such our study is also complementary to other studies of national levies that use CPI data or draw on household panels.

Second, recent influential work by Allcott et al. (2019a) and Dubois et al. (2020) is concerned with distributional aspects of sugar taxes and the optimal tax level. Our work demonstrates that supply-side responses deserve more attention, not just in empirical evaluations but also when it comes to theoretical considerations and structural modelling. For instance, widespread product

[1] Public Health England published a report in 2020 that contains a descriptive analysis of the sugar content in UK soft drinks using Kantar's consumer panel data (Public Health England, 2020, pp. 69-82). Moreover, two recent papers in the medical literature, Bandy et al. (2020) and Scarborough et al. (2020), hint at the role of reformulation but lack the data basis to reliably assess its importance.

reformulation—an aspect that has not been considered enough in the literature on so-called 'sin taxes' in general—substantially reduces the degree to which a tax is regressive. It also limits the potential for revenue recycling. While a precise estimation of elasticities is beyond the scope of our work, the overall price and sales responses to the tax—obtained from what we believe are higher quality data than what has been available to other researchers—imply that demand for products subject to the levy upon its implementation is inelastic, with an elasticity much lower than what is commonly found in the literature.

Lastly, Allcott et al. (2019a) estimate that an optimal national soda tax would be around \$0.0142 per ounce (or £0.33 per litre). As it turns out, the UK Government levied SSBs at effectively £0.288 per litre. We are thus among the first to empirically evaluate the effects of such an optimal tax without having to extrapolate from smaller price variation.

The UK SDIL has a combination of unique features—it has a tiered structure; is avoidable with moderate sugar content; and there was a substantial lag between announcement and implementation—and is among the largest national sugar taxes in a major developed country to ever be enacted. Given its efficacy, there are important supply-side lessons to be learned for other countries, including the US, that may consider enacting a similar policy. Our findings thus augment Allcott et al's (2019b) prescription of guiding principles for the design of sugar taxes.

The remainder of this article is structured as follows. In the next section, we discuss the context and background, as well as the details of the policy. We also provide an overview of the existing evidence base on soda taxes. We then turn to introducing our data in Section 3. In Section 4 we present our results on the effects of the levy on reformulation activities (subsection 4.1), pricing (subsection 4.2), as well as sales volumes and calorie intake (subsection 4.3). The empirical methods that are used to obtain our estimates for each of these three aspects are introduced at the beginning of each subsection. We subject our analysis to various robustness checks in Section 5. Section 6 discusses some of the implications of our findings before Section 7 concludes.

2 Context and Existing Literature

2.1 The UK Soft Drinks Market

The UK soft drinks industry is economically significant: according to the British Soft Drinks Association, UK consumption of soft drinks (including food-service and the on-trade) amounted to some 13.7bn litres in 2019. Soft drinks segments include mainstream carbonated drinks (2019 share of total soft drinks market 38.6%), dilutables[2] (20.8%), bottled water (20.6%), still and juice drinks (7.1%), 100% fruit juice (6.5%), and sports and energy drinks (6.3%) (BSDA, 2020).

The industry is vertically separated. Brand owners control the product formulation and packaging of the product and in partnership with the manufacturer will decide on the container, whether it is packaged as part of a multi-pack, and the price charged to retailers.[3] Retailers decide which brands to stock and the retail price of the good charged to consumers, indicating a clear separation between brand owners and the retail price of products.[4] Retailers include a variety of outlets such as (traditional and discount) supermarkets, convenience stores and leisure and hospitality settings.

Products are either targeted for 'drink now' consumption (in small containers, and typically sold chilled), or 'take home' consumption (in larger containers or packaged as a multi-pack). These two market segments are fundamentally different in terms of the consumer that purchases the product: it will typically be the 'gatekeeper' of the household for take home purchases to be consumed in the future; and the individual consumer for drink now purchases to be consumed immediately. Carbonated drink brands typically have at least two variants: 'diet' (that contains no sugar but is sweetened entirely artificially); and 'regular' (that has historically been sweetened with added sugar).

As can be seen in Figure 1, the aggregate demand for soft drinks is stable across time, but there is considerable seasonal variation with demand spiking during the Christmas and New Year period, and it being higher during summer months than winter months (with the exception of the festive holiday), showing that not surprisingly, warmer weather is a factor that influences

[2]Dilutables are sold in a concentrated format and are intended to be diluted at home. As such, when accounting for consumed volumes it is important to factor in the dilution ratio for the brand in question.

[3]Some brand owners also manufacture the product.

[4]The exception is where the brand offers a price-marked pack (PMP) where a recommended retail price is visible on the container. Note that for supermarket own brands the brand owner and retailer coincide.

demand.

2.2 The UK SDIL

The UK SDIL was announced in March 2016 and implemented in April 2018. The levy applies to soft drinks that contain sugar or have had sugar added during the production process where the sugar content is 5g per 100ml or more, unless they are in an exempt category (such as fruit and vegetable juices that do not have any added sugar, and drinks that contain at least 75% milk). It is 'tiered' with its value depending in a discontinuous way on the amount of sugar the soft drink contains: if the sugar content is 5g per 100ml or more but less than 8g per 100ml (mid sugar) the levy is 18ppl and if it is 8g per 100ml or more (high sugar) it is 24ppl. Soft drinks with less than 5g of sugar per 100ml (low sugar) attract a zero rate levy. The levy becomes a cost of goods for the manufacturer, effectively leading to an increase in the cost of sugar. Any increase in the retail price to the consumer as a result of the levy is subject to UK VAT at 20%. As such, assuming 100% pass through of the levy (from the manufacturer to the retailer, and from the retailer to the consumer) the price of a 330ml high sugar can increases by 9.4p, while the price of a 2l bottle increases by 57.6p. Bearing in mind that in 2015 large format bottles were often sold on promotion at £1 per bottle, this represents a substantial price increase.

2.3 Sugar Taxes

The consumption of high-sugar SSBs has the potential to give rise to health problems when consumed to excess over a sustained period. Similar to many other developed countries, including the US, the UK has exhibited a trend of increasing levels of both adult and childhood obesity over recent years. In England in 2019, 28.0% of adults were obese and a further 36.2% overweight; perhaps more worryingly, 21.0% of children aged 10-11 were classed as being obese and a further 14.1% overweight; and a similar pattern is reported in the other UK nations (Baker, 2021). Obesity is well-known to give rise to an increased risk of serious health problems. A substantial literature provides a well-documented link between the consumption of SSBs and obesity, both in the population as a whole and in children in particular (see, for instance, Malik et al., 2006; Public Health England, 2015).

The link between SSB consumption and detrimental health outcomes implies the consumption of SSBs exhibits both externalities and internalities. Internalities arise because SSBs are a temptation good (they are immediately pleasurable, but involve a subsequent cost) and people may suffer from a self-control problem in relation to their consumption (Schmacker and Smed, 2018). As such, actual consumption can end up exceeding planned consumption (an intentions-behaviour gap) because consumers give in to temptation at the point of making the consumption decision, to the detriment of their long-term interests. Externalities arise because the negative impact of consumption of SSBs on people's health places a cost on society. Moreover, despite most foods in the UK employing a voluntary 'traffic light' system to indicate the content of fat, sugars and salt alongside the exact nutritional content and list of ingredients, there is evidence that consumers' assessment of the sugar content of food in relation to recommended intakes remains imperfect (IGD, 2020), suggesting information concerns. These factors combined suggest consumption of SSBs may be inefficiently high, and as such there is a role for policy in correcting this market failure. In line with WHO recommendations (WHO, 2017), many policy makers around the globe have implemented 'sugar taxes' (see GFRP, 2021).

These are far from uniform in nature. An important delineation concerns whether the tax was implemented nationally in a large economy (as in, for example, Chile, France, India, Mexico, Peru and Portugal) or locally (as in Catalonia (implemented in May 2017; the rest of Spain implemented a different policy in January 2021) and US cities such as Berkeley, Philadelphia, and Boulder (as studied by, for example, Cawley and Frisvold, 2017; Cawley et al., 2018, 2021, respectively)). If a sugar tax is implemented at a local level in a small market then consumers can relatively easily avoid the tax by buying in neighbouring regions, and brand owners face little incentive to take supply-side actions to change their products to avoid being subject to the tax. If implemented at a national level, the incentive for brand owners to reformulate their products will be higher, but of course will depend on the size of the national market relative to their operation. Moreover, the ability of consumers to avoid paying the tax by buying elsewhere will be dampened if not eliminated.

The nature of the tax is also a key delineating factor. Some taxes are only levied on soft drinks with added sugar (as in Berkeley, Catalonia, and Mexico for example), whereas some tax all soft drinks whether they contain sugar or not (as in France, for example). Sugar taxes also vary in terms of how the tax is levied: some do not vary with the sugar content (as in Berkeley, Philidelphia, Mexico, and the original implementation in France), while others do (as in Catalonia and Portugal, which are also based on volume; and Chile and Peru, where the ad valorem rate depends on the sugar content). Where taxes are based on sugar content, the tax is generally discontinuous and jumps up at some threshold sugar level; whereas the taxes based only on volume do not have such jumps. As such, consumers in these different settings have faced a variety of patterns of changes in prices of soft drinks which have had differing effects; and brand owners have faced a variety of different incentives in terms of a supply-side response.

The literature studying the efficacy of sugar taxes has been effectively reviewed in Griffith et al. (2019). The typical question asked is: what is the effect of the implementation of a 'soda tax' on prices (i.e., the extent of pass-through of the tax to consumers) and consumption behaviour? Some studies also consider the effect on sugar consumption or calorific intake. Here we focus on the literature on national implementations of soft drinks taxes. In January 2012 France introduced a national tax on all soft drinks (including those containing only artificial sweeteners) which was 7.16 cents per litre (this was modified in 2018 to depend on the amount of sugar). Berardi et al. (2016) and Etilé et al. (2021) both investigate the change in prices following the introduction of the tax. Berardi et al. (2016) uses non-volume weighted store-level price data and finds full pass through for sodas and almost full pass through for fruit drinks. By contrast, using Kantar panel data, Etilé et al. (2021), finds that average pass-through is only around 40%. Capacci et al. (2019) studies (different) panel data but focus only on two French regions, finding full pass through for sodas and partial pass through for fruit juice. They also study the effect of the tax on volumes, but find no robust evidence that the tax led to a reduction in volumes purchased.

Mexico's soft drinks tax was introduced in January 2014, and involved a tax of one peso per litre on soft drinks containing added sugar (regardless of the amount), which on average amounts to a 9% increase in price (Grogger, 2017). Both Colchero et al. (2015) and Grogger (2017) investigate the increase in price using a price database, finding that the price of taxed soft drinks increased by more than the tax: Grogger (2017) found an average 14% increase in taxed products while the price of untaxed products did not significantly change, and Colchero et al. (2015) found over-shifting but only for carbonated beverages. Aguilar et al. (2021) and Colchero et al. (2015) both used panel data to investigate the impact on consumer behaviour: Colchero et al. (2015) focused on volumes and found purchases of taxed drinks declined by 6% while non-taxed increased by 4%; Aguilar et al. (2021) considered the reduction in calories induced by the tax, which are estimated to fall by 2.7% (they also document full pass-through of the tax with prices increasing by 9.7%). Arteaga et al. (2021) also study the effect on consumer behaviour by using industry data, documenting that the volume of taxed products reduced by 3.8%.

Chile introduced a soft drinks tax in 2014 which imposed an 18% ad valorem tax on soft drinks with at least 6.25g of sugar per 100ml and a lower 10% rate on those with less than 6.25g of sugar per 100ml (from a previous uniform rate of 13%). Caro et al. (2018) uses panel data to investigate the effect of the (relatively small) tax change on prices and consumption behaviour, finding that for high-sugar SSBs prices increased by 2% and volumes and calorie intake fell by 3.4% and 4% respectively, while for low-sugar SSBs prices fell and volumes increased. Nakamura et al. (2018) use a similar data source and methodology, but find a more substantial reduction in the volume of high-sugar SSBs.

Portugal's sugar tax was introduced in February 2017, which has a rate of 16 cents per litre for high-sugar drinks with in excess of 8g of sugar per 100ml, and a rate of 8 cents per litre on drinks with less than 8g of sugar per 100ml (including drinks with zero-sugar). Gonçalves and Dos Santos (2020) use store-level price and sales data from one supermarket chain to investigate pass-through and changes in purchases, finding that the tax was fully passed through for high-sugar drinks and artificially-sweetened drinks, and more than fully passed through for low sugar drinks. Despite these price increases, consumption of high sugar drinks was not significantly affected, while the consumption of low sugar drinks reduced by 18%.

Catalonia's sugar tax is the closest in nature to that of the UK, albeit a regional policy and with lower tax rates. Castelló and Casasnovas (2020) use store-level data from one supermarket chain to investigate the effect on prices and purchases. The tax was fully passed through to consumers, as required in Catalonia by law, and this resulted in a 7.7% reduction in consumption of SSBs, some of which was driven by substitution to low-sugar tax-exempt soft drinks.

So far, with the exception of a small medical literature introduced below, there has been no evaluation of the UK SDIL. Scarborough et al. (2020) collect data from leading UK supermarket websites to investigate the sugar content, price, product size and number of available soft drinks. Given that they use no information on sales no examination of the efficacy of the levy can be deduced from this study, but it does document that a number of brands reduced the sugar content in advance of the implementation of the levy. Bandy et al. (2020) use Euromonitor International (a market research consultancy) data combined with details on nutrient composition collected from websites to document the change in volume of soft drinks sold according to their data, and the change in volume of sugar contained in soft drinks, between 2015 and 2018. While this allows to get something of a handle on the impact of the levy, these data come with reliability concerns as they are based on interviews and secondary data. Euromonitor data also contain no detailed information on individual pack prices, explaining why Bandy et al. (2020) didn't study this aspect of the levy. Pell et al. (2021) undertake an analysis of the volume of soft drinks purchased in the high-tier, low-tier, and zero levy categories using household panel data. They find that the volume of levied soft drinks purchased declines considerably while the volume of non-levied soft drinks remains constant. As with all household panel-based studies, however, a considerable weakness of the data is that it both relies on consumers accurately recording supermarket purchases once they return home, and at-home panel data under-represents the large 'on-the-go' segment of the market.

The features of the UK SDIL—that the levy applies to the whole of the UK market, and it can be completely avoided by reducing the sugar content of the product below a threshold (roughly a teaspoon of sugar per 100ml)—means there is a clear incentive for manufacturers to reformulate their products to avoid substantial increases in their cost of goods, and hence in the prices consumers face. Moreover, the threshold nature of the policy can serve to overcome the 'guessing game' by manufacturers concerning their rivals' reformulation decisions. This supply-side reformulation response has seen very little attention in the existing literature.[5] We investigate how the UK SDIL played out in the UK soft drinks market using a combination of rich data sources to provide rigorous evidence on its efficacy, and the source of this efficacy. We document the calories taken out of soft drinks in advance of the levy being implemented due to the supply-side response of reformulation; we investigate how the prices of soft drinks—both those subject to the levy and those that attracted no levy—changed upon its implementation;

[5] An exception is Gonçalves and Dos Santos (2020) who study the Portuguese case, but while they collect data on sugar content it seems this is from a single point in time, and reformulation is inferred rather than observed, with little being reported on the effect of reformulation since the focus of their study is on volume consumed, as opposed to sugar or calorie intake.

and we investigate the demand response of consumers as a result of the implementation of the levy. This allows us to understand the overall effect of the levy in terms of the total reduction in calories consumed, what proportion of this is attributable to reformulation, and what proportion is attributable to reduced consumption because of the levy being passed through to consumers.

3 Data

The main data source for this study is EPOS data, which for each European Article Number (EAN) barcode gives us the weekly volume of that soft drink sold (in litres), as well as the total amount spent by consumers (in £), from which we can deduce the average price per litre paid during that week. These data provide coverage of around 45,000 supermarkets[6], convenience stores, high street stores, petrol forecourts and travel outlets across the UK. As such, with the exception of some discount supermarkets and the on-trade (in leisure and hospitality settings), our data contain the universe of soft drink sales for our sample period. There are two crucial advantages of these data over 'panel'-based data sources typically used in this area of research: they are population data rather than being extrapolated from a sample where panel members scan their own purchases; and since our data account for sales in the roughly 40,000 convenience and high street stores in the UK we can get an accurate read of the patterns in drink now consumption which is a substantial segment of the soft drink market: in 2019 drink now consumption in our data accounted for 41% of consumer spending on soft drinks, illustrating that the drink now market needs to be considered in any analysis of the SDIL.

Access to our data has been provided by AG Barr plc, a brand-owning UK-focused soft drink business established in Scotland in 1875. They purchase EPOS data from Information Resources, Inc. (IRi) to support market understanding and commercial decision making within their business. A key condition of access to this rich data source was that any analysis based on the data and shared in the public domain would be aggregated at either a category level or at a total market level. This avoids the risk of betraying any commercially sensitive information at a specific brand or retail level and we have respected this throughout the analysis.

[6] All UK supermarket chains are included with the exception of the continental discount supermarkets, Marks and Spencer, and some value retailers. Continental discounters such as Aldi and Lidl are privately owned, famously secretive and decline to share their sales data.

Ours is arguably the most comprehensive data source that has been deployed in an evaluation of any sugar levy or tax. Even the Nielsen “Scantrack" or "RMS" data which are widely used in the US have incomplete coverage, most notably when it comes to convenience stores and grocery stores in rural areas (Ruhm et al., 2012). Our data help us avoid common pitfalls that have plagued the literature on sugar taxes, such as lack of representativeness and coverage (with other scanner data, for example from single supermarket chains; and household panel data[7]); desirability bias and misreporting (with panel data); and difficulty in accounting for promotions and special offers (with infrequently-collected price data from online stores).

Our sample period runs from the week ending on 27 July 2014 to 26 January 2020. We pick the latter cut-off to avoid distortions to shopping behaviour due to the Covid-19 pandemic, and the former cut-off due to changes in data collection prior to mid-July 2014. As such, our data cover about 21 months prior to the announcement of the SDIL, the 25 months between announcement and implementation, and a 21 month period after the levy had been implemented. For each of the 288 weeks, we also merge in national data on average rainfall and temperatures (mean/max/min) because, as noted, weather is an important driver of soft drink sales.

We conduct some of our analyses at the market level using the full data set or a breakdown into the following segments: colas; other flavoured carbonates (OFC); lemonade; sports and energy drinks; mixers; fruit drinks; fruit juices and smoothies; dairy; water and squash. Most of our analyses, however, take place at the brand-level or using brand aggregates. To retain tractability in merging in nutritional data, we selected the 100 leading brands (by consumer spend in 2019) as the focus of our analysis.[8]

Table 1 shows that these brands account for about 73% of total consumer spend in our data and 75% of the total volume. Most of the remaining market share falls on retailers' own-label brands which are less dominant in some categories (e.g., cola; sports and energy) than others (e.g., lemonade; fruit drinks; water).[9]

[7] A comparison of our EPOS data to the main Kantar household panel for 2019, suggests that the household panel captures some 90% of consumer spending on take home packs, but just under 30% of the consumer spend on drink now packs. This is why additional panels and methodologies are set-up to record 'on-the-go' consumption.

