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

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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 and consequent reductions in consumption, particularly for colas. In total, the levy is responsible for a reduction in intake of about 6,600 calories from soft drinks per annum per UK resident. We estimate that 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

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1 Introduction

Sugar-sweetened beverages (SSBs) are a main contributor to the global obesity epidemic and exhibit both negative externalities and internalities. Heeding World Health Organization (WHO) advice, governments across the world have introduced taxes on soft drinks (Griffith et al. (2019)). These include national (Aguilar et al., 2021; Colchero et al., 2015; Grogger, 2017; Gonçalves and Dos Santos, 2020; Etilé et al., 2021) as well as regional (Castelló and Casasnovas, 2020) and local levies (Cawley and Frisvold, 2017; Cawley et al., 2018, 2021). Their main goal has been to disincentivize SSB consumption; consequently, work evaluating the effects of these taxes has focused on estimating their pass-through and the demand response (Allcott et al., 2019b).

This paper delivers evidence that supply-side responses to sugar levies and the incentives for soft drink manufacturers, while understudied, are hugely important. We show that beverage reformulation is a crucial driver of calorie reductions when a levy with a tiered structure is introduced at the national level and imposes a substantial tax on high-sugar drinks, but allows for the levy to be completely avoided below a threshold amount of sugar. To study this supply-side channel, we turn to the United Kingdom (UK) and the introduction of the Soft Drinks Industry Levy (SDIL) where in 2018 SSBs were effectively levied at 29 ppl (pence per litre, 24p levy + 4.8p sales tax), a level close to what Allcott et al. (2019b) estimate is the optimum for a national soda tax. It is also among the largest sugar levies in a major developed country to ever be enacted. Crucially, the policy structure provided an incentive for product reformulation by allowing soft drink manufacturers to completely avoid the levy by cutting the sugar content of their drinks to about a teaspoon of sugar per 100ml during the two years between announcement and implementation of the SDIL.

We provide encouraging evidence that the policy led to large reductions in the sugar content of SSBs which in turn resulted in large reductions in calories consumed. To study the UK sugar levy and reformulation activities, we take advantage of electronic point of sale (EPOS) data. These data give us a weekly read on the near-universe of soft drink transactions in the vast majority of supermarket chains across the UK, as well as thousands of convenience stores. They cover purchases for both "at-home" and "on-the-go" consumption. Our data allow us to understand brands' sugar and calorie content over time and to pinpoint the timing of reformulation. Product reformulations occurred after the announcement of the levy in a staggered fashion where a brand's timing of sugar reductions is arguably determined by idiosyncratic factors. This allows us to isolate the effects of reformulation activities on sales, prices and calorific intake by way of an event-study design (Sun and Abraham, 2021). We also document large and obvious structural breaks in prices and sales volumes that align with the date of the implementation of the levy. An interrupted time-series approach allows us to credibly estimate the effect of the levy on both levied and unlevied brands.

We estimate that the levy is directly responsible for a reduction of about 6,600 calories per year per head of current UK population. Most of these calorie reductions happened in fact before the implementation of the levy 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 accounts for more than 80% of the levy-induced calorie reductions from SSB consumption. The demand-side response to higher prices for levied products following the introduction of the levy—the mechanism through which a sugar tax is typically assumed to mainly work—accounts for the much smaller remainder.

We are among the first to credibly document the importance of supply-side responses and to comprehensively unpack pricing and sales reactions in the context of a tiered SSB tax. A small medical literature (Bandy et al. (2020), Scarborough et al. (2020), Pell et al. (2021)) had noted that reformulation was a consequence of the SDIL but due to data limitations has been unable to quantify the importance of manufacturer responses. We show that these are hugely important. We add to recent influential work by Allcott et al. (2019a) and Dubois et al. (2020) which has been concerned with distributional aspects of sugar taxes and the optimal tax level: widespread product reformulation substantially reduces the degree to which a tax is regressive but also limits the potential for revenue recycling. Our work demonstrates that supply-side responses deserve more attention in the study of 'sin taxes' in general. Our findings add to Allcott et al's (2019b) prescription of guiding principles for the design of sugar taxes. They also carry important lessons for other countries that may consider introducing a similar policy: a tiered and substantial tax that can be fully avoided by manufacturers reformulating their products can act as a powerful catalyst for reducing sugar intake.

2 Background: Reformulation and the UK Soft Drinks Industry Levy

In an effort to curtail growing obesity rates, in March 2016 the UK Government announced the SDIL to be implemented in April 2018. The levy applies to soft drinks that contain sugar or have had sugar added during the production process, unless they are in an exempt category such as fruit and vegetable juices without 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/100ml or more but less than 8g/100ml the levy is 18ppl and if it is 8g/100ml or more it is 24ppl. Soft drinks with less than 5g/100ml of sugar attract a zero rate levy.

Several SDIL features incentivise reformulation. First, the levy constitutes a substantial increase in the cost of goods for the manufacturer, effectively leading to an increase in the cost of sugar. Taking into account that the levy is subject to value-added tax at 20% and assuming a 100% pass through from manufacturer to retailer to consumer, the price of a 2l bottle increases by 57.6 pence at the higher rate. By way of comparison, in 2015 such bottles often sold for £1. Second, brand owners could avoid the levy by reducing the sugar content of their SSBs to a technically feasible level (typically about half of original sugar content) within a reasonable time frame in the two year gap between announcement and implementation.

Third, the structure of the levy acted as a coordination catalyst for reformulation decisions. A brand's optimal reformulation in the face of a levy will depend on the decisions of its competitors. With a continuous levy, there would be considerable uncertainty around how much sugar competing brands would take out, if any at all. That the levy can be completely avoided by reformulating to below 5g/100ml provides a focal point for reformulation, resolving some of the uncertainty around where competitors would reformulate to, if they choose to reformulate. The sheer magnitude of the levy gives confidence that competing brands will indeed reformulate. As such, the threshold nature and magnitude of the levy make competitors' actions more predictable than would be the case with, for example, a linear structure with no discrete cutoff.

Ultimately, most brands that would have been subject to the levy reformulated. Figure 1 illustrates this process for some of the largest individual brands. Consistent with the idea that the levy acted as a coordination mechanism, all major reformulating brands moved to a sugar level just below the 5g/100ml levy threshold and hence avoided the levy when it was implemented. Brands that did not reformulate were typically either sugar free to begin with, such as the diet brands at the bottom of the figure; or were exempt, such as the fruit juice and dairy 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.[1]

Figure 2 shows the same phenomenon for a wider set of brands—the 100 leading brands (by 2019 consumer spend)—which are split 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. The red bars (offset to the right) show the distribution of brands by sugar content 2 years later when the levy was implemented. Prior to the levy announcement, dozens of brands had a sugar content in excess of 8g/100ml and very few sat in the narrow 4-5g band. At the time of the levy implementation, the pattern had flipped.

3 Data and Methods

The main data source for this study is Electronic Point of Sale (EPOS) data, which for each European Article Number 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 across retailers. These data provide coverage of around 45,000 supermarkets, convenience stores, high street stores, petrol forecourts and travel outlets across the UK. We also cover the vast majority of online sales (>95%).

However our data have two shortcomings. First, they are market-level data and thus do not allow us to directly study different groups of consumers. Second, they do not include information on continental discount supermarkets, most notably Aldi and Lidl. While continental discounters have grown their market share over time (Kantar Group, 2023), estimates from the Kantar Homescan database suggest that they account for less than 9.4% of consumer spend on soft drinks. We will adjust our estimates of the total levy-induced calorie reductions in light of this limitation in Section 4.3.

[1] These were Monster Energy and Red Bull; and the full sugar versions of Coca Cola and Pepsi.

With this caveat in mind, our data covers the vast majority of retail soft drinks transactions in the UK. In particular, they have two crucial advantages over 'household 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 on-the-go 'drink-now' consumption which is a substantial segment of the soft drink market: in 2019 drink-now consumption accounted for 41% of consumer spending on soft drinks, illustrating that this market segment 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 data source was that any analysis 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. 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, e.g., from single supermarket chains; and household panel data[2]); desirability bias and misreporting (with survey and household 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. 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) as weather is an important driver of soft drink sales. For our main analysis, we de-seasonalise

[2]A comparison of our EPOS data to the Kantar household panel for 2019, suggests that the household panel captures some 90% of consumer spending on take-home packs, but just under 30% on drink-now packs.

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 bottles and multi-packs, tend to spike, and a set of week of the year fixed-effects.

Our main analysis takes place at the brand-level. 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.[3] These account for about 73% of total consumer spend in our data and 59.2% of 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).

We collected the sugar and calorie content for each of these brands from regulatory nutritional declarations on in-store packing using a combination of brand announcements and weekly store checks throughout the sample period, that were 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.

While we run several brand-level regression analyses, as noted we are not permitted to show time series for individual brands for reasons pertaining to data sensitivity. In order to plot our data and visualise key patterns in Figure 3, we group brands into the following four categories:

1. Levied brands, which remained high sugar and thus subject to the 24ppl levy. The only brands within this category are either colas or energy drinks.

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.

3. Diet/no added sugar/sugar free brands which are artificially sweetened so contain no sugar and virtually no calories.

4. Non-levied brands. This category contains everything else that is not subject to the levy, either because it is in an exempt category or because it contains less than 5g of sugar before the announcement of the levy (but is not classed as a diet drink) such as bottled water and some lemonades.

[3]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.

Figure 3 uses our raw data to show key trends in our main outcomes of interest and provides a comprehensive overview of the state and trends in the UK soft-drinks market. Volumes in the soft-drinks market have been growing (see Panel (a)) while at the same time the number of calories from soft drinks have been declining (see Panel (c)). Both trends are driven by the increasing popularity of diet drinks whose sales volumes increased by almost 50 percent between 2015 and 2020 (black triangles in Figure 3a).

Two important levy-related developments are apparent. First, the blue circles of Figure 3b indicate that the price of levied products increased substantially at the point the levy was implemented with consumers paying on average 56ppl more for levied drinks than before the levy was enacted. The levy-induced price increase was accompanied by a discrete 20% drop in volume and a similarly sized drop in calories around the implementation date. At the same time, both prices and volumes of diet products increase from their pre-existing upward trajectory. We will further unpack these developments in more detail in Section 4.2.

Second and more importantly, the red squares of Figure 3c indicate that calories from reformulated drinks dropped by more than 50% over time, even though sales volumes (see Figure 3a) in the category were flat. These calorie intake reductions occurred after the announcement and prior to the implementation of the levy. 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.

4 Results

4.1 Effects of Levy-Induced Reformulation on Calorie Intake

Figure 4a provides descriptive evidence for the effect of reformulation on total weekly calorie intake. Prior to the announcement of the levy, calories consumed from beverages that reformulated (blue solid line) followed similar trends as those that did not (red dashed line). This changes between the announcement and implementation of the levy when calories from reformulated products halved. We explicitly model the impact of reformulation activities using a difference-in-differences event study specification at the brand level, exploiting that some brands happened to reformulate their products earlier than others.

Our 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 substituted artificial sweetener for part of the sugar in their UK products in 2013 and 2014, respectively. Following 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. [4] It is also 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.

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, traditional two-way fixed effects event-studies 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. In order to consistently estimate the effects of reformulation on calorie intake and sales volume, we therefore use Sun and Abraham's (2021) 'interacted weighted' (IW) estimator which is specifically designed for event-study specifications such as ours.

The IW estimator obtains an estimate of each cohort-specific average treatment effect $CATT_{e,\ell}$ on sales volumes and total calories consumed, represented by y_{bt}. e denotes a group ('cohort') of brands, b, which were treated at the same time, t, and ℓ indicates relative time until/after the reformulation date for each brand. Formally, these lead and lag estimates are obtained by running the following specification where τ_t and γ_b are week and brand fixed-effects respectively:

$$y_{bt} = \tau_t + \gamma_b + \sum_{e \notin C} \sum_{\ell \neq -1} \delta_{e,\ell}(1\{E_b = e\} \times Reform^{\ell}_{b,t}) + \epsilon_{bt} \tag{1}$$

That is, relative period indicators are interacted with group indicators, but groups from set C are excluded. Hence, we have two specification options. Levied brands which do not reformulate ('never-treated') could be included and serve as a control group. However, there is a risk that

[4] Appendix Figure A1 shows that reformulation activities indeed happened gradually.

these brands follow distinctly different sales or pricing trends which may be why they did not reformulate. Alternatively, our preferred approach follows Sun and Abraham's (2021) suggestion of estimating equation (1) using all the 34 reformulating brands except the latest to do so. In practice both approaches yield similar results.