[8] We use the term 'brand' to indicate both a brand and a brand variant if one exists. For example, Pepsi is the overall brand, but in our analysis we treat Regular Pepsi, Diet Pepsi and Pepsi Max as three different brands within the top 100.

[9] Beyond the leading 100 brands, individual brands are small, so substantially increasing coverage of the market, for example by including supermarket own brands, would necessarily involve making some assumptions about sugar content and timing of reformulation to apply to groups of products, which we chose not to do as we have precise

For each of the brands in the top 100, we collected their sugar and calorie content (per 100ml) from regulatory nutritional declarations on in-store packing using a combination of brand announcements and weekly store checks throughout the sample period, that was undertaken for commercial reasons by AG Barr plc. This allows us to very precisely identify the timing of any reformulation activity and the sugar (and calorie) content before and after. It is important to note that there is a lag between the production of a batch and its sale. If a manufacturer decides to reformulate its brand, there is a transition period during which retailers sell non-reformulated stock which is gradually replaced by the reformulated product. In other words, there is a transition period during which both the reformulated and non-reformulated version of a brand are sold. While the EPOS data do not allow us to distinguish between old and new stock (as reformulated products typically do not have a different EAN barcode), the Institute for Grocery Distribution (IGD) estimates that this transition period lasts on average for 28 days (IGD, 2021). Throughout our analysis we thus assume that the share of existing stock among transactions for reformulated brands drops linearly from 100% to 0% over a 4-week period.[10]

While we run several brand-level regression analyses, as noted we are not permitted to reveal individual brands for reasons pertaining to data sensitivity. In order to plot our data and visualise key patterns, we therefore group brands together throughout our analysis, typically into the following four categories:

1. Levied brands, which are high sugar and thus subject to the 24ppl levy. The only brands within this category are either colas or energy drinks, and for some of the analysis we disaggregate as such.

2. Reformulated brands that changed their recipes and as a result either partly but usually entirely avoided the levy by the time it was implemented.[11]

3. Diet/no added sugar/sugar free brands which are artificially sweetened so contain no sugar and virtually no calories. All of these brands have variants either in the reformulated category, or in the full sugar category.

information for the brands we focus on.

[10] All results are robust to changes in the assumed length of the transition period.

[11] Only three brands in our sample undertook reformulation but were still subject to the mid-sugar levy. Since these are minor brands in terms of value, we decided to include these in the reformulated category rather than creating an additional 'mid-levy' category.

4. Non-levied brands. This category contains everything else that is not subject to the levy, either because it is in an exempt category (such as milk-based drinks or 100 percent fruit juices with no added sugar) or because it contains less than 5g of sugar before the announcement of the levy (but is not classed as a diet drink, which would be included in the category above) such as bottled water and some lemonades (which typically contain lower sugar levels).

Note that the inclusion of brands in the reformulated category is based on whether the brand reformulated by the time the levy was implemented, so the composition of categories is fixed throughout the sample period.

Table 2 shows the means of our main outcomes of interest. In columns (1) to (3), we show aggregate category means which are weighted by volume in order to give brands with a larger market share more weight. We also split our sample into three time periods: prior to the announcement of the levy (July 2014 to February 2016), the period between announcement and implementation (March 2016 – March 2018), and a period after the levy was implemented (April 2018 – January 2020).

Several interesting trends are apparent from the descriptive statistics in columns (1) to (3). We will unpack each of these features more throughout our analysis. First, it is noticeable that the soft drinks market has been growing while at the same time the number of calories from soft drinks have been declining (see Panel A). Both trends are driven by the increasing popularity of diet drinks (see Panel D) which, by definition, are very low in calories. It is also noticeable that calories from reformulated drinks (Panel C) dropped by more than 50% over time, even though sales volumes in the category were roughly flat. This is a first indication that reformulation activity has played a crucial role in helping the sugar levy achieve its goal of lowering sugar and calorie intake.

Panel B shows that the price of levied products increased substantially in the post-levy period with consumers paying on average 56ppl more for levied drinks than before the levy was enacted. While this hints at an over-shifting of the 28.8ppl (including VAT) tax, we will show in Section 4.2 that mix effects and cross-product substitution account for well over half of the price increase, and that the tax was only over-shifted for cola brands. The levy-induced price increase was accompanied by a substantial drop in volume and a similarly sized drop in calories. While sales were on a slight downward trajectory even before it was enacted, the levy substantially accelerated this trend.

Panel D suggests that there is a general upward trajectory in the consumption of diet brands, that was accelerated by the implementation of the levy, hinting at substitution out of levied brands into their diet counterparts. It also suggests that the price of these brands increased despite them being exempt from the levy.

Columns (4) to (6) break down our data to brand averages where each of our 100 brands now receives the same weight regardless of market share. We can see that the average price per litre is substantially higher. Some of this is driven by squash: squash is concentrated syrup that is diluted with tap water before consumption (typically in a 1:4 to 1:9 ratio); it is very popular in the UK and accounts for about 40 percent of volume in the 'non-levied' category (see Panel E). A comparison of Columns (1) to (3) versus (4) to (6) of Panel B is also suggestive of strong market concentration which is driven by cola and energy drink markets, both of which have two brands with substantial market share in Coke and Pepsi, and Red Bull and Monster, respectively.

4 Analysis and Results

In this section we analyse the effects of the announcement and subsequent implementation of the sugar levy on pricing, volume, and total calories consumed. The introduction of the levy features three distinct aspects, each of which is modelled using a slightly different approach: we first evaluate the effect of product reformulation and sugar reductions by exploiting the staggered nature of reformulation activities in a difference-in-differences setup. Second, we model the pass-through of the tax using a structural break technique and further unpack an apparent tax over-shifting result for levied brands. Third, we re-apply our time-series approach and combine it with descriptive evidence to outline sales reactions and substitution behaviour. We describe our approach in more detail in each of the three respective subsections.

4.1 Reformulation

Figure 1 suggested that much of the reduction in calorie intake from soft drinks in fact occurred prior to the implementation of the sugar levy, but after the levy was announced. This hints at a supply-side response to the announcement of the levy on the part of brand owners to reduce the sugar content of their brands to avoid their products being subject to the levy. Figure 3 strongly supports the notion of such a supply-side response. In this figure we split our top 100 brands into 5 bands according to sugar content. The blue bars (offset to the left) show the number of brands in different sugar content bands in the week of the announcement of the levy. Of the top 100 brands in our sample, almost half had a sugar content in excess of 8g per 100ml and would thus potentially be subject to the high 24ppl tax upon implementation of the levy.[12] There were very few brands in the 4-5g and 5-8g ranges respectively and the 0-4g category is dominated by diet products that contain no sugar.

The red bars (offset to the right) show the distribution of brands by sugar content 2 years later when the levy was implemented. Brands that are liable for the levy are shown in opaque red. It is noticeable that most brands that would have been subject to the levy have reduced their sugar content. In fact, almost one third of brands now sit in the 4-5g category just below the lower tier of the levy. Put differently, Figure 3 shows that the vast majority of soft drink brand owners anticipated the implementation of the levy and reacted by substituting other sweeteners for sugar which allowed them to completely avoid the levy. 5 grams of sugar per 100ml is roughly equivalent to 20kcal whereas sweetener is basically calorie-free. This reformulation activity, therefore, may well have resulted in large calorie consumption reductions.

Figure 4 shows changes in sugar levels (or lack thereof) for some of the largest individual brands. It is striking that many well-known brands changed the sugar content of their product and virtually all of them moved to a sugar level just below the 5g levy threshold. Brands that did not reformulate were either sugar free to begin with, such as the diet brands shown at the bottom of the figure; or were exempt, such as the brands displayed in the top right corner of the chart. The only major brands which chose not to reformulate and thus were subject to the 24ppl levy are the four brands that form quasi-duopolies in the cola and energy drinks segments of the

[12] Note that some of these brands are dairy-based drinks or fruit juices, and thus levy-exempt regardless of sugar content.

market.

Figure 5 provides compelling evidence that the substitution of artificial sweetener for sugar, while keeping brands otherwise unchanged, is indeed responsible for a reduction of roughly 5 billion calories per week from the top 100 soft drink brands in our sample. In this chart, we split our brands into two groups: brands that reformulated (i.e., those in our category 2; solid blue line) and those which did not change their formula (i.e., those in categories 1, 3 and 4; dashed red line) and plot the total calories consumed in the UK attributable to these groups. Both lines are on a moderate downward trajectory prior to the announcement of the levy. This reflects general consumer trends towards a preference for diet and low calorie products and away from SSBs. The most striking feature of Figure 5 is the large reduction in calories that is accounted for by reformulating brands. Much of this reduction takes place between levy announcement and implementation (grey shaded area), with the trend flattening off after the implementation of the levy. No such dramatic reduction is observed for non-reformulating brands which stay on a similar path throughout levy announcement, implementation, and thereafter. Appendix Figure A3 further shows that the above calorie reductions are not driven by lower consumption as sales volumes do not show any change in trend.

We explicitly model the impact of reformulation activities using a difference-in-differences event study specification at the brand level. We exploit that some brands happened to reformulate their products earlier than others. As a result, late-reformulators form a useful comparison group to early-reformulators, allowing us to isolate the causal effect of product reformulation on sales, total calories, calories per 100ml, and pricing. Intuitively, products that have not (yet) reformulated provide a useful counter-factual for how our outcomes of interest would have evolved in the absence of the reformulation decision.

This identification strategy is aided by the fact that reformulation timing is driven by non-systematic factors such as differences in the technical challenge of reformulation and whether the brand owners had calorie reduction options progressed in their R&D pipelines. For instance, Fanta and Dr Pepper had already reduced the sugar content of their UK products in 2013 and 2014, respectively. Post the announcement of the SDIL they were among the first brands to introduce a version with sugar levels further reduced to just below the 5g/100ml threshold.[13] It is also

[13] Appendix Figure A2 illustrates the timing of reformulations, it is noticeable that reformulation activities indeed

noteworthy that any reformulation was not typically promoted or marketed by brands implying the opportunity for stockpiling was limited. Our event-study results below consequently show no evidence of anticipatory behaviour around reformulation episodes.

Specifically, we model the effects of reformulation using the following event study specification:

$$y_{bt} = \alpha + \tau_t + \gamma_b + \sum_{\tau=0}^{m} \delta_{-\tau} Reform_{b,t-\tau} + \sum_{\tau=1}^{q} \delta_{+\tau} Reform_{b,t+\tau} + \epsilon_{bt} \tag{1}$$

y_{bt} is our outcomes of interest: (log) sales volumes; (log) calorie intake; price per litre; and calories per 100ml for brand b in week t. τ_t and γ_b are week and brand fixed-effects, respectively. Note that the inclusion of a full set of time fixed-effects accounts for seasonality and weather effects while our brand fixed-effects subsume all product-specific time-invariant influences. All standard errors are adjusted for clustering at the brand level.

The main coefficients of interest come from our set of 4-week leads and lags represented by the set of δ_τ coefficients which are shown in Appendix Figure A4. Recent work by, among others, Goodman-Bacon (2021), De Chaisemartin and d'Haultfoeuille (2020), and Callaway and Sant'Anna (2021) has shown that with dynamic and heterogeneous treatment effects, our estimates of the lead and lag coefficients will be biased even under the assumption that early and late-reformulating brands were following similar outcome trends and would have continued to do so in the absence of any reformulation (the so-called 'common time trend assumption'). Put differently, all reformulating brands need to show the same treatment profile in order for an OLS estimation of equation (1) to produce valid estimates.

Given that most brands reformulate from about 10-11g of sugar per 100ml to just under 5g, this homogeneity assumption might plausibly be met. Nonetheless, our preferred procedure to identify the effects of reformulation on calorie intake and sales volumes uses the 'interacted weighted' (IW) estimator proposed by Sun and Abraham (2021). Indeed, Sun and Abraham's (2021) estimator is specifically designed for event-study specifications such as ours and produces consistent estimates even with heterogeneous treatment effects.

Intuitively the IW estimator obtains an estimate of each cohort-specific average treatment

happened gradually and for idiosyncratic reasons.

effect $CATT_{e,\ell}$ where e denotes a group of brands ('cohorts') which were treated at the same time, and ℓ indicates relative time until/after the reformulation date for each brand. Sun and Abraham (2021) show that the contamination of lead and lag coefficients in traditional two-way fixed effects models can be avoided by obtaining estimates for each $CATT_{e,\ell}$ while using a control group that has not (yet) been treated.[14]

Hence, we have two control group options. First, levied brands which do not reformulate and are thus 'never-treated' can serve as a control group. However, there is a risk that these brands follow distinctly different sales or pricing trends which may be why they did not reformulate. That, in turn, would jeopardise the common-time trends assumption. An alternative suggested by Sun and Abraham (2021) is picking the last of our 34 reformulating brands as the control group for constructing a series of $CATT_{e,\ell}$ estimates. In practice both approaches yield very similar results. Figure 6 summarises the main result from an analysis using the second approach while Appendix Figure A5 shows the results for a setup using never-treated units. Both charts plot our main coefficients of interest which are 4-week leads and lags along with 95% confidence intervals for the effects of product reformulation on calorie intake (blue line with circle symbols) and sales volume (red line with square symbols).

The leads provide a useful check for the main identifying assumption which is more likely to be met if there are no pre-reformulation trend differences between early and late reformulating brands. The main coefficients of interest are the lag coefficients which document the trajectory of our main outcomes of interest after reformulation and relative to brands that have yet to reformulate. Note that for ease of interpretation we have translated our point estimates into percentage terms. As suggested by Sun and Abraham (2021), we drop the 4-week period before reformulation, $t = -1$, as well as the furthest away lead, $< t - 6$, as reference periods.

Three features in Figure 6 stand out. First, all leads are hovering around zero suggesting that there is little in the way of differences in time trends, or anticipation behaviour. Second, there is a large drop in calorie intake in the 2 months after reformulation. The later lags suggest that in the long-run reformulation reduces calorie consumption by around 50%. Or put differently, around six months after a brand reformulates, calorie intake from this brand is just over 50% lower than

[14] Consistent estimates for lead/lag coefficients are then obtained as weighted averages of our cohort-specific average treatment effect estimates.

it would have been, had the brand not reformulated. Of course, the initial trajectory is partly mechanical as retailers go through existing stock before only displaying the reformulated version of a brand. It is, however, notable that this reduction is stable in the long-run. Finally, sales volumes do not change very much. Some lag coefficients are negative but none are statistically significant at the 5% level. This finding also holds if we apply a traditional two-way fixed effects event-study setup (see Appendix Figure A4) or leverage never-reformulating brands as the main comparison group in Sun and Abraham's (2021) IW approach (see Appendix Figure A5).

Our event-study specification confirms the suggestive patterns of Figures 5 and A3 by showing that reformulation reduced calories because each litre contained fewer calories, and not because substantially fewer litres were sold: volumes are stable around reformulation events. Table A1 in the Appendix shows the raw coefficient estimates. Column (3) demonstrates that the calorie content of a typical reformulated SSB was cut, on average, by 22-23 calories per 100ml which, not surprisingly, corresponds to about a 50% reduction in calorie content. Column (4) shows that reformulation activities were not accompanied by sustained changes in prices, providing evidence that sales were not stabilised by making a low sugar reformulation more palpable to consumers by way of a lower price. As mentioned above, brands did not draw attention to product reformulations through on-pack communication or advertising.[15]

We now turn to quantify the importance of reformulation activity in explaining the success of the UK SDIL in terms of calorie reductions. Assessed against a mean weekly calorie intake of just under 10 billion calories from reformulating brands in the months before levy announcement, the above-documented 50% effect suggests that reformulation within our top 100 brands is directly responsible for a reduction of 5.1 billion calories per week by the end of our sample period in January 2020.[16] What is more, our diff-in-diff estimate is best interpreted as reductions relative to a counterfactual in which no reformulation took place. That is, this estimate is net of any pre-existing trends or changes in preferences for lower calorie beverages. In Section 6 we conduct a more detailed calculation on total levy-induced calorie reductions and will document that

[15]Recent research by the IGD suggests that almost half of consumers do not look at nutritional information at all (IGD, 2020). In the case of soft-drink reformulation, sugar reductions to just below 5g on a 330ml can (which is considered as a single portion size) did not lead to a change in the red color of the sugar element of the traffic light labelling on the front of a pack.

[16]Mean weekly calorie consumption from reformulating brands in the pre-announcment period was 9.9 billion calories (see Table 2). The point estimate for the final lag is -0.729 (see Table A1). Hence: $9.9bn \times (e^{-0.729} - 1) = -5.1bn$.

reformulation is responsible for more than 80% of levy-induced calorie reductions, most of which were realised in advance of the levy being implemented.

4.2 Pricing

4.2.1 Graphical Evidence and Method for Pricing Analysis

We start again with a graphical examination of trends in pricing patterns. For that purpose Figure 7 shows pricing trends for our four product categories detailed in Section 3: levied products (>8g of sugar per 100ml) subject to the 24ppl levy; reformulated products; diet and zero-sugar products; and other brands which are exempt from the levy.

At first glance, Figure 7 suggests that the SDIL was not just passed through to consumers (as is typically found for food taxes, see e.g. Gaarder (2019)), but substantially over-shifted. In fact, the blue line (levied products) suggests that the average consumer paid 50ppl more for a levied brand even though the sugar levy, accounting for the addition of VAT, was only 28.8ppl. No price increase is apparent for reformulated brands which is consistent with the evidence presented in Table A1. There is also no discernible change in the average price for other non-levied products. However, interestingly Figure 7 provides suggestive evidence of an increase in the price of diet products a few weeks after the implementation of the levy; a point we will return to shortly.

We further analyse the effect of the SDIL on pricing (and volume/calories) using a structural break technique. This approach is commonly used in macroeconomics, but also very much lends itself to our setting. Note that we also considered using non-levied products as a control-group in another difference-in-difference setting. However, we saw in the previous section that reformulation activities led to changes in calorie content thus inducing confounding variation. Figure 7 further suggests that producers may have reacted strategically to the levy by also changing the prices of diet brands. This suggests spill-over effects, which violate a key identifying assumption of such an approach.

Our preferred approach is an interrupted time series approach which has been applied, for instance, by Evans et al. (2019) and Jayachandran et al. (2010), albeit in different topical contexts.[17] Conceptually, this approach resembles a parametric regression discontinuity design (Hahn et al.,

[17] A key difference is that both these studies exploit breaks in trends whereas we have a break in *levels* in our setting which requires a few small changes.

2001) with time as the running variable and the introduction of the levy as the 'treatment'. We start with a structural break test by running a model of the following form:

$$y_{ct}^{res} = \alpha + \beta D_t(\tau) + \epsilon_{ct} \tag{2}$$

y_{ct} is our outcome of interest (here, price per litre) for each of our four brand categories c in week t. We regress this outcome on an indicator $D_t(\tau)$ that is equal to 1 for week τ and all subsequent weeks and zero otherwise. We have 288 weeks in our sample and for each of our 288 estimates we test the hypothesis that $\beta = 0$ and calculate the corresponding F-statistic. In other words, we conduct a series of tests for a structural break in levels. Table 3 then shows the five largest F-statistics which point us to the best possible break points. In order to not mistake seasonality for a break, we first de-seasonalise our outcomes by regressing them on controls for temperature and rainfall, a set of dummies for each of the 5 weeks around Christmas when sales of soft drinks, in particular large packages, tend to increase, and a set of week of the year fixed-effects. Appendix Figures A1a to A1f contrast our de-seasonalised data with the raw data. Overall, our approach removes the striking peaks around Christmas while preserving the main patterns that are apparent in the raw data.

The SDIL was implemented in April 2018 and indeed Panel A of Table 3 suggests that over the 288 weeks in our sample, it is in this period that our test detects a structural break in the price of levied products. This was also obvious from Figure 7, but Panel B and C reveal that the break in price was accompanied by a break in volume and calories.

With our suspected break point confirmed, we model the impact of the levy on retail prices as a function of an overall trend and our identified level shift:

$$y_{ct}^{res} = \alpha + f(Time_t) + \beta Post_t + \epsilon_{ct} \tag{3}$$

The dependent variable y_{ct}^{res} is the volume-weighted, seasonally-adjusted average price for brands in our four categories. The category of levied products are of particular interest in order to determine the pass-through of the tax. $Time_t$ is a continuous variable, centered around the week ending on April 1st 2018. We experimented with higher-order polynomials of $Time_t$ but found that this has little effect on our results. Our preferred specification is thus a parsimonious, quadratic setup. $Post_t$ is a dummy variable that is equal to one for weeks ending after April 6th 2018 (the exact date of implementation). Our coefficient of interest is β which measures the average price increase once the levy went into effect.

We also estimate a similar model that, in addition to a break in levels, allows for a break in trends:

$$y_{ct}^{res} = \alpha + f(Time_t) + \beta Post_t + \gamma Post_t \times f(Time_t) + \epsilon_{ct} \tag{4}$$

Here, we are interested in both β and γ where the latter coefficient may pick up a change in the slope of pricing after the introduction of the levy. Figure 7 suggests that price adjustment is almost instantaneous and shows little change in slope, so we would expect the parsimonious model in equation (3) to be preferable and for β to be highly significant in both specifications. We still report the results for a model that allows for linear trend breaks, as described by equation (4), as a robustness check.

4.2.2 Main Result—Tax Over-shifting

Our results are reported in Table 4. Panel A suggests that the implementation of the SDIL shifted the price of taxed products up by between 48ppl (column (1)) and 50ppl (column (2)), which is in line with graphical evidence of Figure 7. It appears, therefore, as if a 28.8ppl tax (inclusive of VAT) was over-shifted by a factor of almost 2. However, this result needs to be unpacked more carefully.

Our outcome measure is volume-weighted average price per litre of product sold within each of our four categories. As such, changes in consumption behaviour within the levied category can mechanically influence the average ppl of levied brands. These include: consumers of relatively low-priced (in terms of ppl) levied brands being more likely to exit the levied category than consumers of relatively high-priced levied brands upon implementation of the levy (because the relative price increase is higher, and they might be more price-sensitive) which increases the market share of higher priced brands (a *brand mix effect*); and consumers switching from (relatively inexpensive on a ppl basis) large volume containers to (relatively expensive on a ppl basis) small volume containers (a *container mix effect*). As such, the coefficients in Panel A of

Table 4, which reflect the average price per litre that is paid by consumers, will differ from the tax pass-through if consumers changed their purchasing habits in these ways.

Our EPOS data allow us to explore both of these mix effects. First, we explore the container mix effect. In Section 4.3.2 we explore drink-now (small container size) vs take-home (large container size) consumption, and find that price increases for levied products were similar (in terms of ppl) for small drink-now and large take-home products, but drink-now drinks, which on a per litre basis tend to be more expensive, show a smaller sales response to the introduction of the SDIL. This suggests that there will be a container mix effect as smaller, relatively high price, containers will have relatively more representation post-levy implementation.

This can be partially countenanced by considering the simple unweighted average price (in ppl) paid by consumers. Table 5 gives us an estimate of the average pass-through. Here we re-run our analysis at the brand-level giving each of the levied brands the same weight. By definition, this accounts for volume changes and substitution effects across brands. We find that the average price increase per brand is around 37ppl implying a pass-through rate of 128%, statistically significantly higher than full pass-through, but lower than the 168% suggested in Table 4.

The levied category is made up of colas and energy drinks. Figure 8 shows that the brand mix effect is indeed very important in this context. Panel (a) shows the price per litre and volume for levied energy drinks. As is apparent from the blue bars, this segment of the market has consistently grown and the introduction of the SDIL has done nothing to alter this trend (also see Appendix Figure A10). By contrast, levied colas have seen declining volumes and the implementation of the SDIL has exacerbated this trend. What is more, a comparison of the right-hand side y-axis of Figure 8a and 8b reveals that levied energy drinks have a substantially higher price per litre than levied colas. Both categories naturally saw a substantial price increase as soon as the levy was enacted (red lines), but the volume-weighted average price per litre will be amplified because of the change in composition of total volume in the levied category.

To overcome this issue, we disaggregate the levied category into these two segments to see the effect on average prices for each segment. Columns (3) to (6) of Table 5 estimates the pass-through by segment (using un-weighted data) and finds that for levied energy brands prices increased by 32-33ppl, implying a pass through rate of 111-115%; and for levied colas prices increased by 39-41ppl implying a pass-through rate of 135-142%. At the 1% significance level, we cannot reject the null hypothesis of a 100% pass-through rate for energy drinks (p-value: 0.026) but can do so for colas (p-value < 0.01). We thus conclude that pass-through of the UK SDIL was at least full for levied energy drinks, and it was over-shifted for levied colas with a pass-through rate of around 140%.

There are several explanations for this over-shifting result. For one, over-shifting is consistent with a long-established retail phenomenon of "pricing in the nines" (Basu, 1997). For instance, it is well documented that US grocery stores typically choose alcoholic spirits prices that end in 99 cents and change these in $1 increments (Conlon and Rao, 2020; Gehrsitz et al., 2021). A similar phenomenon is observable in the UK soft drinks market where retailers set prices such that they end in 5p (e.g. £1.25), 9p (e.g. £0.99) or 'round pounds' (e.g. £1). When raising prices, retailers typically round up rather than down in order to reach the closest price point. Appendix Figure A6, for instance, shows that the price of a 330ml can of red Coke went from 65p to 79p. That is an effective levy of 9.5p was passed on as 14p such that a higher price target point was reached. It should be noted that Appendix Figure A6 shows the pricing for so called price-marked packs (PMPs) which are containers that have a recommended retail price printed on the container itself. Analyzing PMPs allows us to sidestep the fact that within a store the same product is often sold at different prices as it may be included in a multi-buy promotion, or as a 'meal-deal' component.

A second explanation lies in the idea of margin preservation. A key performance indicator for retailers is "profit on return" (POR) which is defined as profit divided by price minus VAT. A full pass-through of the tax would increase the denominator relatively more than the numerator, thus depressing margins. In order to maintain POR (and thus justify giving shelf-space to a given product), retailers need to over-shift the cost increase. Lastly, continual inflationary pressure and menu costs may also have played a role: some of the increase in price may be due to lagged or anticipated inflationary pressures that happened to be included as a change in price was necessitated by the levy.

4.2.3 Price Response of Non-Levied Brands

Columns (5) and (6) of Panel A in Table 4 reveal another important and interesting pattern, namely that the price of diet brands also increased by 8 to 10ppl at the point the levy was implemented, even though these products are not subject to the levy. Indeed, this finding is also consistent with the graphical evidence of Figure 7 and the structural break test of Table 3, both of which suggest price increases in this category shortly after the implementation of the levy. It is important to note that the diet category is dominated by brands which are best described as sugar-free variants of levied products. These sugar-free alternatives make up about 84% of the diet category, and almost the entirety of the diet cola market. As such, sugar-free alternatives are arguably the closest substitutes to levied products. Given this substitutability, such an increase in the price for diet products is the expected price response to a (levy-induced) increase in the price of levied variants.

There is also suggestive evidence of a very small price increase in the reformulated category. Columns (3) and (4) of Table 4's Panel A indicate a 2.4ppl increase for these brands, although we cannot reject the null hypothesis of no price change at the 1% significance level. We find no statistically significant price response for other levy-exempt brands (columns (7) and (8)). This category is dominated by water and squash, neither of which is likely to be a natural substitute for levied brands. More generally, the results of our structural break test of Table 3 show that this levy-exempt category is characterised by very stable pricing. The largest F-statistic in Panel A of this table is only about 1/25 the size of the largest F-stat for the levied category. A visual inspection of Figure 7 confirms that pricing is largely unchanged by either the announcement or implementation of the levy.[18]

[18]Note that the results of our structural break technique for reformulated and levy-exempt products should be taken with a pinch of salt. Table 3 did not identify a clear structural break for either category around the time of the levy. In particular the results in column (3) and (4) of Panel C of Table 4 reflect pre-implementation trend breaks due to reformulation (see Section 4.1) rather than a drop in calories at the time of levy implementation.

4.3 Volume and Calorie Intake

4.3.1 Main Results Volume and Calories

The previous section established that the tax was on average more than fully passed on to consumers and that the price of arguably the closest substitutes—diet versions of levied products—also increased. We now turn to analyse how consumers responded to these price increases. We follow the same structure as in the previous section: we start with a graphical analysis which is then cast into the trend break model given by equations (3) and (4) before we further unpack our main results.

Figures 9 and 10 reveal a variety of further, interesting features of the UK soft drinks market. First, it is noticeable that the 'other non-levied' category (shown in teal with diamond symbols) is very sizable, accounting for a little less than half of total volume among our top 100 brands. However, this 'other non-levied' category makes only a small contribution to total calories consumed, reflecting the fact that water and water-diluted squash are the main components. Neither Figure 9 nor Figure 10 reveal a particularly pronounced volume or calorie response for these levy-exempt brands.

Second, the volume of zero-sugar diet products sold (shown in black with triangle symbols) has seen continuous growth through our sample period, with sales volumes increasing by almost 50 percent between 2015 and 2020. This reflects a general trend in consumer preferences for low-calorie products. Third, calories consumed from SSBs have seen large reductions through our sample period: brands that reformulated (shown in red squares) saw little in the way of volume reductions but the reformulations resulted in very large reductions in calorie intake (which has been documented in Section 4.1 and is again apparent in Figure 10); in addition, it is suggested in Figure 9 that brands that did not reformulate and were subject to the levy upon implementation (blue circles), and consequently saw large price increases, suffered a sharp reduction in sales volumes. Figure 10, in turn, shows that this drop in volume consequently resulted in a drop in calories consumed from levied products.

These patterns are largely confirmed by our level-shift analysis in Panels B and C of Table 4. Columns (1) and (2) show that as a result of the implementation of the levy, the volume of levied products sold dropped by about 18%. The drop in volume was mechanically accompanied by a similarly-sized reduction in total calories from this category, which amounts to a calorie reduction from levied drinks of almost 1.2 billion per week.[19] As is apparent from Figure 8 this drop is mostly driven by lower consumption of high-sugar colas whereas levied energy brands continued their upward trend in sales volumes.[20]

Columns (5) and (6) indicate that, despite the increase in their price, diet drinks were the main beneficiary of tax-induced substitution with volume increases of up to 7.6%.[21] In the week before the levy was implemented, diet drinks recorded slightly more than double the sales volumes of levied products. Hence, in absolute terms the increase in diet sales offset most of the drop in sales of levied products. Diet versions of levied drinks, in turn, make up a constant share of about 85% of the diet category. While this suggests substitution from levied brands mainly towards their respective diet variants, a detailed analysis of brand and brand-variant loyalty is beyond the scope of this paper and would require either extensive household-level panel data or mass retailer loyalty card data which can track individual shopper behaviour. Interestingly, columns (7) and (8) of Panel B reveal that consumption in the 'other non-levied' category increased by about 4% once the levy was introduced and calories changed by about the same magnitude (see Panel C). Figure 10 showed that baseline calorie content in this category is moderate, so this amounts to a small increase of around 0.2 billion calories consumed.

4.3.2 Drink-Now vs. Take-Home Purchases

So far we have investigated our categories primarily at the aggregate market level. Our split between energy and cola brands within the levied category has uncovered interesting heterogeneity in our main effects. We now break down our analysis to distinguish the effects of the levy on 'drink-now' and 'take-home' purchases respectively. This is an important distinction not least because the drink-now segment of the soft drinks market is typically not fully reflected in the large household panels which are based on in-home scanning and hence far better set-up to record take-home rather than drink-now purchases which occur away from home.

[19] Assessed against an average weekly calorie intake of 6.4bn prior to the enactment of the levy (see Table 2), the coefficient of -0.198 suggests a change of $6.4bn \times (e^{-0.198} - 1) = -1.2bn$.

[20] We further unpack differences between the cola and energy segment, as well as differences by container size in Section 4.3.2.

[21] The results for calorie increases in Panel C, while statistically significant, are not economically significant: most diet products have less than 3kcal per 100ml, so that even the 10% increase suggested by column (4) amounts to an increase of less than 0.02 billion calories.

We therefore break down our analysis by container size. For this purpose we define as drink-now containers single cans or bottles containing less than 750ml, and define containers or packs with aggregate volumes larger than 750m as take-home.[22] Drink-now products are often available chilled in both large supermarkets and convenience stores and lend themselves to immediate consumption by the purchaser. Take-home products, conversely, are more likely to be consumed at home and frequently shared by the purchaser with other household members. A comparison of columns (1) and (5) of Panel A in Table 6 shows that the levy led to similar price increases for both take-home and drink-now colas. However inspection of columns (2) and (6) reveals that volumes dropped by twice as much for take-home containers than for drink-now. This pattern is even more pronounced for levied energy drinks for which take-home volumes dropped by about 13% (see column (4)) whereas drink-now consumption saw no economically or statistically significant change (see column (8)). This is all the more significant as for levied brands in the energy segment drink-now consumption accounts for about 80% of the total volume.

On a per-litre basis, price increases for both drink-now and take-home colas are both around 40p. Table 6, however, shows that the pre-levy mean price per litre for drink-now colas was about £2.28, as opposed to £0.92 for take-home. That is, in percentage-terms drink-now colas saw a smaller increase in prices. These differences are reflected in drink-now volumes being less responsive to changes in prices as a result of the implementation of the levy. This finding also indicates that a lack of consideration for the sizable drink-now segment of the market may lead studies based on household panel data to overestimate the responsiveness of SSB demand to the implementation of a sugar tax.

Panel B of Table 6 again documents that a large chunk of the immediate drop in consumption of levied brands in both the take-home and drink-now market is made up for by increased consumption of diet versions of these very products. Here our dependent variables are price and (log) sales volumes of the diet versions of levied brands. A comparison of column (2) in both panels, for example, reveals that more than half the drop in take-home levied cola volume is offset by an increase in diet cola sales (after accounting for the volume in these two segments, detailed in the table). This is despite the moderate price increase for diet products.

[22]The few instances with containers of exactly 750ml were classified on a case-by-case basis. For instance, 750ml bottles of water were classified as being for drink-now consumption, whereas those of fruit juices and smoothies were classified as take-home packs.

5 Robustness

In this section, we subject our analysis to a series of robustness checks. We start by assessing the representativeness of our main sample consisting of the 100 leading brands and brand-variants. Table 1 in Section 3 showed that these brands account for about 73% of consumer spending on soft drinks in our data. The remaining 27% are mainly made up by store own brands. Together with store own brands, the brands in our sample would account for more than 90% of total consumer spend on soft drinks. Despite this high coverage, we might fail to pick up important pricing and substitution patterns. For instance, it may be that a levy-induced price increase in branded products prompts an increase in demand for own labels.

Appendix Figures A9 and A10, however, suggest that this is unlikely to be the case. Due to reformulation activity documented in Section 4.1, it was primarily brands in the cola and energy segments that were subject to the levy. Crucially, there is no deviation across the full market and the segment captured by the main brands around the time the levy was enacted. In other words, there is nothing to suggest that consumers switched from branded cola and energy products to own-store labels in response to the increase in prices of levied brands. Appendix Figures A11 to A18) document the same pattern for our other eight beverage segments. For all of them, total market (blue circles) and the market made up by the main brands (red squares) follow virtually identical seasonal patterns in pricing and sales, which speaks to the representativeness of our data. Price levels tend to be lower for the total market which again reflects the fact that our sample of 100 leading brands does not include (typically less expensive) store own brands. There is no sharp break in sales volumes when the levy was implemented in any of the soft drink segments. Put differently, the top 100 brands seem to accurately represent the overall soft drinks market and it is unlikely that we miss any meaningful cross-category substitution.

Next, as an additional robustness check, we re-run our pricing and volume analysis for levied brands using a difference-in-differences approach with water as the control beverage. This is a common approach in the literature (see Taylor et al., 2019; Berardi et al., 2016; Etilé et al., 2021; Gonçalves and Dos Santos, 2020, among others). The advantage of this approach is that—in contrast to our interrupted time series approach—it allows for a full set of week fixed-effects, thus potentially better accounting for specific shocks or events affecting the overall soft drinks market.

However, Appendix Figure A19a shows that the common time trend assumption underpinning this approach may be violated. Whereas levied products had experienced a slight decline in volume in the pre-levy period, water sales were on a slight upward trajectory. The results in Appendix Table A2 should thus be taken with a pinch of salt. Column (2) suggests that the levy led to a drop in sales of levied products relative to water by about 22%. Given the divergence in pre-treatment trends, this is likely to be an over-estimate and thus consistent with our main results (see columns (1) and (2) of Table 4) which suggest about an 18% reduction.

One concern might be that the volume reduction for levied cola products may in part be driven by changes in distribution or retailer support for the brands, that is it may be the case that availability and visibility of levied products, rather than their price *per se*, is driving the volume reductions that we documented in the previous sub-section. Appendix Figure A7 shows the number of weekly store scanning distribution points, a common benchmark measure for retailer support. It is clear that retail support for levied energy has continued to grow and retailer support for levied colas only dipped marginally following the implementation of the levy. This reflects the brand strength of levied drinks which are typically considered 'must stock' lines by retailers.[23]

Retailers may, however, decide to promote full-sugar colas less than diet colas, thus decreasing the visibility of levied products. To investigate this potential impact, we compiled quarterly averages from our EPOS data of the proportion of sales that were sold on promotion. Appendix Figure A8 plots quarterly averages of the proportion of sales that were sold on promotion for full-sugar, typically levied colas on the one hand, and diet colas on the other hand. The figure fails to produce clear cut evidence that a lack of promotions is responsible for the drop in sales for regular colas. Promotional sales shares for both full-sugar and diet colas vary over time, but they do not diverge substantially at the time the levy is enacted.

[23]Note that the uptick in all categories around the time of the levy is due to the issuance of new EANs.

6 Discussion

6.1 Levy-induced Calorie Reductions from the 100 Leading Brands

In our analysis we have documented the effects of the UK SDIL within our EPOS read of the top 100 brands by sales value. In summary, we have shown that reformulation activities, that predated the implementation of the levy, are responsible for a reduction of around 5.1 billion calories per week from soft drinks; and the demand response due to higher prices for levied brands following the implementation of the levy is responsible for cutting a further 1.2 billion calories, although part of this is offset by an approximately 0.2 billion calorie intake increase as a result of substitution into levy-exempt brands. In total, therefore, the UK SDIL induced a total reduction of 6.1bn calories per week from soft drinks consumption, and our estimate is that reformulation accounts for around 84% of this, with the remaining 16% coming from the consumer response to higher prices induced by the levy.