In a second step, the IW estimator obtains weights, which are commensurate to the sample share of each group in a given period. IW estimates are constructed as a weighted average of the $\hat{\delta}_{e,\ell}$ from equation (1). Sun and Abraham (2021) show that these estimates avoid the contamination of lead and lag coefficients in traditional two-way fixed effects models. Figure 4b summarises the main result from this analysis. It plots 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).[5]

Three features in Figure 4b stand out. First, all leads are hovering around zero suggesting that there is little in the way of pre-existing 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 two months after a brand reformulates, calorie intake from this brand is just over 50% lower than 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. Put differently, reformulation reduced calories because each litre contained fewer calories, and not because substantially fewer litres were sold.[6] The absence of either a pre- or post-treatment sales response also mitigates concerns about the Stable Unit Treatment Value Assumption (SUTVA) underpinning our approach. The SUTVA would be violated if consumers of early-reformulating products switched to late-reformulating (or non-reformulated) drinks. More likely, consumers did not even notice product reformulation

[5] Appendix Figure A2 shows the results for a setup using never-treated brands.

[6] The raw coefficients are displayed in Appendix Table A1 which also shows that reformulation activities were not accompanied by changes in prices. That is, sales were not stabilised by making a low sugar reformulation more palatable to consumers by way of a lower price.

as brands did not draw attention to them through on-pack communication or advertising. This is aided by the way the UK nutritional traffic light labeling works: sugar reductions to around 5g/100ml on a 330ml can did not lead to a change in the red color of the sugar element of the traffic light labelling on the pack.[7]

4.2 Effects of Levy Implementation on Prices and Volumes

We next highlight the effects of the SDIL implementation on pricing and sales volumes of levied brands. We take a descriptive approach because the implementation affected both levied brands and their substitutes, so it is hard to identify an unaffected comparison group. In order to account for category and container mix effects, we distinguish between levied cola (Coca Cola and Pepsi) and energy (Monster and Red Bull), and their respective diet versions (Coke Zero, Diet Coke, Pepsi Max, Diet Pepsi, Monster Ultra, Red Bull Sugarfree), and split our analysis by drink-now (containers <750ml) and take-home (≥750ml) purchases. Figures 5a and 5b focus on colas as these dwarf energy drinks in terms of volume and are thus the primary driver of any change.[8]

Figure 5a indicates that the levy was over-shifted to consumers. For drink-now colas, the per litre price was around £2.28 in the weeks leading up to levy implementation and around £2.65 after implementation. This suggests the £0.29 levy may have been over-shifted.[9] A similar pattern is apparent for take-home colas. Note that price per litre is weighted by pre-implementation volumes. That is, for each of the 10 categories listed in Figure 5b, price is computed as a weighted average of the price per litre of the brands in a given category where the weights are commensurate with a brand's pre-implementation volume share. Brand-mix effects (e.g. consumers switching from Coke to Pepsi) therefore do not explain this price increase, although within-brand switching (across bar-codes or retailers) may contribute.

Figure 5b provides compelling descriptive evidence that higher prices resulted in both a reduction in the consumption of levied colas and a substitution towards un-taxed diet-versions. The Figure shows that diet-versions had surpassed their full-sugar equivalents in popularity even before the SDIL. For take-home colas, the dominant category, the implementation of the levy then

[7] Alé-Chilet and Moshary (2022) show that salient nutritional warning labels for cereal can trigger both supply and demand responses.

[8] Corresponding figures for energy drinks are reported in Appendix Figure A3.

[9] Note that tax over-shifting is consistent with theoretical predictions in a market with imperfect competition. Our overshifting-result is also consistent with O'Connell and Smith (2021).

led to a drop in weekly full-sugar sales of around 2.5 million litres (20%) with a similarly-sized increase in sales of diet versions. Put differently, our descriptive analysis suggests that the SDIL implementation prompted a substantial number of consumers to switch from full-sugar to diet colas. A similar pattern, albeit at a smaller scale, is apparent for drink-now colas.

We obtain explicit point estimates and confidence intervals for these pricing and volume effects using an interrputed time-series approach that allows for both level and slope shifts:

$$y_{ct}^{res} = \alpha + \beta Post_t + f(Time_t) + \gamma Post_t \times f(Time_t) + \epsilon_{ct} \quad (2)$$

The dependent variable y_{ct}^{res} is the seasonally-adjusted average price and volume for a subcategory c (e.g. take-home full-sugar colas). $Post_t$ is a dummy variable taking on a value of 1 for weeks after April 1st 2018. $Time_t$ is a continuous variable, centered around this week.[10] Our coefficient of interest is β which measures the average price increase once the levy was implemented. We run this model for twelve subcategories listed in Figure 5c.

This Figure confirms the result of tax overshifting. Our point estimates for the price per litre increase are £0.36 and £0.41 for full-sugar take-home and drink-now colas respectively, compared with a £0.29 levy. Most of this increase is generated by upward movement in the shelf price of existing packs but some comes through downsizing of packages to maintain existing or lower price points. For example, Coke replaced their 1.75l bottle with a 1.5l version in some retail outlets. Our estimates also suggest slight overshifting for drink-now energy and we cannot reject a mere full pass-through for large container/pack sizes. An interesting, and arguably unintended, consequence is that diet-variants of levied goods also experienced price increases of typically 6-8ppl. It should be noted that these estimates are obtained using a descriptive approach. That is, we cannot rule out that the documented price increase may reflect general inflationary pressure or an unobservable event that happened to occur at the same time as the levy change. These are, therefore, estimates for the levy pass-through and do not necessarily have a causal interpretation. Nevertheless, the timing and symmetry are striking and suggest that the SDIL is the main driver.