It is important to note that these are estimates for changes relative to a counterfactual with no levy-induced reformulation activities or substitutions/reductions. That is, these effects are not driven by a longer-term underlying trend in consumer preferences for lower calorie products and brand owners' attempts to satisfy this demand by launching, advertising and promoting no added sugar variants and in some cases reformulating higher sugar products to lower levels even without the incentives created by the levy. Indeed, considering that between mid-2014 and early-2020, weekly calorie intake from the main soft drink brands dropped from about 23bn to 15bn calories, our findings suggest that the SDIL accounted for three quarters of these reductions and thus acted as a massive accelerator of these underlying trends.

6.2 Back-of-the-Envelope Calculation of Total Calorie Reduction

Of course, our estimated change in calorie intake refers to just the top 100 brands, which cover most but not all of the soft drinks market. As noted, retailer own brands make up the majority of the remaining sales in each respective category segment, but the sheer number of individual EANs means it is infeasible to track reformulation changes product-by-product. We are, however, able to estimate an aggregated response across the overall own brand offering.

Over the course of 2018, all major retailers announced that they had fully reformulated their entire own label range to sit below the 5g of sugar per 100ml SDIL threshold. This was not surprising: integral to the own label proposition is the delivery of value for money; since sugar is relatively expensive there is an incentive to replace sugar with other sweeteners. Retailers own label also has a higher share of exempt segments—e.g., water; fruit juice; and dairy where it accounts for 42, 63 and 28% of volume respectively—whereas in the segments where most reformulation took place—OFCs; energy drinks; and fruit drinks—own label accounts for only 18, 13 and 25% of volume respectively. It is also notable that own-label brands' sales volumes barely changed from 2.374bn litres in January 2018 to 2.352bn litres in January 2020.

These insights allow us to estimate the additional calorie reductions from own label brands, under a set of straightforward assumptions. For each soft drink segment, we know the total own label sales volume split between diet and regular products. For the dairy, lemonade, fruit juice, and water segments of the market, we assume that no reformulation took place because these segments were either levy-exempt or below the 5g/100ml threshold prior to announcement. For all other segments, we assume that own label products originally contained the same sugar level as a typical branded version of the product and that they reformulated to a sugar level just below the 5g/100ml threshold. This calculation implies that own-brand labels are responsible for a further reduction in calories of 165m per week.

Adding in the own label sales to the 100 brands takes the coverage to 93.1% of the available EPOS data set. The remaining 6.9% is spread across some 2,000 small brands. To be conservative in estimating the total calorie reduction, we assume that none of these brands reformulated, thus ignoring these potential calorie reductions.

As set-out in the data section, the EPOS data gives high-quality data for grocery and convenience sales of soft drinks. However, there are 'missing' elements when considering a total market picture. The first missing element is the sales in grocery and convenience stores not covered by the EPOS data. This includes sales in Continental discounters; value retailers such as 'poundstores'; and specialist retailers such as Marks and Spencer. The best data source to approximate sales in these retailers is household panel data, which we are able to access via AG Barr plc. This records aggregated sales through these retailers at 1.5bn litres per year (as sold). This adds an additional 15% of volume to that contained in the EPOS data. Assuming that these retailers sell approximately the same product mix as the mainstream retailers captured in the

EPOS data, we estimate that the levy induced a further reduction of 0.9bn calories per week.

The other missing elements of the soft drink market are 'Foodservice' and 'Licensed' respectively which cover contract catering, fast food, leisure venues, travel, hotels, pubs and restaurants. Britvic plc, a key supplier to these channels, reports total annual channel sales of 1.8bn litres (Britvic plc., 2018). Because the on-trade fundamentally differs from the off-trade channel, we cannot simply extrapolate from our EPOS estimates. In particular, consumers in Foodservice and Licensed are likely to be less price sensitive and the average retail price per litre is significantly higher (typically by a factor of 6) than in grocery and convenience. Any levy-induced price increases for levied beverages are thus much smaller in relative terms. In order to err on the conservative side, we assume that the these price increases are too small to prompt on-trade consumers to reduce their consumption of levied drinks.

That is, we infer that all calorie reductions in this channel will stem from product reformulation. To calculate the total calorie reductions, we assume that reformulating brands reduced their calorie content from 42 to 21 calories/100ml and held sales volumes constant, which seems reasonable given the results in Section 4.1. Similar to off-premise consumption, there is indeed no discernible change in total annualised sales volumes in these channels. Imposing these assumptions yields an estimate of a total calorie reduction in Foodservice and Licensed of approximately 1.3bn calories per week.

Overall, a conservative estimate is that total calorie reductions due to the sugar levy amounted to about 8.5bn calories per week, 6.3bn of which are from mainstream off-premise sales, 0.9bn by way of other retail channels, and 1.3bn in Foodservice and Licensed. With a 2019 UK population of 66.8 million (ONS, 2020), this translates into an annual per capita calorie reduction of more than 6,600 calories. Of course, this still substantially underestimates the calorie reduction for those individuals who are frequent consumers of soft drinks.

It is possible that part of these calorie reductions are offset by an increase in consumption of high-calorific solid foods, such as sweets or chocolate bars. An investigation of this kind of substitution behavior is beyond the scope of our study. Such an analysis would require detailed panel data, ideally individual-level data that includes on-the-go purchases and are supplemented with food diary information. The second-best option is using household panels which are available and offer an attractive avenue for future research of this aspect of the UK SDIL. Existing research using a US Homescan dataset indicates that a tax on soft drinks does not lead to substitution to other sugary foods (Finkelstein et al., 2013). We have also shown that reformulations were generally not accompanied by a drop in sales, and that purchases of diet products increased as volumes of levied products fell. As a result, the size of the total soft drink market has continued to grow even as the levy was announced and implemented. That makes it unlikely that substitution towards snacks and/or confectionery with high sugar content offset the large calorie reductions we document. After all, less sugary soft drinks are likely to be better substitutes for sugary soft drinks than, say, chocolate bars.

6.3 Policy Implications

We have documented that the mere announcement of the UK SDIL triggered a supply response in the form of product reformulation. The implementation of the levy induced strategic price setting among both levied and non-levied brands, and triggered a variety of substitution behaviours. A precise estimate of the elasticity of demand for either individual brands or beverage categories is therefore hard to obtain without imposing strong assumptions. After all, an elasticity measures the effect of price changes on consumption holding all else equal. Our work has shown that *ceteris* is unlikely to be *paribus* when it comes to a national sugar levy.

With that being said, our study provides a broad idea about how responsive soft drink market demand is to tax and price increases. Structural modelling by Dubois et al. (2020) estimates an own price elasticity for sugary drinks of -1.58, and in excess of -2.50 for most individual, branded products. In light of our work, it seems more likely that demand for SSBs is in fact inelastic. After all, prices of levied drinks went up by about a quarter resulting in a sales drop of less than one fifth. Sales in levied energy drinks, arguably one of the fastest growing segments of the soft drink market, barely changed at all. As such our results are also consistent with recent findings by Seiler et al. (2021) for the Philadelphia sugar tax, and the consumption tax literature in general (e.g. Kroft et al. (2020)). In terms of calorie reductions, the levy was still a success; not because of a strong demand-side response, but because of reformulation activities by suppliers.

Our study, therefore, holds several important lessons for policy makers in the UK and beyond. First, reformulation substantially reduces the potential for national sugar taxes to raise revenue, and thus for revenue recycling. When the UK Treasury announced its plans for the SDIL in 2016, it estimated that the tax would raise about £530 million per year, all of which was earmarked to help tackle the obesity crisis in schools by way of providing healthier meals and support for school sports. In 2019/20, levy revenue amounted to only £336 million. Second, there are some segments of the soft drinks market, and thus likely groups of consumers, who are not particularly price-responsive. Third, supply-side reformulation responses alleviate at least some of the distributional concerns about sugar taxes and make such a policy less regressive, an issue that has received considerable attention in the literature (see, for instance, Allcott et al., 2019b), although the unintended consequence of price increases of non-levied products must also be borne in mind when evaluating such.

Finally, the UK case shows that if reductions in calorie intake from soft drinks are the main policy goal, these can be achieved by a tax structure that is tiered, sets a clear target sugar level below which the tax can be completely avoided, and is announced well in advance of its implementation. This provides both the incentive and opportunity for brand owners to reduce the sugar content of their drinks. In the case of the UK, a sufficiently mature soft drinks industry that was already moving in the direction of lower calorie drinks had the skill and supplier relationships to respond to these incentives and provided lower calorie versions of their products that satisfied consumer tastes. Policy makers who consider expanding similar levies in other geographies or product categories should be aware of these conditions under which tax incentives can act as a catalyst for calorie reductions.

7 Conclusion

In this article we have used high-quality Electronic Point of Sale (EPOS) data for a sample period from July 2014 to January 2020, combined with longitudinal data on the nutritional content of the main soft drink brands to evaluate the UK Soft Drinks Industry Levy (SDIL). The levy was announced in March 2016 and subsequently implemented in April 2018, and places a tax on sugar sweetened beverages (SSBs) which if fully passed on to consumers amounts to 28.8 pence per litre (ppl) if the product contains 8g of sugar per 100ml or more, and 21.6ppl if the product contains between 5 and 8g of sugar per 100ml. If the product contains less than 5g of sugar per

100ml, no tax is due.

We demonstrate that for retail transactions for the 100 leading brands in our EPOS data, which make up the vast majority of the UK soft drinks market, the UK SDIL led to 6.1 billion fewer calories being consumed in the UK every week. Relative to a pre-announcement baseline of 23bn calories per week being attributable to soft drink consumption, this represents a substantial 26.5% reduction, almost an order of magnitude larger than the 2.7% reduction documented for Mexico (Aguilar et al., 2021). Remarkably, more than 80% of this drop is attributable to the reformulation of SSBs which occurred in advance of the implementation of the levy. The remainder is attributable to changing consumer behaviour following the implementation of the levy. A back-of-the-envelope calculation that extrapolates beyond the retail channel and the main brands suggests reductions of about 8.5bn calories per week, or and annual reduction of some 6,600 calories per UK resident. Our study highlights how a tiered levy with a clearly defined sugar level below which products remain un-taxed can act as an important accelerator of supply-side reformulation and, in turn, calorie reductions. It also highlights the understudied importance of supply-side responses to food taxes and regulations in general (see Barahona et al. (2020) and Griffith et al. (2017)).

For products that remained subject to the levy, the levy was fully passed through for energy drinks, and was over-shifted for colas with a pass-through rate of approximately 140%. Despite considerably higher prices, demand for levied energy drinks did not fall, but the same is not true of levied cola, which saw a substantial volume reduction. We document a similar-size increase in the volume of both diet and levy-exempt products, and interestingly a rather substantial 8ppl increase in the price of diet products which might be considered as something of an unintended consequence of the SDIL.

In addition, our study uncovered a variety of responses to economic incentives and behaviors, such as: soft drinks manufacturers tended to reduce their sugar content to levels that just exempted their products from the levy; and retailers set prices at specific price points (typically ending with 5s or 9s) which protect their margins, thus generating the above over-shifting results. Consumers in the 'drink-now' market segment—which has mostly been ignored by previous research despite accounting for almost 40% of consumer spending on soft drinks in the UK—are substantially less price-sensitive than those who buy 'take-home' products. All of these aspects are important to understand the structure of the soft drinks market and, by extension, the way soft drink taxes operate and can succeed or fail.

The UK SDIL has no doubt been successful in achieving its aim of "[contributing] to the government's plans to reduce childhood obesity by removing added sugar from soft drinks". In fact, the calorie reductions documented in this paper dwarf those achieved by linear or non-tiered volumetric taxes that have been implemented elsewhere. This is primarily due to supplier rather than consumer responses. Grummon et al. (2019) and Allcott et al. (2019b) propose some guiding principles for policy-makers considering implementing sugar taxes. Our study of the UK's experience allows us to make several important additions to these: ensure the tax is tiered and substantial, with the opportunity to avoid it completely following reasonable and technically feasible reformulation—this reduces uncertainty about competitors' likely reformulation responses and provides a strong incentive to manufacturers to reduce sugar; allow sufficient time between announcement and implementation—this provides manufacturers with the time to overcome the technical and commercial challenges of reformulation; beware of the unintended consequence of increases in the price of substitute tax-exempt goods; and do not rely on the tax revenue because a tax that effectively incentivises reformulation should generate little.

References

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

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

——— (2019b): "Should we tax sugar-sweetened beverages? An overview of theory and evidence," *Journal of Economic Perspectives*, 33, 202–27.

Arteaga, J. C., D. Flores, and E. Luna (2021): "The effect of a soft drink tax in Mexico: evidence from time-series industry data," *Australian Journal of Agricultural and Resource Economics*, 65, 349–366.

Baker, C. (2021): "House of Commons Library: Briefing paper number 3336, 12 January 2021: Obesity statistics," .

Bandy, L., P. Scarborough, R. Harrington, M. Rayner, and S. Jebb (2020): "Reductions in sugar sales from soft drinks in the UK from 2015 to 2018," *BMC medicine*, 18, 1–10.

Barahona, N., C. Otero, S. Otero, and J. Kim (2020): "Equilibrium effects of food labeling policies," *Working Paper*.

Basu, K. (1997): "Why are so many goods priced to end in nine? And why this practice hurts the producers," *Economics Letters*, 54, 41–44.

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

Britvic plc. (2018): "Foodservice and Licensed 2017 Soft Drinks Review," `https://www.britvic.com/~/media/Files/B/Britvic-V3/documents/pdf/foodservice-and-licensed-2017.pdf`, accessed: 2021-06-18.

BSDA (2020): "British Soft Drinks Association Annual Report," `https://www.britishsoftdrinks.com/write/MediaUploads/BSDA$_$Annual$_$Report$_$2020.pdf`https://www.britishsoftdrinks.com/write/MediaUploads/BSDA$_{A}nnual_{R}eport_{2}020.pd, accessed: 2021-06-18.$

Callaway, B. and P. H. Sant'Anna (2021): "Difference-in-differences with multiple time periods," *Journal of Econometrics*, 225, 200–230.

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

Caro, J. C., C. Corvalán, M. Reyes, A. Silva, B. Popkin, and L. S. Taillie (2018): "Chile's 2014 sugar-sweetened beverage tax and changes in prices and purchases of sugar-sweetened beverages: An observational study in an urban environment," *PLoS medicine*, 15, e1002597.

Castelló, J. V. and G. L. Casasnovas (2020): "Impact of SSB taxes on sales," *Economics & Human Biology*, 36, 100821.

Cawley, J., D. Frisvold, D. Jones, and C. Lensing (2021): "The Pass-Through of a Tax on Sugar-Sweetened Beverages in Boulder, Colorado," *American Journal of Agricultural Economics*, 103, 987–1005.

Cawley, J. and D. E. Frisvold (2017): "The pass-through of taxes on sugar-sweetened beverages to retail prices: the case of Berkeley, California," *Journal of Policy Analysis and Management*, 36, 303–326.

Cawley, J., B. Willage, and D. Frisvold (2018): "Pass-through of a tax on sugar-sweetened beverages at the Philadelphia International Airport," *Jama*, 319, 305–306.

Colchero, M. A., J. C. Salgado, M. Unar-Munguía, M. Molina, S. Ng, and J. A. Rivera-Dommarco (2015): "Changes in prices after an excise tax to sweetened sugar beverages was implemented in Mexico: evidence from urban areas," *PloS one*, 10, e0144408.

Conlon, C. T. and N. L. Rao (2020): "Discrete prices and the incidence and efficiency of excise taxes," *American Economic Journal: Economic Policy*, 12, 111–43.

De Chaisemartin, C. and X. d'Haultfoeuille (2020): "Two-way fixed effects estimators with heterogeneous treatment effects," *American Economic Review*, 110, 2964–96.

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

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

Evans, W. N., E. M. Lieber, and P. Power (2019): "How the reformulation of OxyContin ignited the heroin epidemic," *Review of Economics and Statistics*, 101, 1–15.

Finkelstein, E. A., C. Zhen, M. Bilger, J. Nonnemaker, A. M. Farooqui, and J. E. Todd (2013):

"Implications of a sugar-sweetened beverage (SSB) tax when substitutions to non-beverage items are considered," *Journal of Health Economics*, 32, 219–239.

Gaarder, I. (2019): "Incidence and distributional effects of value added taxes," *The Economic Journal*, 129, 853–876.

Gehrsitz, M., H. Saffer, and M. Grossman (2021): "The effect of changes in alcohol tax differentials on alcohol consumption," *Journal of Public Economics*, 204, 104520.

GFRP (2021): "Global Food Research Programme: Sugary drink taxes around the world," `https://globalfoodresearchprogram.web.unc.edu/wp-content/uploads/sites/10803/2021/04/SSB_sugary_drink_taxes_maps.pdf`, accessed: 2021-06-18.

Gonçalves, J. and J. P. Dos Santos (2020): "Brown sugar, how come you taste so good? The impact of a soda tax on prices and consumption," *Social Science & Medicine*, 264, 113332.

Goodman-Bacon, A. (2021): "Difference-in-differences with variation in treatment timing," *Journal of Econometrics*.

Griffith, R., M. O'Connell, and K. Smith (2017): "The importance of product reformulation versus consumer choice in improving diet quality," *Economica*, 84, 34–53.

Griffith, R., M. O'Connell, K. Smith, and R. Stroud (2019): "The evidence on the effects of soft drink taxes," *IFS Briefing Note BN255*.

Grogger, J. (2017): "Soda taxes and the prices of sodas and other drinks: evidence from Mexico," *American Journal of Agricultural Economics*, 99, 481–498.

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

Hahn, J., P. Todd, and W. Van der Klaauw (2001): "Identification and estimation of treatment effects with a regression-discontinuity design," *Econometrica*, 69, 201–209.

IGD (2020): "Shoppers and front of pack nutrition labelling," *Institute of Grocery Distribution - Shopper Insights*, `https://www.igd.com/Portals/0/Downloads/Charitable%20Impact/Shoppers-and-front-of-pack-nutrition-labelling.pdf`.

——— (2021): "Shoppers and front of pack nutrition labelling," *Institute of Grocery Distribution - Supply Chain Benchmarking*, `https://supplychainanalysis.igd.com/Topics/Industry-inspiration/Benchmarking`.

Jayachandran, S., A. Lleras-Muney, and K. V. Smith (2010): "Modern medicine and the twentieth century decline in mortality: Evidence on the impact of sulfa drugs," *American Economic Journal: Applied Economics*, 2, 118–46.

KROFT, K., J.-W. P. LALIBERTÉ, R. LEAL-VIZCAÍNO, AND M. J. NOTOWIDIGDO (2020): "Salience and Taxation with Imperfect Competition," Tech. rep., National Bureau of Economic Research.

MALIK, V. S., M. B. SCHULZE, AND F. B. HU (2006): "Intake of sugar-sweetened beverages and weight gain: a systematic review–," *The American Journal of Clinical Nutrition*, 84, 274–288.

NAKAMURA, R., A. J. MIRELMAN, C. CUADRADO, N. SILVA-ILLANES, J. DUNSTAN, AND M. SUHRCKE (2018): "Evaluating the 2014 sugar-sweetened beverage tax in Chile: an observational study in urban areas," *PLoS medicine*, 15, e1002596.