This is even more plausible for the drop in full-sugar cola sales and simultaneous increase

[10] In Appendix Table A2 we conducted a test that indeed detected structural breaks in April 2018, the month of the SDIL implementation.

in diet-version sales, documented in Figure 5b. Our interrupted time series estimates in Figure 5d suggest that the levy reduced take-home cola sales by about 2.5 million litres per week while simultaneously inducing an increase of diet-version consumption of 2.1 million litres. Once other diet-drinks are taken into account, the drop in levied cola consumption is more than offset (see fourth point estimate from bottom in Figure 5d). Many consumers appear to have switched from full-sugar colas to diet versions (e.g., Coca Cola to Diet Coke), although some switched to other diet brands or levy-exempt categories. A similar pattern is apparent for the smaller drink-now segment where increased consumption of diet colas alone offsets the drop in levied cola consumption.

Interestingly, we find that drink-now energy sales continued to grow (a pattern shown visually in Appendix Figure A3). This likely reflects the strength of this fast-growing category which is popular among arguably less price sensitive consumers who consider sugar a functional ingredient.

4.3 Aggregate Levy Effect on Calories

We next quantify the overall effect of the levy on total calorie consumption. The importance of reformulation activity is hard to overstate. Assessed against a mean weekly calorie intake of about 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 5.1bn calories per week by the end of our sample period in January 2020. The demand response due to higher prices for levied brands following levy implementation cut a further 1.2bn calories, by reducing combined take-home and drink-now cola (420 calories per litre) sales by an estimated 2.8m litres per day. However, 0.2bn of these calorie reductions are offset by substitution into levy-exempt brands. In total, therefore, the SDIL induced a total reduction of 6.1bn calories per week from soft drinks consumption. 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.

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 the longer-term underlying trend in consumer preferences for lower calorie products and brand owners' attempts to satisfy this demand by launching and promoting no-added-sugar variants. 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.

Our estimated change in calorie intake refers to just the top 100 brands, which cover three quarters of the EPOS dataset in terms of consumer spending. Retailers' own-label brands account for another 18%. Given their focus on value-for-money it is all but certain that retailers cut the sugar content to just below 5g/100ml for all segments that were not levy-exempt. Aggregate own-brand sales across leviable segments barely changed with levy implementation. Extrapolating from these volumes, we estimate that own-brands account for a reduction of an additional 165 million calories per week. This is a relatively small reduction because own-label brands tend to have little market share in levied segments (e.g. cola and energy) and large market shares in levy-exempt segments (e.g. water, fruit juice). The remaining (and also stable) 6.9% of market share is distributed across some 2,000 small brands most of which fell under the levy's small producer (production levels <1 million litres per year) exemption provision. To err on the side of underestimating the effectiveness of the levy, we assume that no reformulation, and thus no calorie reduction, took place for these brands.

Using a household panel to approximate sales in continental discounters and other outlets not covered by our EPOS data and conservatively assuming that they sell a similar product mix, we estimate that the levy induced a further reduction of 0.9bn calories per week in these retail outlets. Lastly Britvic plc. (2018), a key supplier to the on-trade "Foodservice" and "Licensed" channels, each year publishes a report on these markets. Using the on-trade equivalent to our off-trade data ("Curren Goodden Associates" (CGA) data), they detail a combined scale for these two channels of 1.8bn litres. Because prices are higher by a factor of about 6 compared to grocery stores, we assume no change in consumption for levied products. Observing that sales of reformulated brands held constant, we estimate a total calorie reduction of about 1.3bn calories per week in the on-trade sector.

Overall, a conservative estimate is that total calorie reductions due to the SDIL amounted to about 8.5bn calories per week. 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. Assuming no changes in lifestyle, this is equivalent to a 2-4lbs reduction in body weight for an overweight adult (Guth (2014); NIH (2014)). This still substantially underestimates the calorie reduction and weight loss 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. 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. That makes it unlikely that substitution towards snacks and/or confectionery with high sugar content offset the large calorie reductions we document.

5 Conclusion and Policy Implications

We use high-quality Electronic Point of Sale (EPOS) data combined with longitudinal information 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/100ml of sugar or more, and 21.6ppl if the product contains between 5 and 8g/100ml of sugar. If the product contains less than 5g/100ml of sugar no tax is due.

We show that the levy resulted in large calorie reductions of about 8.5bn calories per week, or an annual reduction of some 6,600 calories per UK resident. These reductions are more than ten times larger than those documented for Mexico's sugar tax (Aguilar et al., 2021). The key driver was a supply-side response. More than 80% of calorie reductions are 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, which was over-shifted for colas. Despite considerably higher prices, demand for levied energy drinks did not fall. The same is not true of levied cola, which saw a substantial decline. We also document an offsetting increase in the volume of diet and levy-exempt products, and interestingly an increase in the price of diet products which might be considered an unintended consequence of the SDIL. 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), Griffith et al. (2017), Curtis et al. (2016)).

Grummon et al. (2019) and Allcott et al. (2019b) propose some guiding principles for policymakers contemplating taxing SSBs. Our study of the UK's experience allows us to make several important additions to these: 1) consider a tiered and substantial tax, 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; 2) allow sufficient time between announcement and implementation—this provides manufacturers with the time to overcome the technical and commercial challenges of reformulation; 3) 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; 4) beware of the unintended consequence of price increases of substitute tax-exempt goods; and 5) do not rely on revenue recycling because a tax that effectively incentivizes reformulation should generate little. There are clear lessons for implementing sugar taxes in other markets where reformulation is feasible. These may be taken on board, for example, in revisions of the UK's recently-published National Food Strategy (NFS, 2021) which initially proposed a uniform and continuous tax on sugar in all markets.

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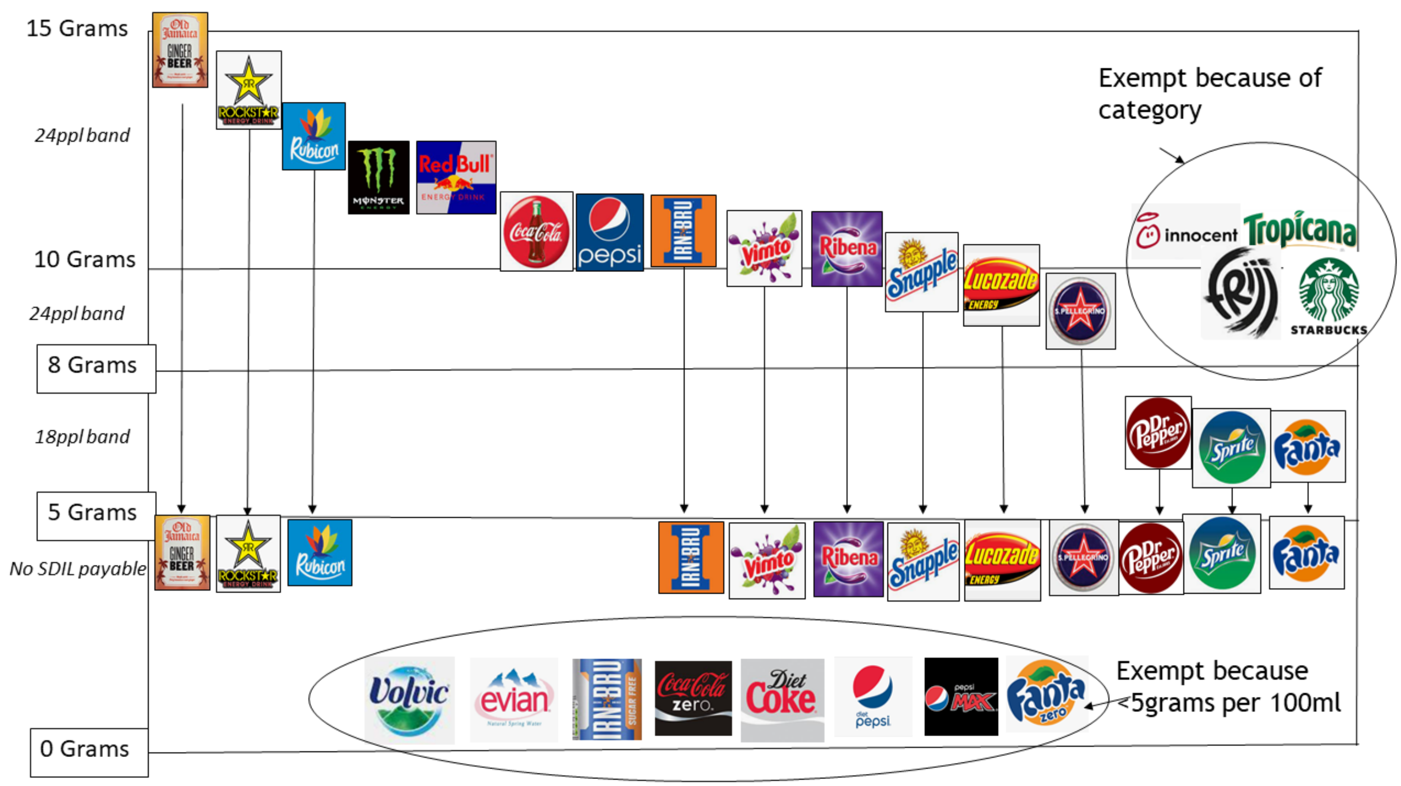
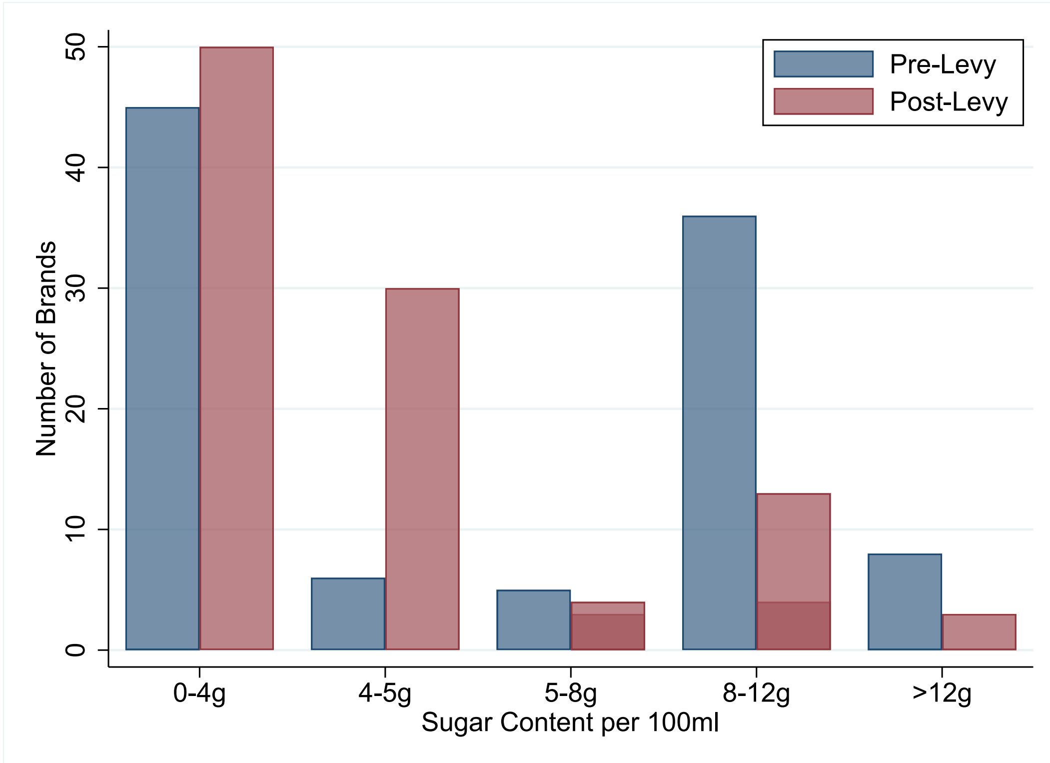
Tables and Figures