ONS (2020): "United Kingdom population mid-year estimate," `https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/timeseries/ukpop/pop`, accessed: 2021-06-18.

PELL, D., O. MYTTON, T. L. PENNEY, A. BRIGGS, S. CUMMINS, C. PENN-JONES, M. RAYNER, H. RUTTER, P. SCARBOROUGH, S. J. SHARP, ET AL. (2021): "Changes in soft drinks purchased by British households associated with the UK soft drinks industry levy: controlled interrupted time series analysis," *BMJ*, 372.

PUBLIC HEALTH ENGLAND (2015): "Sugar reduction: the evidence for action," `https://www.gov.uk/government/publications/sugar-reduction-from-evidence-into-action`, accessed: 2021-06-18.

——— (2020): "Sugar reduction: progress report, 2015 to 2019," `https://www.gov.uk/government/publications/sugar-reduction-report-on-progress-between-2015-and-2019`, accessed: 2021-06-18.

RUHM, C. J., A. S. JONES, K. A. MCGEARY, W. C. KERR, J. V. TERZA, T. K. GREENFIELD, AND R. S. PANDIAN (2012): "What US data should be used to measure the price elasticity of demand for alcohol?" *Journal of Health Economics*, 31, 851–862.

SCARBOROUGH, P., V. ADHIKARI, R. A. HARRINGTON, A. ELHUSSEIN, A. BRIGGS, M. RAYNER, J. ADAMS, S. CUMMINS, T. PENNEY, AND M. WHITE (2020): "Impact of the announcement and implementation of the UK Soft Drinks Industry Levy on sugar content, price, product size and number of available soft drinks in the UK, 2015-19: A controlled interrupted time series analysis," *PLoS medicine*, 17, e1003025.

Schmacker, R. and S. Smed (2018): "Sin Taxes and Self-Control," *DIW Working Paper No. 1881*.

Seiler, S., A. Tuchman, and S. Yao (2021): "The impact of soda taxes: Pass-through, tax avoidance, and nutritional effects," *Journal of Marketing Research*, 58, 22–49.

Sun, L. and S. Abraham (2021): "Estimating dynamic treatment effects in event studies with heterogeneous treatment effects," *Journal of Econometrics*, 225, 175–199.

Taylor, R. L., S. Kaplan, S. B. Villas-Boas, and K. Jung (2019): "Soda wars: The effect of a soda tax election on university beverage sales," *Economic Inquiry*, 57, 1480–1496.

UK Government (2016): "Policy Paper: Soft Drinks Industry Levy," `https://www.gov.uk/government/publications/soft-drinks-industry-levy/soft-drinks-industry-levy`, accessed: 2021-06-18.

WHO (2017): "Taxes on sugary drinks: Why do it?" `https://apps.who.int/iris/bitstream/handle/10665/260253/WHO-NMH-PND-16.5Rev.1-eng.pdf;jsessionid=36E57797711595A82D1863B09959C2DD?sequence=1`, accessed: 2021-06-18.

Tables and Figures

Table 1: Market coverage of the top 100 brands.

	Market		Top 100 Brands			% Market	
	Value	Volume	Value	Volume	N	Value	Volume
Total Soft Drinks	45008.35	53015.54	33050.98	31386.39	100	0.73	0.75
Total Cola	10132.19	9649.76	9956.64	9122.10	7	0.98	0.95
Total OFC	4606.37	4430.20	3738.21	3300.96	25	0.81	0.75
Total Lemonade	884.25	1898.25	376.90	623.72	4	0.43	0.33
Total Sports and Energy	7094.24	3440.53	6329.20	2878.43	15	0.89	0.84
Total Mixers	1172.49	1214.65	664.98	261.40	7	0.57	0.22
Total Carbs	23889.54	20633.39	21065.93	16186.62	58	0.88	0.78
Total Fruit Drinks	5006.72	2902.61	1955.13	1133.45	11	0.39	0.39
Total Fruit Juice	4985.46	3646.56	3399.90	1426.50	8	0.68	0.39
Total Dairy	2018.49	847.87	1013.34	377.35	6	0.50	0.45
Total Water	6431.51	11827.13	4086.43	5873.40	14	0.64	0.50
Total Squash	2676.63	13157.97	1530.25	6389.08	5	0.57	0.49
Total Still	21118.81	32382.15	11985.05	15199.77	42	0.57	0.47

Notes: This table shows consumer spend (in millions of £) and sales volumes (in millions of litres, as consumed, accounting for the dilution of squash) by soft drinks segment for the full observation period from July 27th 2014 to January 26th 2020. It does so separately for the full market covered by our EPOS data as well as for the 100 most popular brands (by £-sales in 2019) that are used for our main analysis. The final two columns show the percentage of consumer spend and volume that is accounted for by these 100 brands.

Table 2: Summary statistics—top 100 brands, average per week.

	(1)	(2)	(3)	(4)	(5)	(6)
	Weighted Category Average			Unweighted Brand Average		
	Jul 2014-Feb 2016	Mar 2016-Mar 2018	Apr 2018-Jan 2020	Jul 2014-Feb 2016	Mar 2016-Mar 2018	Apr 2018-Jan 2020
Panel A: All Brands						
£ per Litre	1.00	1.03	1.13	1.74	1.73	1.77
Volume in Mio Litres	106.18	108.16	112.40	1.09	1.09	1.12
Calories in Billions	22.21	19.91	15.20	0.23	0.20	0.15
Calories per 100ml	20.93	18.41	13.56	25.49	23.34	17.46
Observations	84	109	95	8218	10862	9500
Panel B: Levied Brands						
£ per Litre	1.31	1.41	1.97	2.15	2.13	2.51
Volume in Mio Litres	16.04	14.88	12.08	4.01	3.72	3.02
Calories in Billions	6.89	6.41	5.25	1.72	1.60	1.31
Calories per 100ml	42.96	43.08	43.48	44.25	44.25	44.25
Observations	84	109	95	336	436	380
Panel C: Reformulated Brands						
£ per Litre	1.40	1.39	1.44	1.67	1.68	1.68
Volume in Mio Litres	21.88	21.34	20.53	0.65	0.63	0.60
Calories in Billions	9.88	8.34	4.72	0.29	0.25	0.14
Calories per 100ml	45.18	38.98	23.03	42.29	37.22	20.24
Observations	84	109	95	2842	3706	3230
Panel D: Diet Brands						
£ per Litre	1.04	1.10	1.23	1.66	1.64	1.67
Volume in Mio Litres	20.65	22.96	27.89	0.90	0.96	1.16
Calories in Billions	0.13	0.17	0.22	0.01	0.01	0.01
Calories per 100ml	0.65	0.74	0.78	2.23	2.19	2.18
Observations	84	109	95	1932	2594	2280
Panel E: Non-Levied Brands						
£ per Litre	0.69	0.72	0.75	1.82	1.79	1.83
Volume in Mio Litres	47.62	48.97	51.90	1.29	1.29	1.37
Calories in Billions	5.31	4.99	5.01	0.14	0.13	0.13
Calories per 100ml	11.21	10.22	9.74	22.55	21.96	21.81
Observations	84	109	95	3108	4126	3610

Notes: This table shows the means for our sample of 100 leading brands. All data are weekly from the week ending on July 27th 2014 to January 26th 2020. The sugar levy was announced on March 16th 2016 and implemented on April 6th 2018. Columns (1) to (3) show weekly category means that are weighted by volume; that is, brands with high sales volumes receive a higher weight. Columns (4) to (6) show unweighted means, where each brand receives the same weight regardless of volume.

Table 3: Top 5 structural level breaks by beverage category.

Panel A: Pricing (£ per litre)								
	Levied		Reformulated		Diet/ Zero-Sugar		Levy-Exempt	
Rank	Date	F-Stat	Date	F-Stat	Date	F-Stat	Date	F-Stat
1	15 Apr 2018	2005.5	24 Feb 2019	100.3	22 Apr 2018	273.8	17 Feb 2019	81.5
2	08 Apr 2018	1885.3	17 Feb 2019	98.9	15 Apr 2018	270.9	24 Feb 2019	81.3
3	22 Apr 2018	1820.3	10 Feb 2019	91.0	06 May 2018	266.2	22 May 2016	80.2
4	29 Apr 2018	1551.7	03 Feb 2019	78.4	29 Apr 2018	265.8	08 May 2016	79.9
5	01 Apr 2018	1544.4	27 Jan 2019	51.2	13 May 2018	263.3	01 May 2016	79.7

Panel B: Volume (Million Litres)								
	Levied		Reformulated		Diet/ Zero-Sugar		Levy-Exempt	
Rank	Date	F-Stat	Date	F-Stat	Date	F-Stat	Date	F-Stat
1	08 Apr 2018	316.5	24 Feb 2019	89.9	04 Feb 2018	287.1	07 Jan 2018	18.3
2	01 Apr 2018	314.4	17 Feb 2019	87.4	11 Feb 2018	283.1	21 Jan 2018	17.8
3	15 Apr 2018	311.8	03 Feb 2019	83.0	12 Aug 2018	278.8	14 Jan 2018	17.8
4	25 Mar 2018	307.4	10 Feb 2019	82.3	14 Jan 2018	276.2	28 Jan 2018	17.4
5	22 Apr 2018	299.2	27 Jan 2019	76.0	18 Feb 2018	273.0	16 Jul 2017	17.0

Panel C: Calories (Billions)								
	Levied		Reformulated		Diet/ Zero-Sugar		Levy-Exempt	
Rank	Date	F-Stat	Date	F-Stat	Date	F-Stat	Date	F-Stat
1	08 Apr 2018	300.0	02 Jul 2017	459.9	04 Feb 2018	240.8	26 Jun 2016	27.7
2	01 Apr 2018	299.6	16 Jul 2017	442.5	11 Feb 2018	237.8	27 Nov 201	27.4
3	15 Apr 2018	296.5	23 Jul 2017	440.8	14 Jan 2018	232.3	19 Jun 2016	27.3
4	25 Mar 2018	293.9	11 Jun 2017	436.3	18 Feb 2018	229.7	13 Jul 2016	27.3
5	22 Apr 2018	284.6	25 Jun 2017	429.5	28 Jan 2018	229.5	04 Dec 2016	27.2

Notes: This table shows the results of a test for breaks in our outcomes of interest. Structural breaks are estimated as outlined in equation (2). This table reports the 5 weeks with the largest F-statistic.

Table 4: Levy effects on pricing, sales, and calorie intake—aggregate level.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Effects on Pricing (Consumer Outlay)								
	Levied		Reformulated		Diet		Levy-Exempt	
$Post_t$	0.484***	0.507***	0.024*	0.024**	0.082***	0.098***	-0.012	-0.008
	(0.027)	(0.023)	(0.014)	(0.012)	(0.019)	(0.018)	(0.010)	(0.009)
$Post_t \times Time_t$		-0.001***		0.001***		-0.000*		0.000*
		(0.000)		(0.000)		(0.000)		(0.000)
Panel B: Effects on (Log) Volume								
	Levied		Reformulated		Diet		Levy-Exempt	
$Post_t$	-0.202***	-0.201***	0.014	0.018	0.060***	0.073***	0.043***	0.042***
	(0.018)	(0.015)	(0.017)	(0.016)	(0.019)	(0.016)	(0.016)	(0.015)
$Post_t \times Time_t$		0.002***		-0.001**		-0.000		-0.000*
		(0.000)		(0.000)		(0.000)		(0.000)
Panel C: Effects on (Log) Calories								
	Levied		Reformulated		Diet		Levy-Exempt	
$Post_t$	-0.198***	-0.196***	-0.234***	-0.324***	0.069**	0.087***	0.021	0.048***
	(0.018)	(0.015)	(0.078)	(0.058)	(0.027)	(0.023)	(0.015)	(0.014)
$Post_t \times Time_t$		0.002***		0.002***		-0.001***		0.001***
		(0.000)		(0.001)		(0.000)		(0.000)
R^2	0.972	0.976	0.373	0.409	0.830	0.837	0.843	0.836
N	288	288	288	288	288	288	288	288

Notes: Newey-West standard errors allowing for autocorrelation in the error term for up to two lags are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
This table shows regression results of two structural break models as outlined by equations (3) and (4). All data are weekly national aggregates weighted by sales volume. R-Squared refers to the pricing regression (Panel A).

Table 5: Levy effects on pricing (pass-through)–unweighted brand level.

	(1)	(2)	(3)	(4)	(5)	(6)
	All Levied		Levied Energy		Levied Colas	
$Post_t$	0.370***	0.376***	0.331***	0.320***	0.393***	0.413***
	(0.014)	(0.013)	(0.017)	(0.014)	(0.017)	(0.016)
$Post_t \times Time_t$		0.000		0.002***		-0.001***
		(0.000)		(0.000)		(0.000)
Brand-FEs	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.995	0.995	0.994	0.994	0.955	0.957
N	1152	1152	576	576	576	576

Notes: Heteroscedasticity-robust standard errors in parentheses. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

This table shows regression results of two structural break models as outlined by equations (3) and (4). Brand-fixed-effects are included in all specifications. The unit of observation for this specification is the brand-week, all data are unweighted.

Table 6: Price and sales volumes by container size

Panel A: Levied Brands

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Take-Home Sizes				Drink-Now Sizes			
	Colas		Energy		Colas		Energy	
	Price	Volume	Price	Volume	Price	Volume	Price	Volume
$Post_t$	0.372***	-0.258***	0.387***	-0.139***	0.410***	-0.132***	0.279***	-0.001
	(0.026)	(0.026)	(0.043)	(0.032)	(0.022)	(0.016)	(0.020)	(0.021)
Mean:	0.92	8.62	2.58	0.43	2.28	2.06	3.47	1.64
R^2	0.763	0.315	0.960	0.815	0.743	0.838	0.985	0.734
N	288	288	288	288	288	288	288	288

Panel B: Diet Versions of Levied Brands

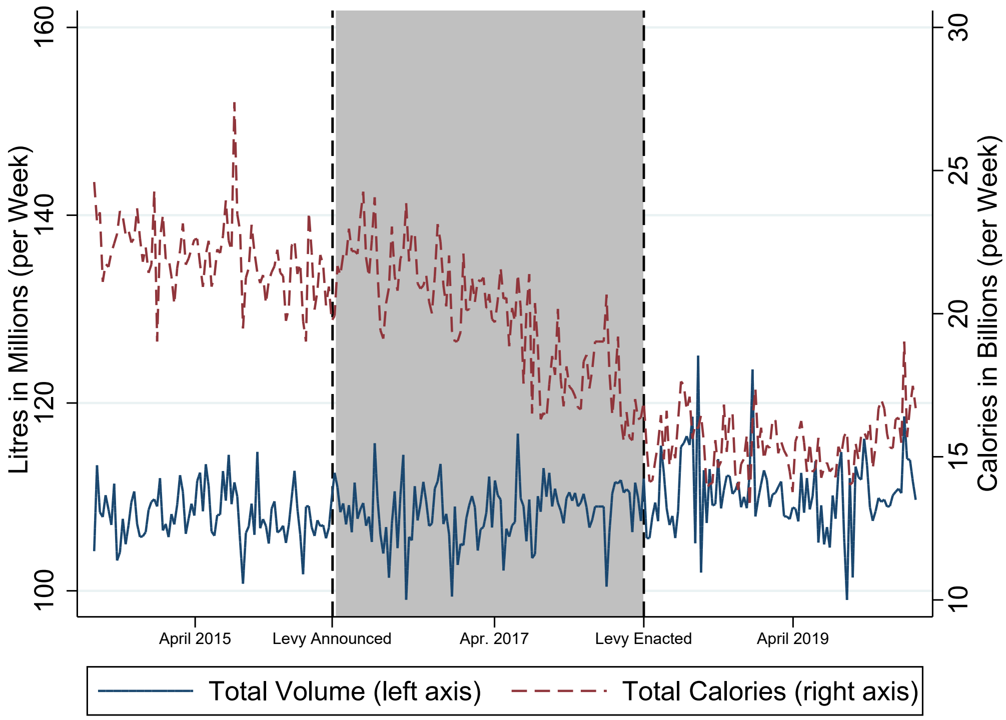
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Take-Home Sizes				Drink-Now Sizes			
	Colas		Energy		Colas		Energy	
	Price	Volume	Price	Volume	Price	Volume	Price	Volume
$Post_t$	0.077***	0.068***	-0.011	0.271***	0.087***	0.072***	0.122***	0.015
	(0.016)	(0.016)	(0.056)	(0.064)	(0.011)	(0.014)	(0.040)	(0.031)
Mean	0.84	15.56	2.28	0.17	2.13	2.77	2.57	0.87
R^2	0.803	0.711	0.824	0.672	0.318	0.716	0.862	0.755
N	288	288	288	288	288	288	288	288

Notes: Newey-West standard errors allowing for autocorrelation in the error term for up to two lags are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

This table shows regression results of two structural break models as outlined by equation (4). All data are weekly national aggregates weighted by sales volume.

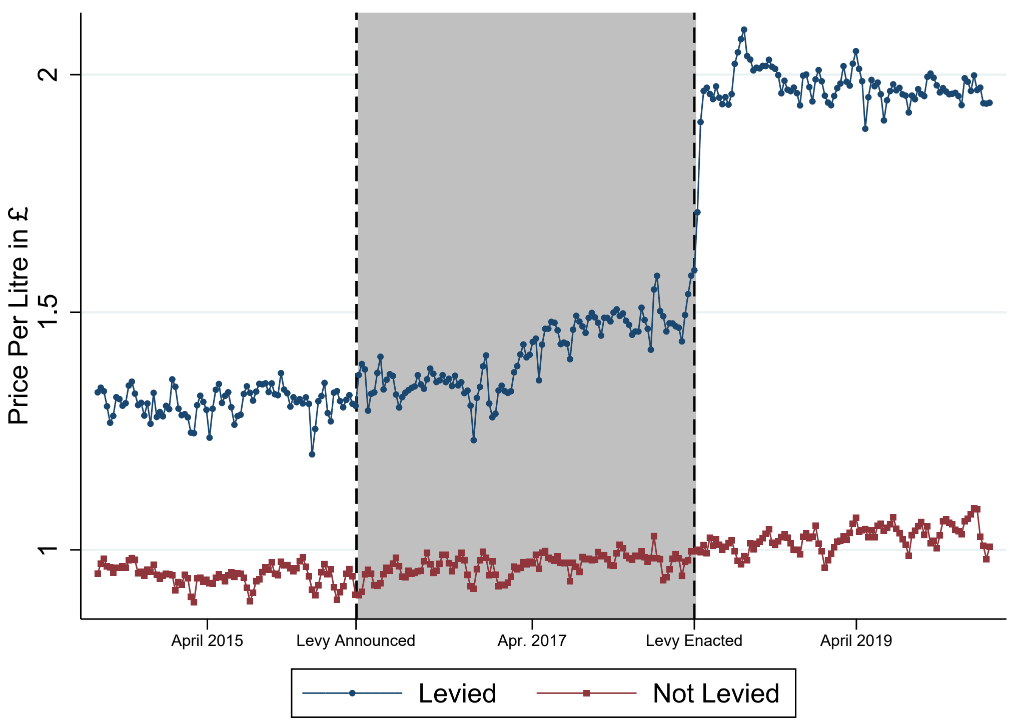
Mean gives the weekly average price and volume for March 2018, the month prior to the implementation of the levy. Price is in £, volume in million litres. Both measures are seasonally adjusted. For the regression analysis we use the natural logarithm of volume as the dependent variable.