Figure 1: Sugar Content of Selected Brands



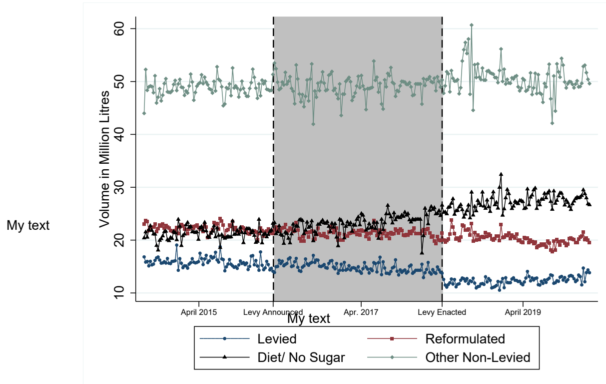
Notes: This figure illustrates sugar content and reformulation activities for a few selected brands. Brands that reformulated show up twice with arrows indicating the sugar reductions. Brands that chose to not reformulate or did not need to reformulate are only represented once. Brand logos are owned 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 2: Number of Brands by Sugar Content Pre- and Post-Levy Implementation

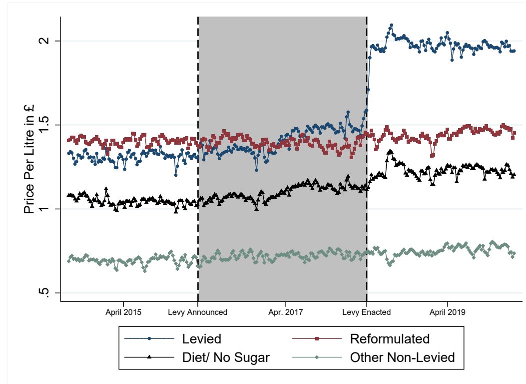


Notes: This figure shows the number of brands in our sample by sugar content. Blue bars show frequency prior to the announcement of the levy. Red bars show frequencies after the implementation of the levy. Brands with sugar content below 5g per 100ml are levy-exempt. A levy of 18ppl is applied to brands 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; brands that are actually subject to the levy are highlighted in opaque red.

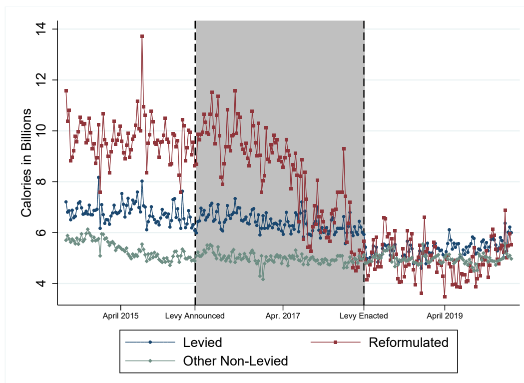
Figure 3: Trends in the UK Soft Drinks Market



(a) Volumes



(b) Pricing



(c) Calories

Notes: This figure shows the raw data for weekly sales volumes (in millions of litres, Panel (a)), price per litre (in £, Panel (b)), and calorie consumption from soft drinks (in billions, Panel (c)) for four categories of beverages: levied soft drinks, brands which reformulate, diet and no sugar products which attract zero levy, and levy-exempt products. The average price per litre is volume-weighted. The calorie time series for diet/zero-sugar beverages is not shown because by definition these drinks contain barely any calories. The first vertical dashed line indicates the announcement, the second indicates the implementation of the SDIL.

Figure 4: Effects of Reformulation on Sales and Total Calories Consumed

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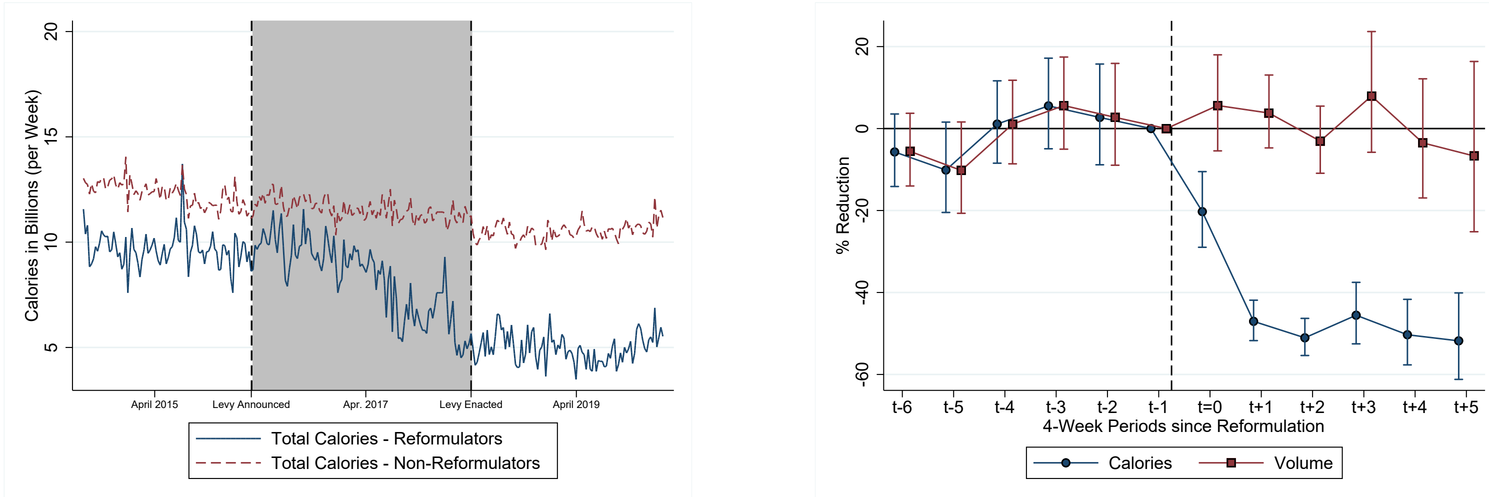

(a) Total Calories Trends

(b) Event-Study Estimates

Notes: This figure shows the effect of reformulation on weekly calorie consumption (and sales). Sub-Figure (a) shows the raw but seasonally adjusted calorie counts for brands that reformulated before the levy was implemented (blue solid line) and for all other brands (levied, diet, and exempt brands; red dashed line). Sub-Figure (b) 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 the 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. Estimates have been transformed into percentage changes.