Figure 1: Aggregate weekly consumption for main UK soft drinks brands by volume (in millions of litres) and calories (in billions).



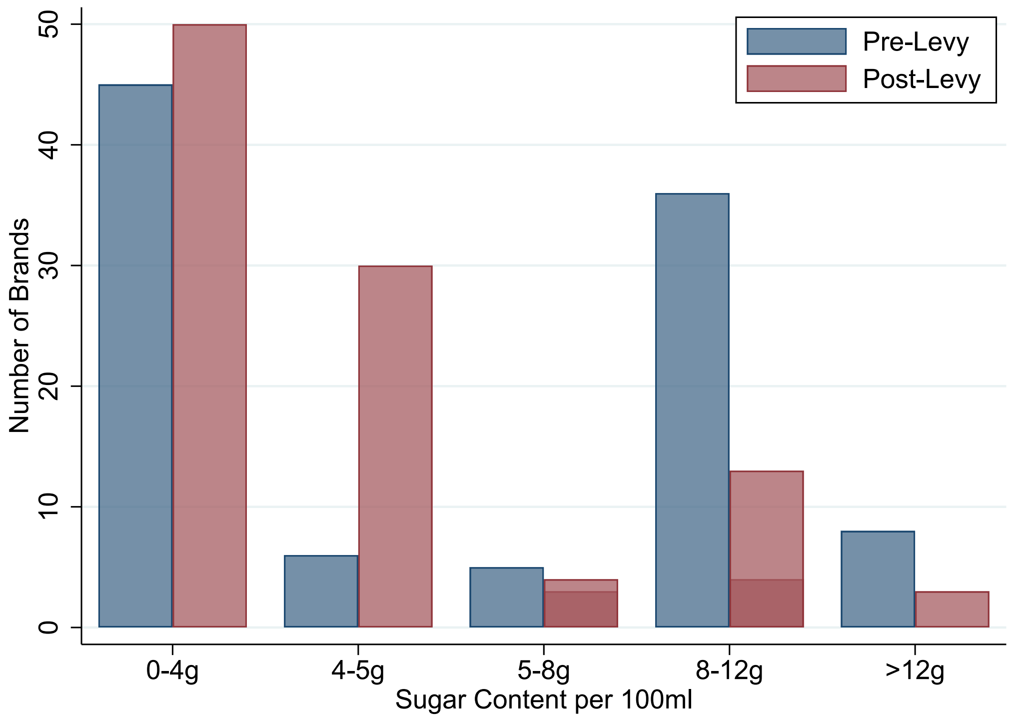
Notes: This figure shows weekly sales volume and calorie consumption for the top 100 brands in our data. All data are seasonally adjusted.

Figure 2: Pricing of levied and non-levied soft drinks.



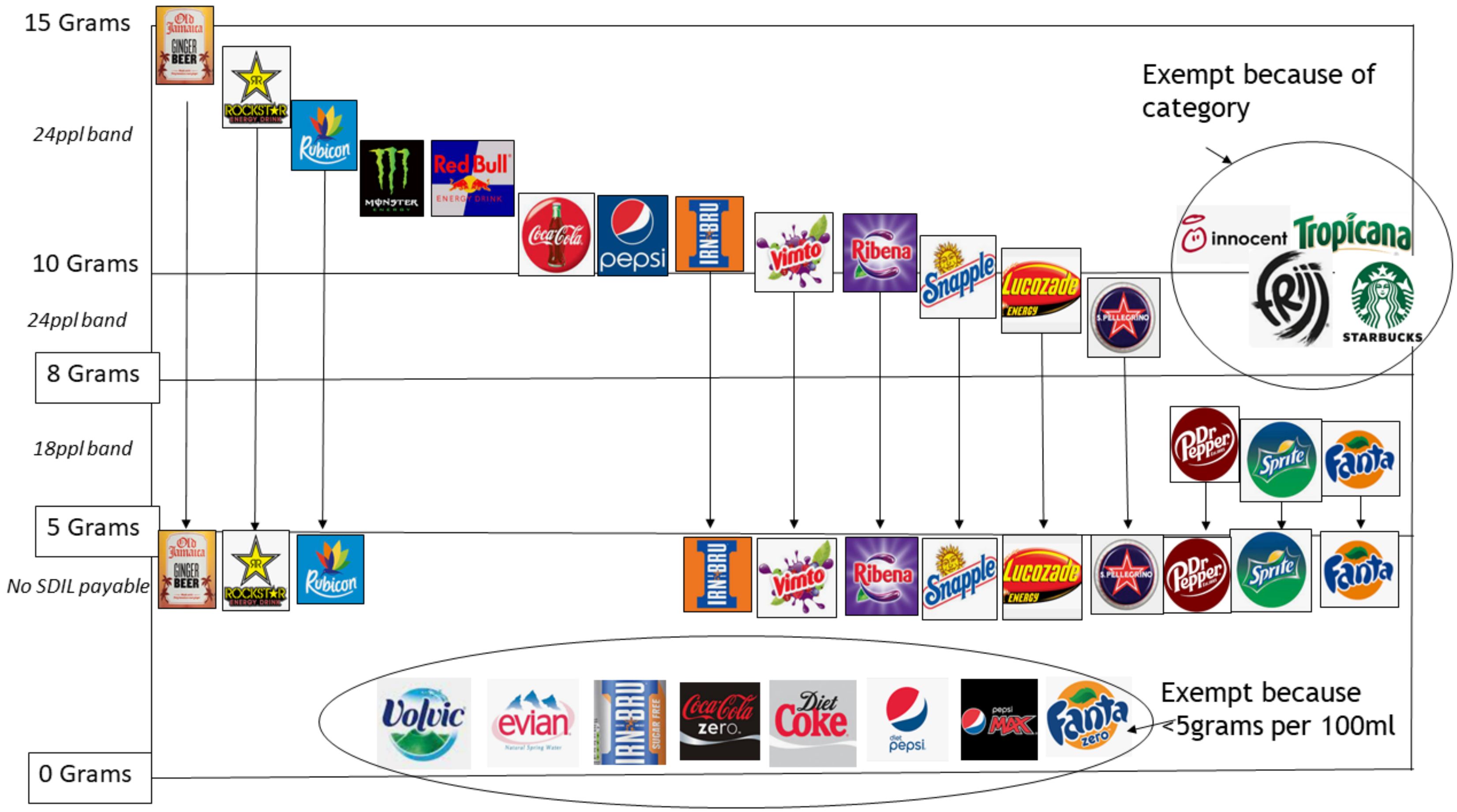
Notes: This figure shows the weekly average price per litre (in £) for the top 100 brands in our data.All data are seasonally adjusted.

Figure 3: Number of brands by sugar content pre- and post-levy implementation.



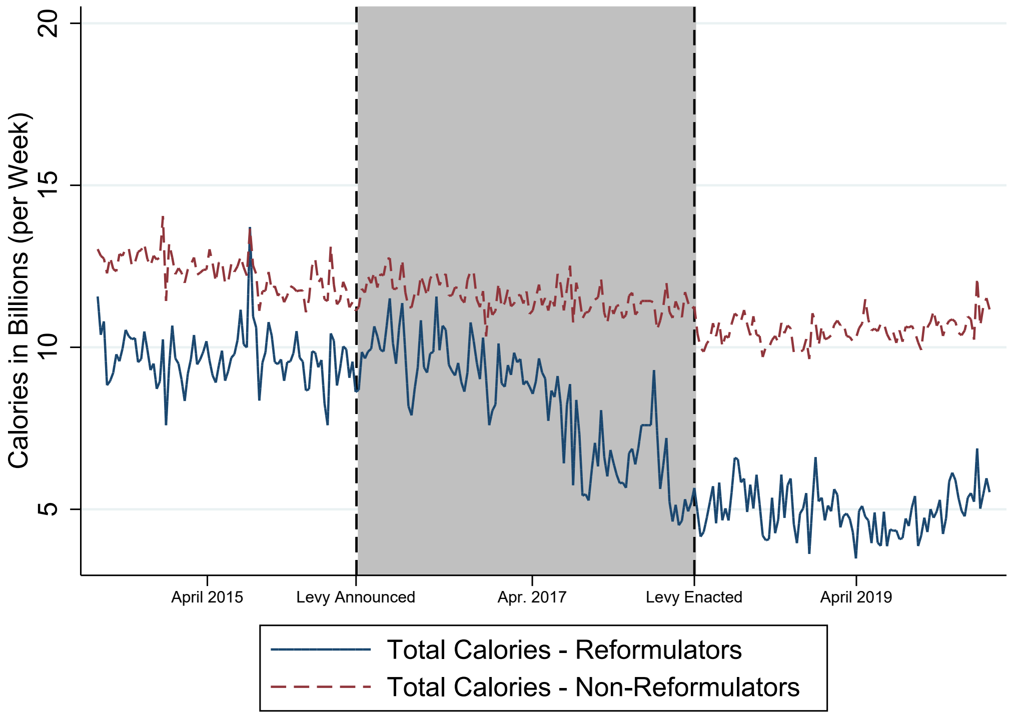
Notes: This figure shows the number of brands in our sample by sugar content. Blue bars show frequency just prior to the announcement of the levy. Red bars show frequencies after the implementation of the levy. Brands with sugar content below 5g per 100ml are levy-exempt. A levy of 18ppl is applied to brands with a sugar content between 5 and 8g per 100ml, while the levy for brands with more than 8g of sugar per 100ml is 24ppl. Note that dairy and fruit juices are exempt from the levy even if they exceed the sugar content thresholds; those brands that are actually subject to the levy are highlighted in opaque red.

Figure 4: Sugar Content of Selected Brands



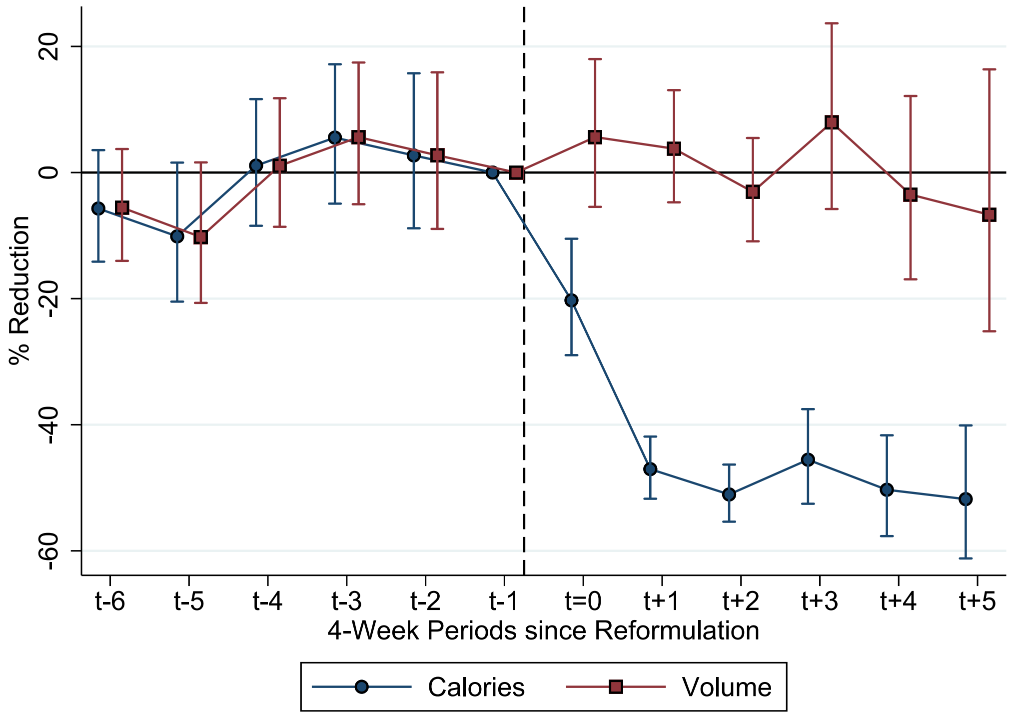
Notes: This figure illustrates sugar content and reformulation activities for a few selected brands. Brands that reformulated show up twice with arrows indicating the sugar reductions. Brands that chose to not reformulate or did not need to reformulate are only represented once. Brands logos are owned by AG Barr Plc, the Coca-Cola-Company, Desnoes and Geddes Ltd, Dr Pepper Snapple Group, Group Danone, Monster Beverage Corp, Mueller Milk & Ingredients, Nestle Waters, Nichols Plc, PepsiCo, Red Bull GmbH, Starbucks Corporation, and Suntory Holdings Ltd, respectively, and were reproduced under the S30 Copyright, Designs and Patents Act 1988 (CDPA).

Figure 5: Total calories consumed for reformulated and non-reformulated brands.



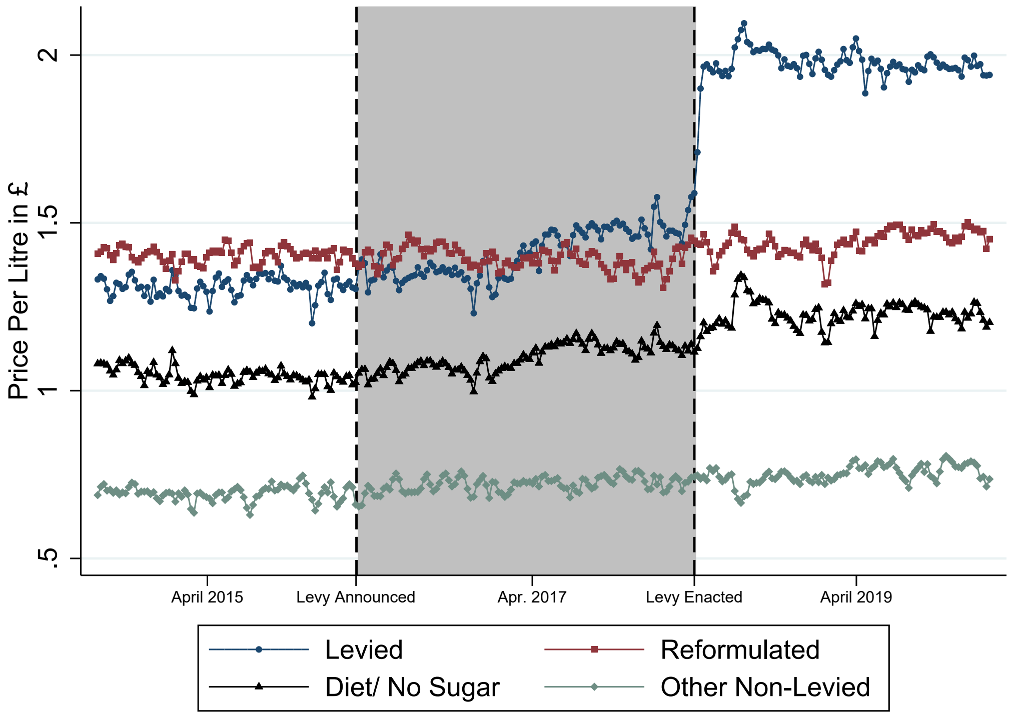
Notes: This figure shows weekly calorie consumption aggregates. The blue solid line shows calorie counts for brands that reformulated their beverages before the levy was implemented. The red dashed line shows aggregates for all other brands, i.e. levied, diet, and exempt brands. All data are seasonally adjusted.

Figure 6: Effect of reformulation on sales and calories consumed for reformulated brands.



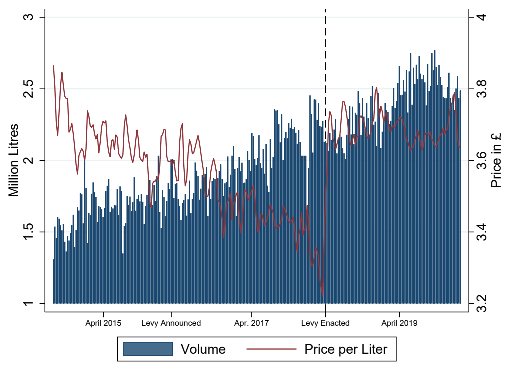
Notes: This figure shows two sets of results corresponding to an event-study estimated using Sun and Abraham's (2021) interacted weighted estimator. The last brand reformulated at the end of April 2018 and is used as main control group. Time periods after 29 April 2018 are excluded from the analysis. The dashed vertical line indicates the date at which a brand reformulated its product. The blue circles (offset to the left for clarity of presentation) show 4-week lead and lag coefficients along with 95% confidence intervals for (log) calories consumed. The red squares (offset to the right) show the corresponding parameters for (log) sales volumes. All estimates have been transformed into percentage changes.

Figure 7: Pricing trends.

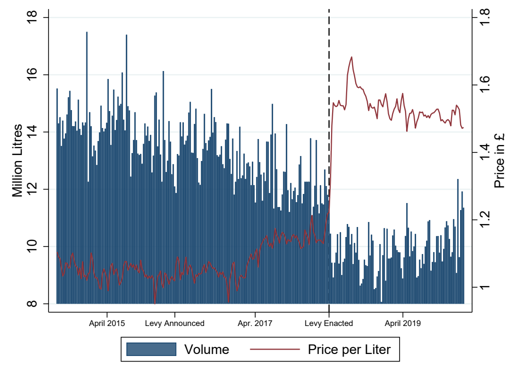


Notes: This figure shows the weekly average price per litre (in £) for four categories of beverages: levied soft drinks, brands which reformulated, diet and no sugar products which attract zero levy, and levy-exempt products (see pp. 14 for full definitions). Within each category, the average price per litre is volume-weighted.

Figure 8: Levied category by beverage type.