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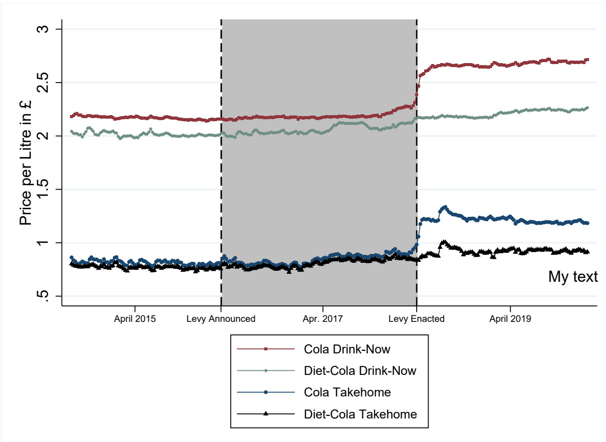
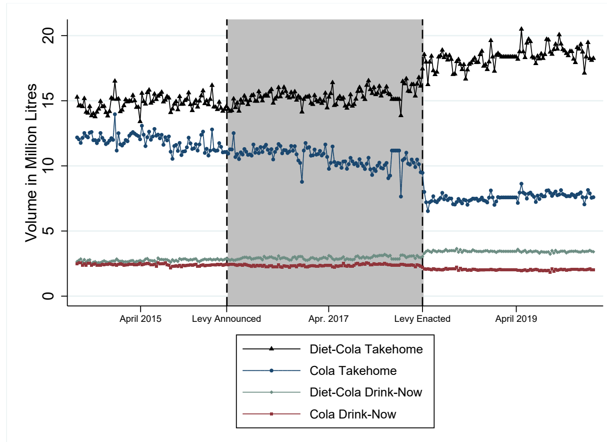
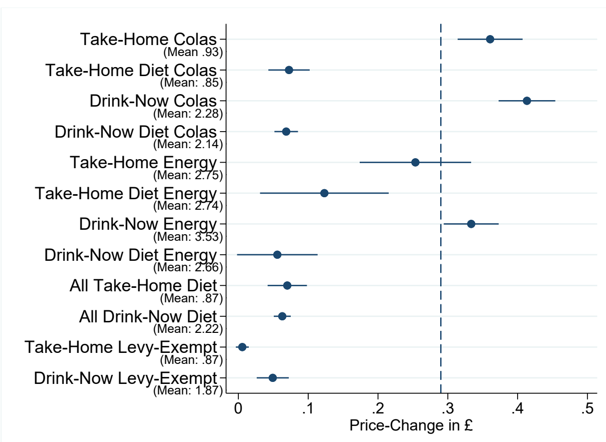
Figure 5: Effects on Prices and Sales of Levied Products and their Substitutes



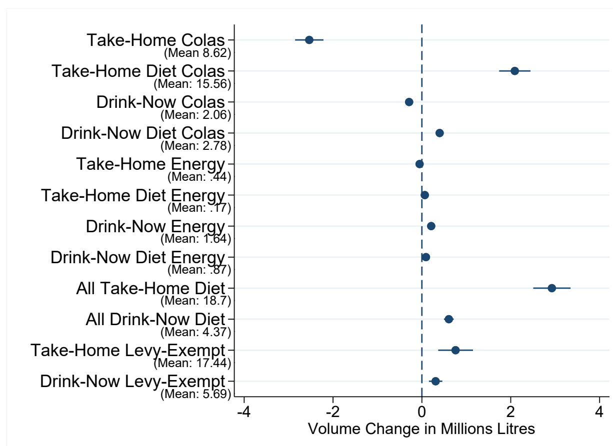
(a) Price Per Litre - Colas and Diet Colas



(b) Sales Volume - Colas and Diet Colas



(c) Price Effects on Levied and Diet Products



(d) Volume Effects on Levied and Diet Products

Notes: The top two figures show trends in pricing and sales volumes for levied colas and their diet versions. We distinguish between large take-home and small drink-now containers/packs. The bottom two figures explicitly estimate the effect of the levy implementation on pricing (Sub-Figure (c)) and sales (Sub-Figure (d)) by way of an interrupted time-series approach as outlined in equation (2). Each dot represents a point estimate and is accompanied by 95% confidence intervals, which are based on Newey-West standard errors allowing for autocorrelation in the error term for up to two lags. We estimate the model separately for take-home and drink-now products, for colas and their diet-substitutes, for energy drinks, and their diet substitutes, for the overall diet drinks category, as well as the levy-exempt category. All data are seasonally adjusted weekly aggregates, prices are weighted by pre-levy volumes.

Appendix Tables and Figures

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 weigh 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 4b according to % change $= e^{\delta} - 1$.

Table A2: 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)

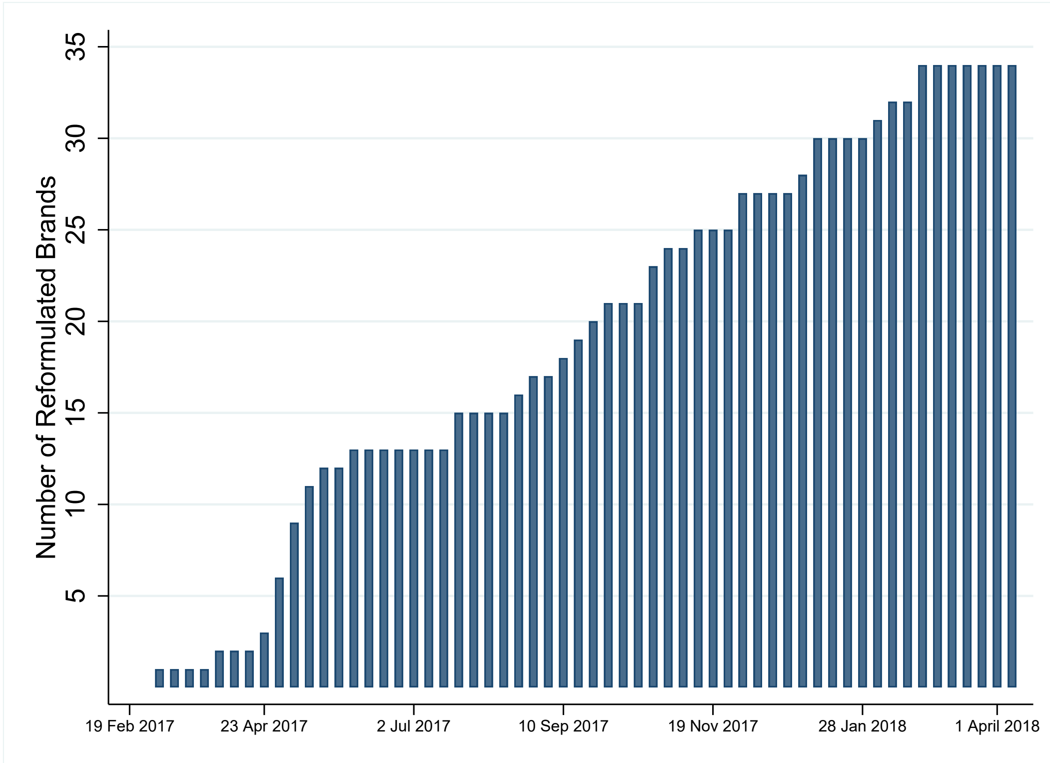
	Levied		Reformulated		Diet/ Zero-Sugar		Levy-Exempt	
Rank	Date	F-Stat	Date	F-Stat	Date	F-Stat	Date	F-Stat
1	08 Apr 2018	300.0	02 Jul 2017	459.9	04 Feb 2018	240.8	26 Jun 2016	27.7
2	01 Apr 2018	299.6	16 Jul 2017	442.5	11 Feb 2018	237.8	27 Nov 201	27.4
3	15 Apr 2018	296.5	23 Jul 2017	440.8	14 Jan 2018	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. Specifically, we run a model of the following form:

$$y^{res}_{ct} = \alpha + \beta D_t(\tau) + \epsilon_{ct} \tag{3}$$

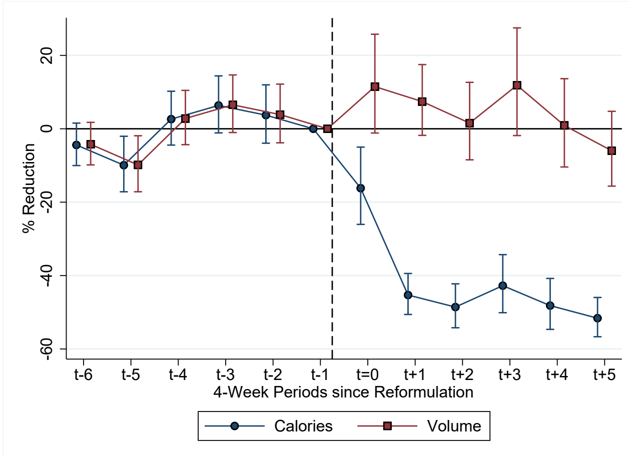
y_{ct} is our outcome of interest: price per litre in Panel A, volume sales in Panel B and total calories in Panel C. For each of our four brand categories c in week t. We regress this outcome on an indicator $D_t(\tau)$ that is equal to 1 for week τ and all subsequent weeks and zero otherwise. We have 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. This table 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, all outcomes have been de-seaonalised 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.

Figure A1: 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 A2: Sun and Abraham (2020) Estimator - Levied Brands as Control Group



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 the 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.

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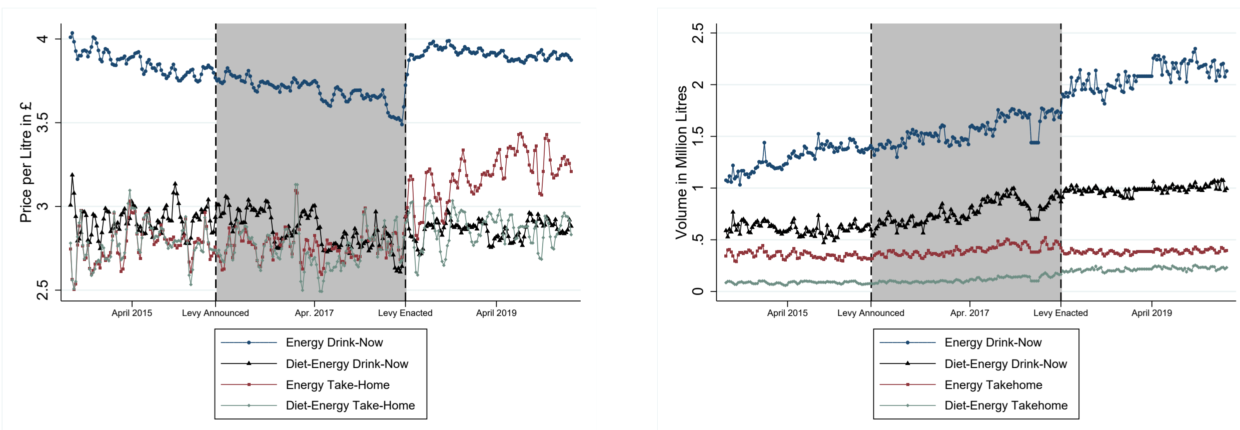
Figure A3: Effects on Prices and Sales of Levied Energy Drinks and their Substitutes



(a) Price Per Litre - Energy and Diet-Energy Drinks

(b) Sales Volume - Energy and Diet-Energy Drinks

Notes: The top two figures show trends in pricing and volume sales for levied energy drinks and their diet versions. We distinguish between large take-home and small drink-now containers/packs. All data are seasonally adjusted weekly aggregates, prices are weighted by pre-levy volumes.