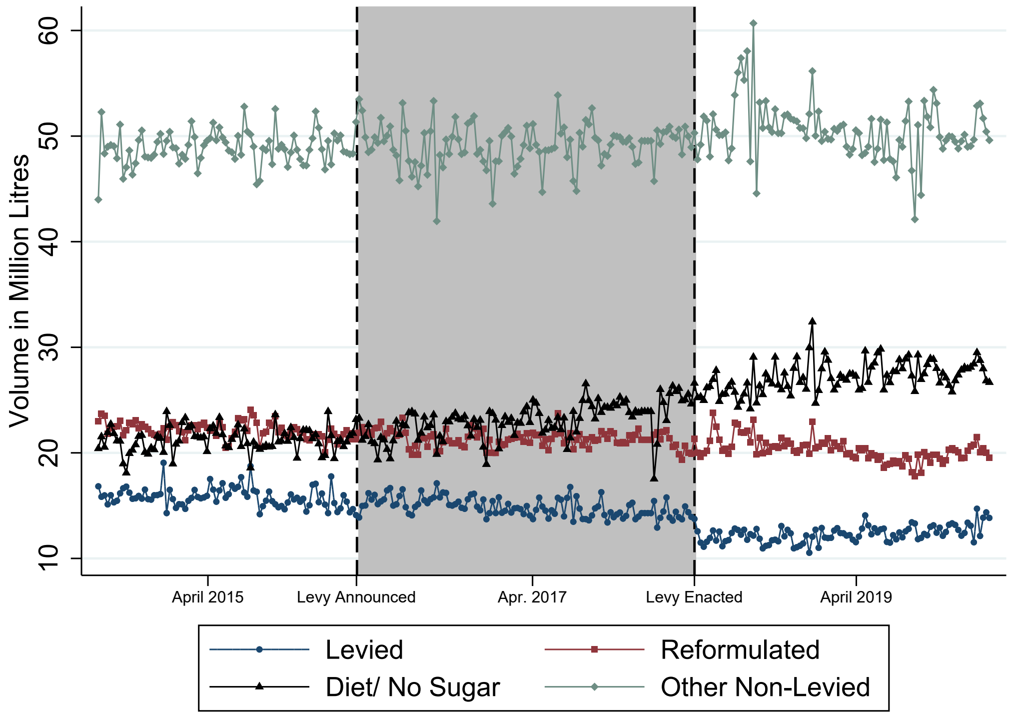
(a) Levied energy



(b) Levied cola

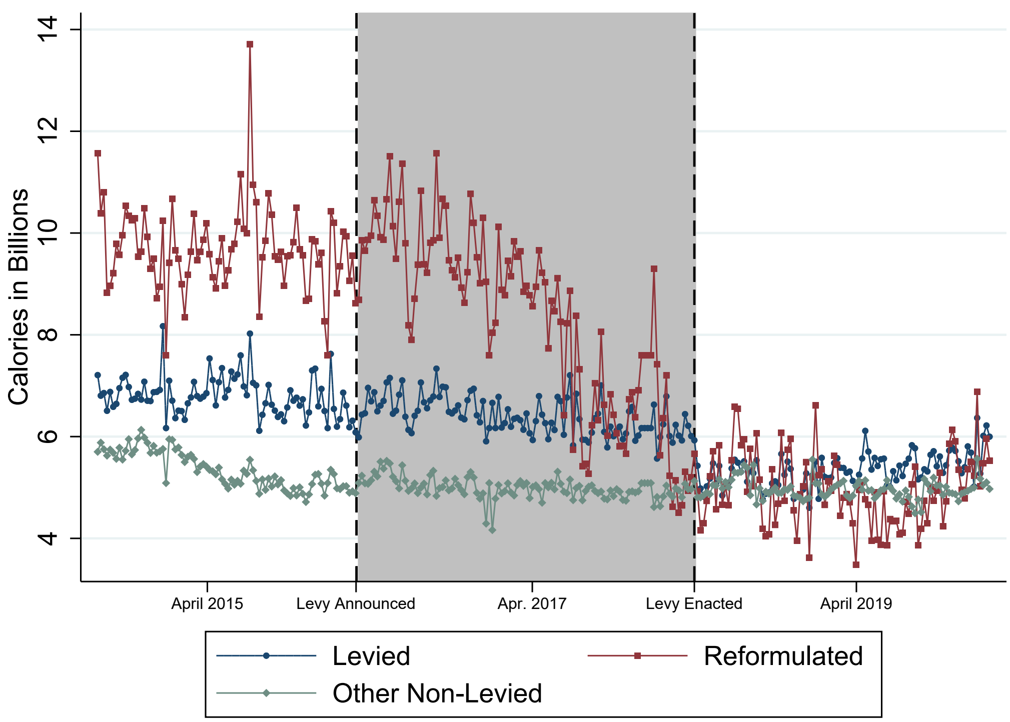
Notes: The red lines show the weekly average price per litre (in £) measured on the right y-axis, alongside weekly sales volumes (in million litres) shown by the blue bars and measured on the left y-axis. Panel (a) shows both measures for levied sports and energy drinks, whereas Panel (b) displays measures for levied colas. Price data are weighted by volume sales in both charts.

Figure 9: Volume trends in our four categories.



Notes: This figure shows the weekly sales volumes (in millions of litres) for four categories of beverages: levied soft drinks; brands which reformulated; diet and no sugar products which are not subject to the levy; and levy-exempt products (see pp. 14 for full definitions).

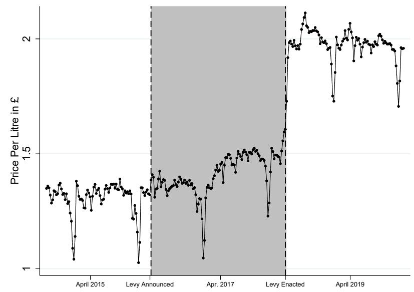
Figure 10: Calorie trends in calorie-containing categories.



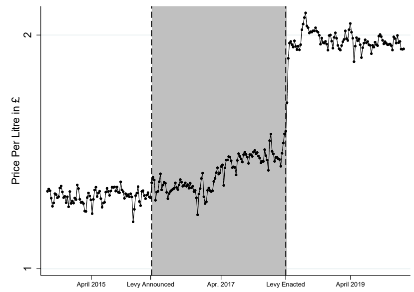
Notes: This figure shows the weekly calorie consumption from soft drinks (in billions) for three categories of beverages: levied soft drinks, brands which reformulated, and levy-exempt products. The time series for diet/zero-sugar beverages is not shown because by definition these drinks contain barely any calories (see pp. 14 for full definitions).

Appendix Tables and Figures

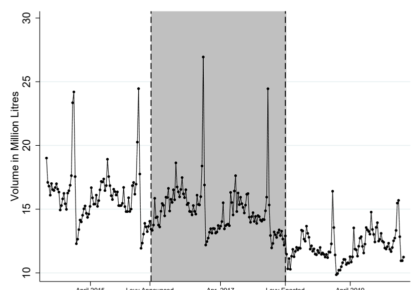
Figure A1: Seasonal adjustment—levied brand aggregates.



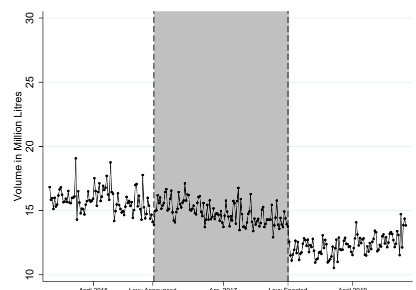
(a) Price per litre—raw data



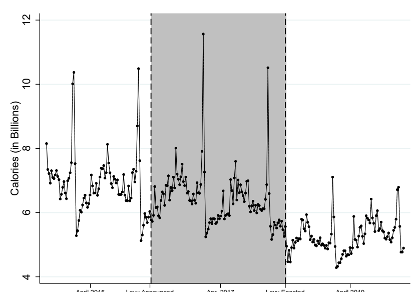
(b) Price per litre—seasonally adj. data



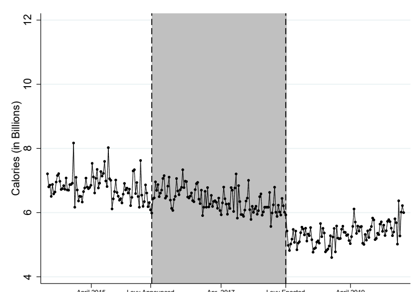
(c) Volume—raw data



(d) Volume—seasonally adj. data



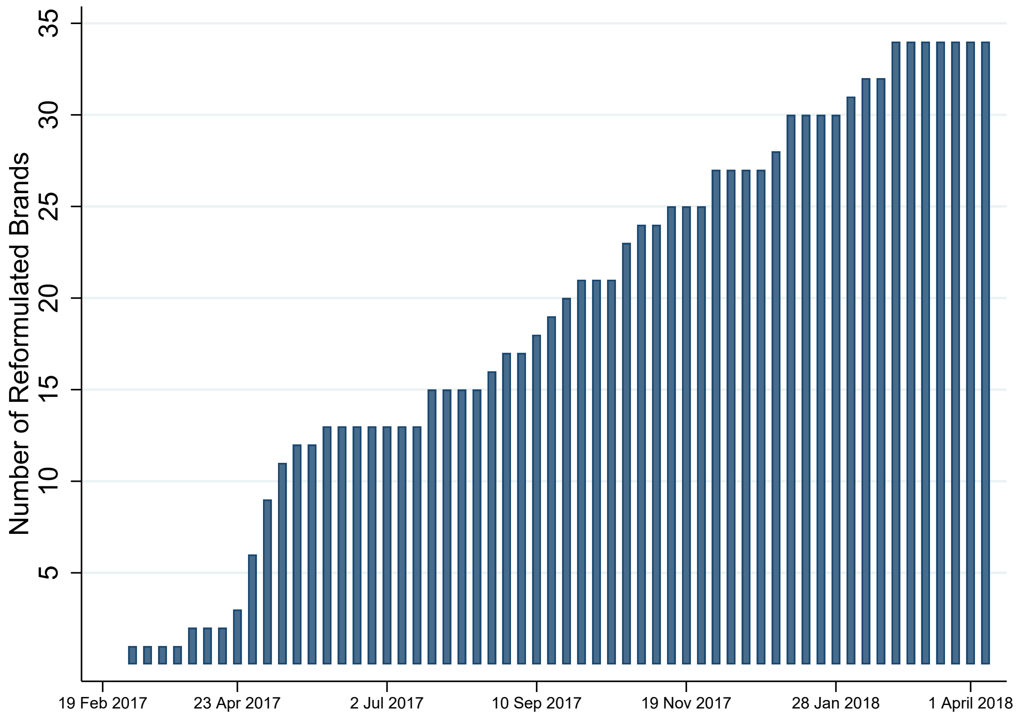
(e) Calories—raw data



(f) Calories—seasonally adj. data

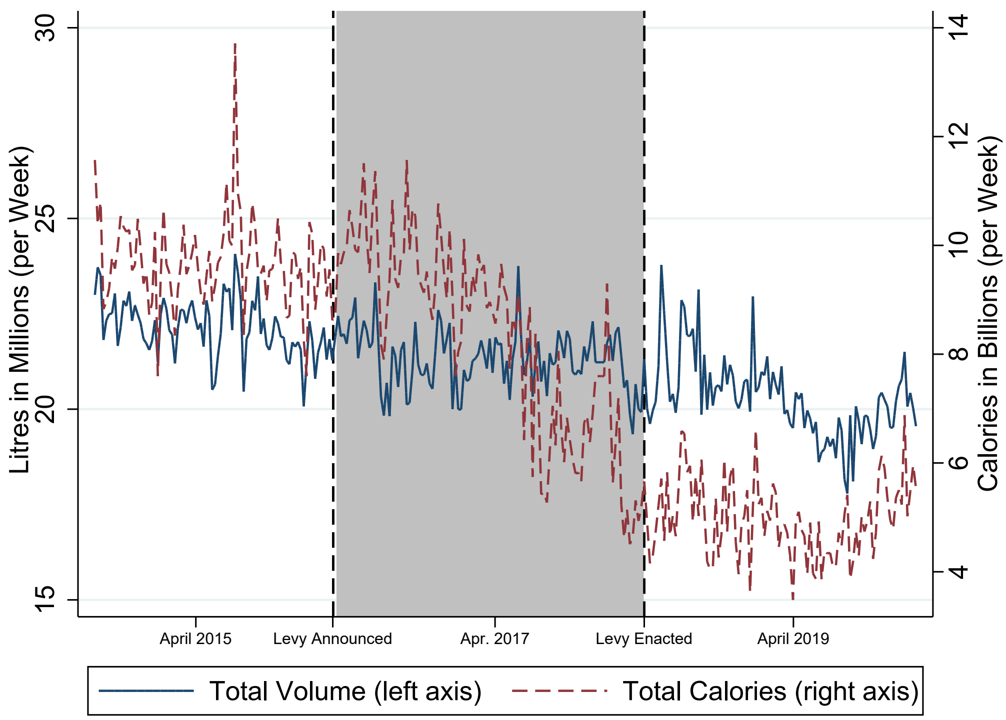
Notes: Figures on the left show the raw data for our three main outcomes, the corresponding figures on the right-hand side show the seasonally-adjusted data. We seasonally adjust by regressing the outcome of interest on an indicator for whether a week contains the Christmas holiday, as well as first and second-order leads and lags; year-specific Christmas dummies for 2014, 2015, and 2016; indicators for whether the weekly average temperature was between 5 and 10 degrees Celsius, 10-15 °C, 15-18 °C, and over 18 °C, respectively; indicators for weekly maximum temperature between 5 and 15 °C, 15-22 °C, and over 27 °C respectively; a continuous control for rainfall as well as a set of week-of-year fixed-effects. The residuals from this regression are shifted up by the mean of the raw variable.

Figure A2: Reformulation Timing



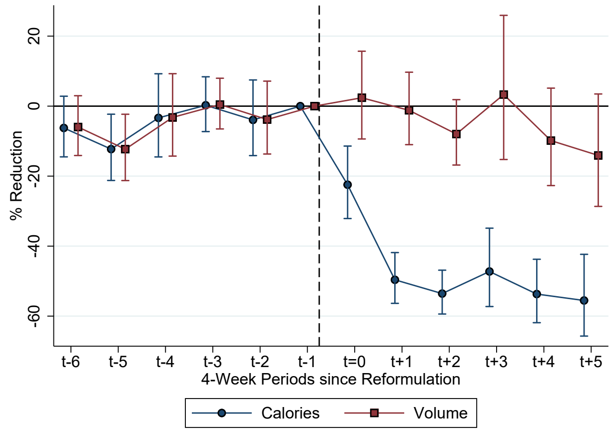
Notes: This figure shows the cumulative number of brands which have reformulated their products by way of reducing their sugar content. The sugar levy was announced in March 2016 and implemented in April 2018.

Figure A3: Volume and calories consumed for reformulated brands.



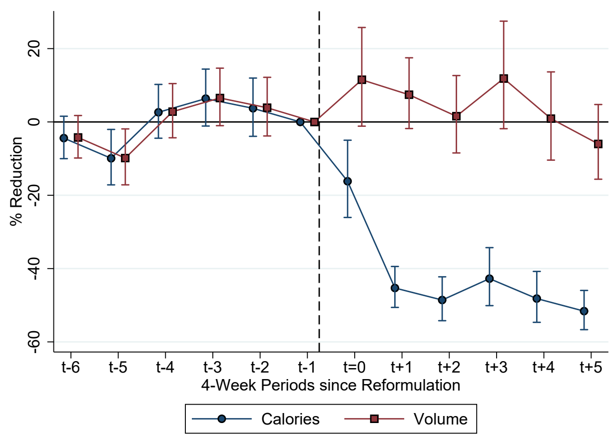
Notes: This figure shows weekly sales volume and calorie consumption aggregates across all brands that reformulated their beverages in advance of the implementation of the levy. All data are seasonally adjusted.

Figure A4: Classic Two-Way Fixed Effects Event-Study Estimation



Notes: This figure shows two sets of results corresponding to a traditional two-way fixed effects event-study as shown in equation (1). Periods after 1 April 2018 (when the levy went into effect) are excluded. The dashed vertical line indicates the date at which a brand reformulated its product. The blue circles (offset to the left for clarity of presentation) show 4-week lead and lag coefficients along with 95% confidence intervals for (log) calories consumed. The red squares (offset to the right) show the corresponding parameters for (log) sales volumes. The two dropped leads are $t = -1$ and $t < -6$. All estimates have been transformed into percentage changes.

Figure A5: Sun and Abraham (2020) Estimator



Notes: This figure shows two sets of results corresponding to an event-study estimated using Sun and Abraham's 2021 interacted weighted estimator. Levied, non-reformulating brands are used as main control group. Periods after 1 April 2018 (when the levy went into effect) are excluded. The dashed vertical line indicates the date at which a brand reformulated its product. The blue circles (offset to the left for clarity of presentation) show 4-week lead and lag coefficients along with 95% confidence intervals for (log) calories consumed. The red squares (offset to the right) show the corresponding parameters for (log) sales volumes. The two dropped leads are $t = -1$ and $t < -6$. All estimates have been transformed into percentage changes.

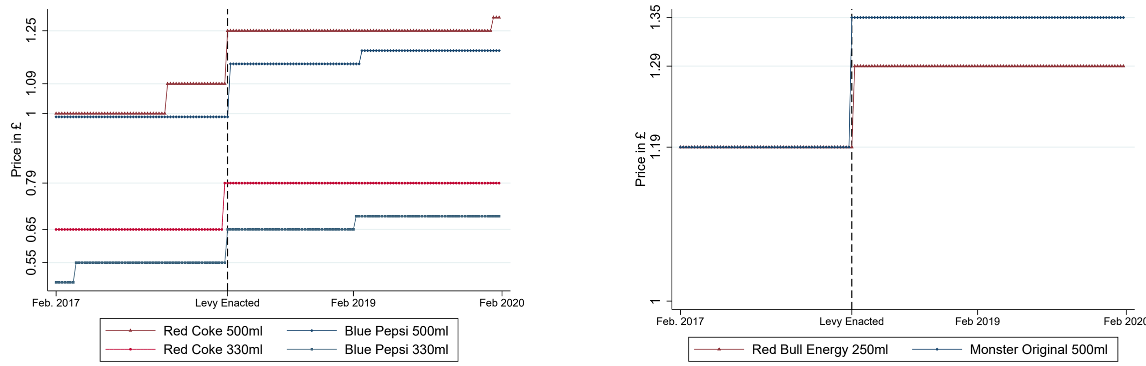
Table A1: Event-study estimates: effects of reformulation

	(1) (Log) Calories	(2) (Log) Volume	(3) Cal per 100m	(4) £-Price per Litre
$t-6$	-0.0588	-0.058	0.050	-0.004
	(0.046)	(0.046)	(0.068)	(0.013)
$t-5$	-0.107*	-0.108*	0.052	0.039**
	(0.060)	(0.061)	(0.117)	(0.014)
$t-4$	0.011	0.011	0.029	-0.021
	(0.049)	(0.050)	(0.090)	(0.016)
$t-3$	0.054	0.055	-0.018	-0.009
	(0.051)	(0.052)	(0.083)	(0.016)
$t-2$	0.027	0.027	-0.001	-0.004
	(0.059)	(0.059)	(0.079)	(0.014)
$t=0$	-0.227***	0.055	-11.157***	0.005
	(0.057)	(0.054)	(0.888)	(0.012)
$t+1$	-0.636***	0.037	-22.593***	-0.041***
	(0.046)	(0.042)	(1.489)	(0.011)
$t+2$	-0.714***	-0.031	-22.860***	-0.007
	(0.045)	(0.041)	(1.476)	(0.011)
$t+3$	-0.608***	-0.076	-22.736***	0.030
	(0.068)	(0.067)	(1.500)	(0.019)
$t+4$	-0.699***	-0.036	-22.785***	-0.002
	(0.079)	(0.074)	(1.949)	(0.015)
$\geq t+5$	-0.729***	-0.069	-23.483***	-0.009
	(0.107)	(0.109)	(.879)	(0.012)
R^2	0.98	0.97	0.99	0.97
N	6,684	6,684	6,684	6,684
Week Fixed-Effects	Yes	Yes	Yes	Yes
Brand Fixed-Effects	Yes	Yes	Yes	Yes

Notes: Standard errors in parentheses are adjusted for clustering at the brand level, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

This table shows regression results corresponding to an event-study specification estimated using the approach outlined in Sun and Abraham (2021). Only reformulating brands are part of the sample which is truncated at the date on which the last brand reformulates (29 April 2018). In all specification, we weight by litre sales. Only observations pertaining to brands that reformulated their beverages are part of the estimation sample. We regress our outcomes of interest, (log) calories consumed, (log) sales volume, calories per 100ml, and price (in £ per litre) on a set of 4-week leads and lags relative to each brands reformulation date. The two dropped leads are $t = -1$ and $t < -6$. Coefficients are transformed into percentage changes in Figure 6 according to % change $= e^{\delta} - 1$.

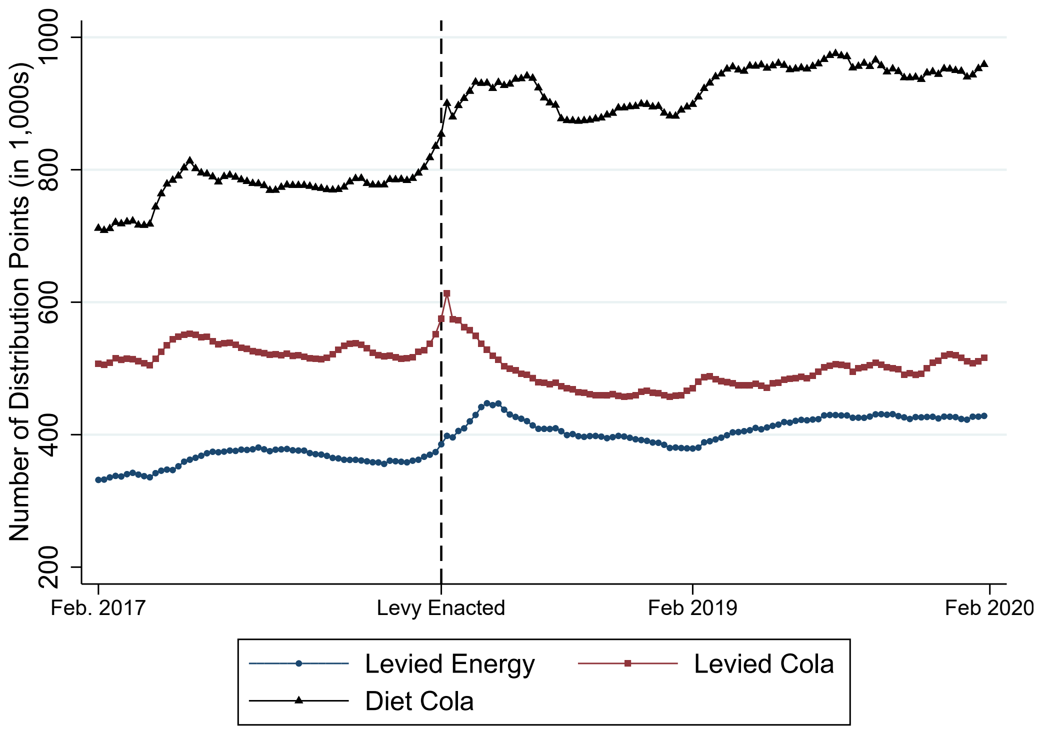
Figure A6: Pricing of price-marked packs.



(a) PMPs—colas (b) PMPs—energy drinks

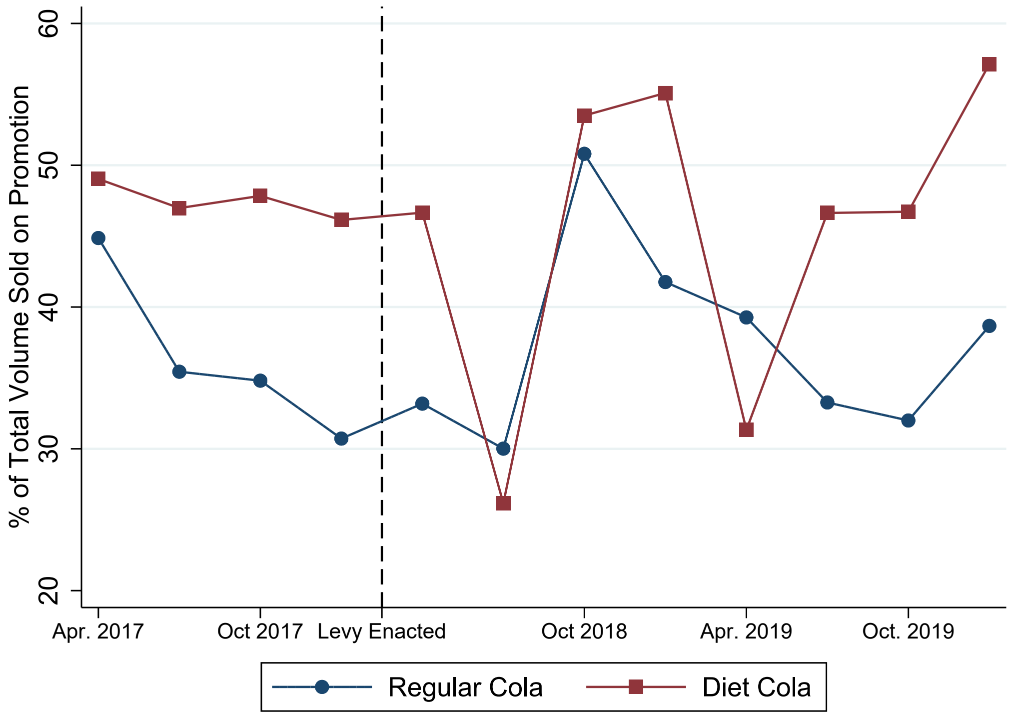
Notes: These charts show the pricing for select drink-now variants of price-marked-packs (PMPs). PMPs have a recommended retail price printed on the container itself by the brand owner. The y-axis documents these price while the x-axis shows when new PMPs with new price labels are released.

Figure A7: Number of scanning distribution points by beverage category.



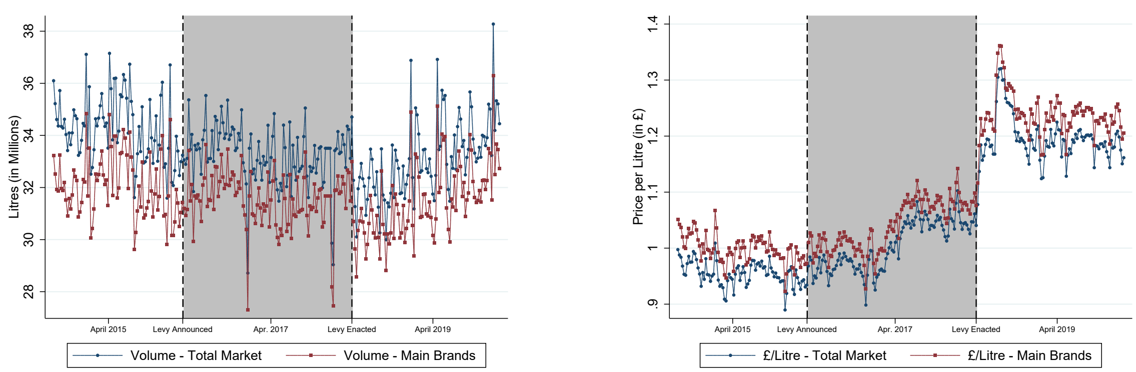
Notes: This figure shows the number of distribution points—a proxy for how widely products are available—at a weekly level from February 2017 until January 2020.

Figure A8: Promotion sales as percentage of total volume.



Notes: This figure shows the percentage of total sales volumes that was sold on promotion. Data on promotions are available at the fiscal quarterly level.

Figure A9: Comparison of total market and top brands—colas.

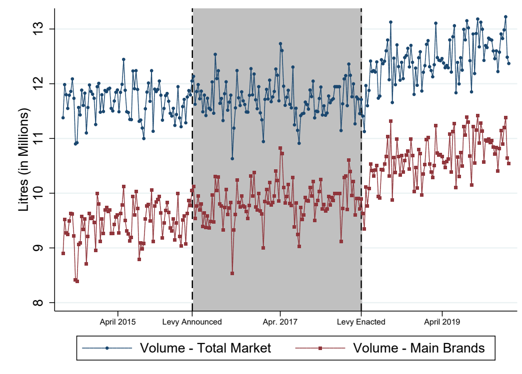


(a) Volume

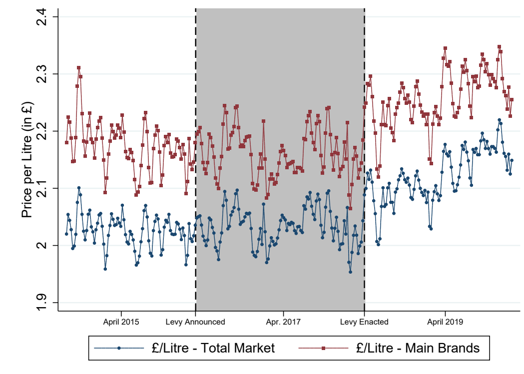
(b) Price

Notes: Figure (a) compares weekly sales volumes of cola brands within our sample of 100 leading brands (red squares) with the total market sales in this segment as per the full EPOS read (blue circles). The vast majority of the difference is accounted for by own-label brands. Figure (b) shows the same comparison but for price (in £/litre).

Figure A10: Comparison of total market and top brands—sports & energy.



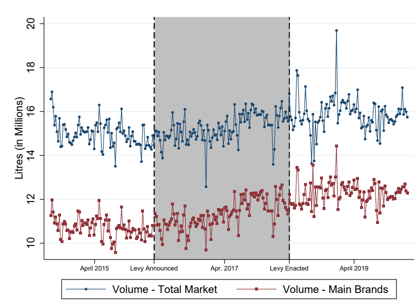
(a) Volume



(b) Price

Notes: Figure (a) compares weekly sales volume of sports and energy drinks brands within our sample of 100 leading brands (red squares) with the total market sales in this segment as per the full EPOS read (blue circles). The vast majority of the difference is accounted for by own-label brands. Figure (b) shows the same comparison but for price (in £/litre).

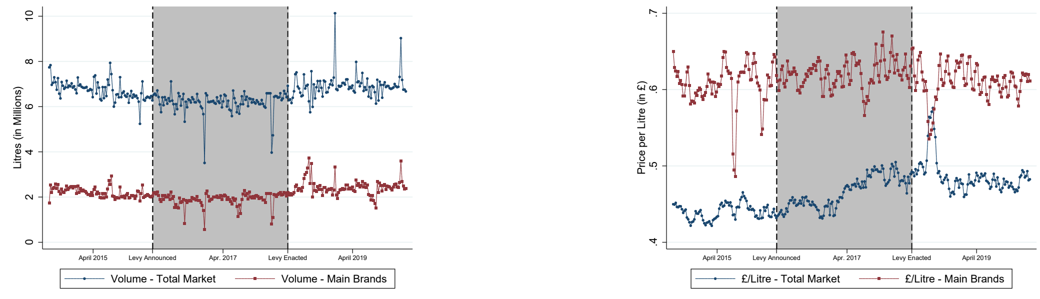
Figure A11: Top brands vs full-market comparison—OFC.



(a) Volume

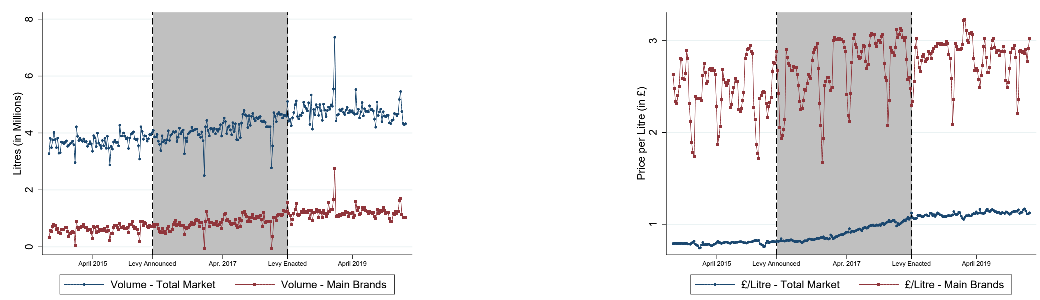
(b) Price

Figure A12: Top brands vs full-market comparison—lemonade.



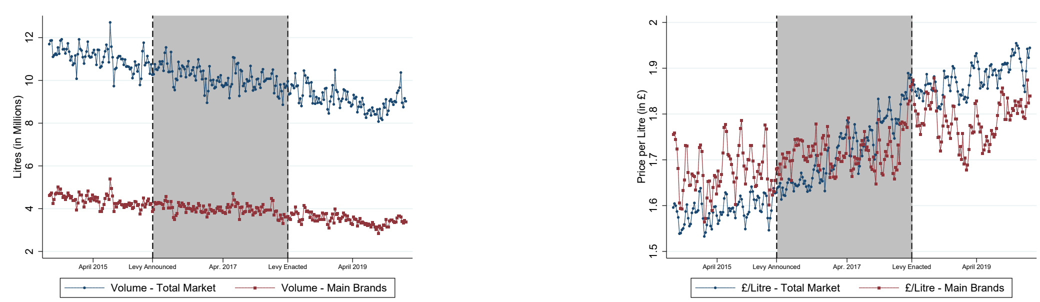
(a) Volume (b) Price

Figure A13: Top brands vs full-market comparison—mixers.



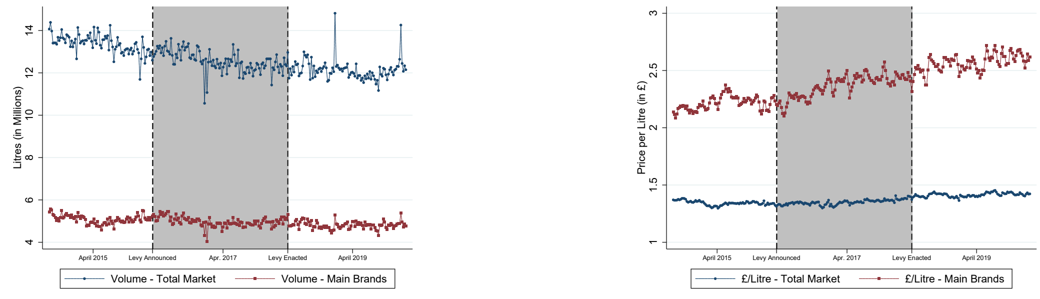
(a) Volume (b) Price

Figure A14: Top brands vs full-market comparison—fruit drinks.



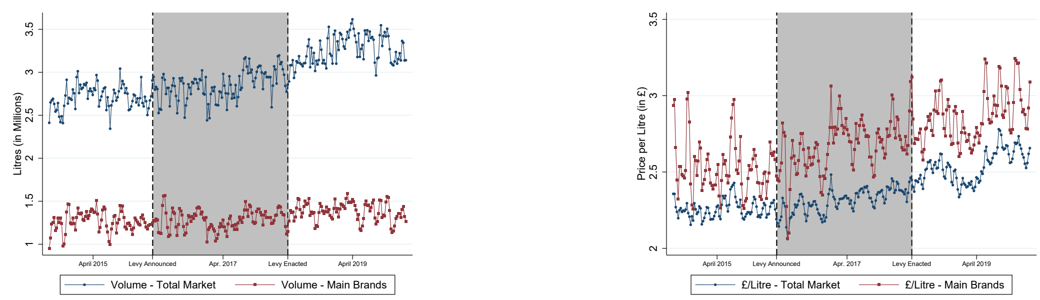
(a) Volume (b) Price

Figure A15: Top brands vs full-market comparison—fruit juice.



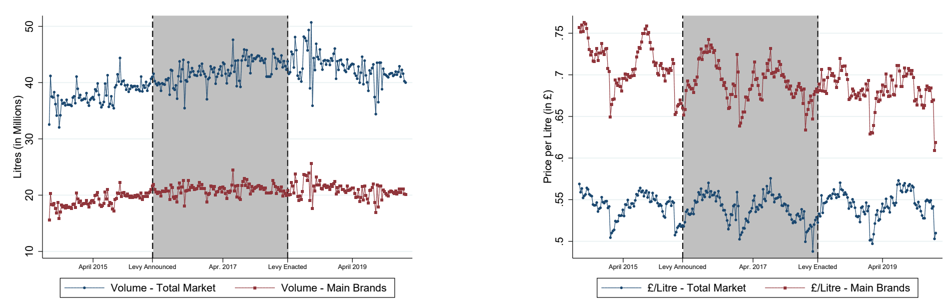
(a) Volume (b) Price

Figure A16: Top brands vs full-market comparison—dairy.



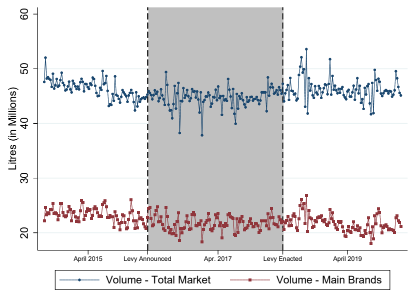
(a) Volume (b) Price

Figure A17: Top brands vs full-market comparison—water

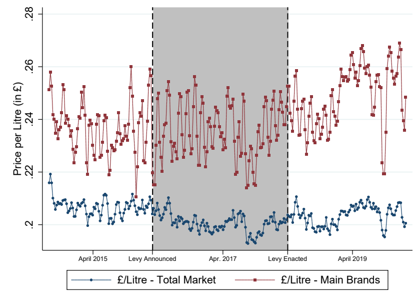


(a) Volume (b) Price

Figure A18: Top brands vs full-market comparison—squash.



(a) Volume



(b) Price

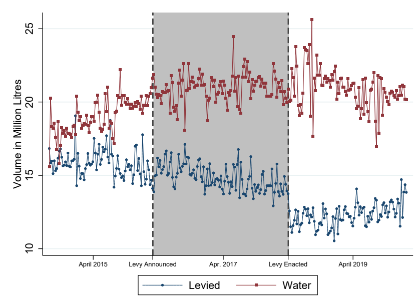
Table A2: Diff-in-diff analysis with water as control group.

	(1)	(2)	(3)	(4)
	Aggregate Level		Brand Level	
	Price	Volume	Price	Volume
Levied $\times$ *Post*	0.623***	-0.253***	0.325***	0.009
	(0.010)	(0.014)	(0.078)	(0.262)
R^2	0.994	0.924	0.991	0.910
N	576	576	4896	4691

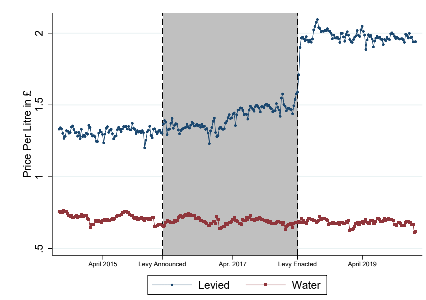
*Notes:*Heteroscedasticity-robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

This table shows the results of a differences-in-differences specification where levied brands are the treatment group and water brands serve as control group. Columns (1) and (2) conduct the analysis at the aggregate level, i.e. with a single treatment and a single control group. Column (3) and (4) show the results at the brand-level, i.e. the with the brand-week as the unit of observation. Both specifications contain week fixed-effects, the brand-level specification also contains brand fixed-effects. The main coefficient of interest is an interaction between a dummy which indicates whether a product is in the levied category and a post dummy that is equal to 1 for periods after the levy was enacted.

Figure A19: Water as a control group.



(a) Volume



(b) Price

Notes: This figure shows trends in volume sales as well as price per litre for levied brands (blue circles) and levy-exempt water (red squares).