ISSN 2282-6483

Alma Mater Studiorum - Università di Bologna
DEPARTMENT OF ECONOMICS

A tax is a signal: theory and evidence

Francesca Barigozzi
Laura Cornelsen
Mario Mazzocchi

Quaderni - Working Paper DSE N°1206

A tax is a signal: theory and evidence*

Francesca Barigozzi†

Laura Cornelsen‡

Mario Mazzocchi§

June 2025

Abstract

We propose a theoretical model in which uninformed consumers update their beliefs about the health effects of sugar in soft drinks through two sequential policies: an information campaign and a sugar tax. The information campaign is modeled as a costless signal (cheap talk), while the tax policy is modeled as a costly signal. While the information campaign conveys only partial information, we show that the tax policy can generate a fully revealing equilibrium, thereby transmitting accurate information to consumers.

Our empirical analysis supports the theoretical predictions. Exploiting the *announcement* (on March 16, 2016) of the tiered structure of the UK Soft Drinks Industry Levy, we provide evidence consistent with the tax policy functioning as an effective signaling device. Immediately after the tax announcement and before implementation, both the purchased volumes and the sugar content of taxed soft drinks declined, while purchases of exempted sugar-sweetened beverages remained unchanged. In contrast, the preceding information campaign had a similar effect across all soft drinks, regardless of their sugar content.

Keywords: Sugar tax, Tax announcement, Information campaign, Tax revenue, Negative externality.
***JEL*-Classification:** D82, D12, H31.

---

*Data from Kantar's Worldpanel used in this research were purchased with support from the UK Medical Research Council (Fellowship in Economics of Health, Grant References MR/L012324/1 and MR/P021999/1), and the af Jochnick Foundation. Mario Mazzocchi's contribution was partially supported by PNRR funds under the PE10 project – ONFOODS: 'Research and Innovation Network on Food and Nutrition – Sustainability, Safety and Security – Working ON Foods' (Grant Reference PE0000003, CUP J33C22002860001, 2022–2025). We thank Pierre Dubois, Giacomo Calzolari, Matthew Wakefield, Vincenzo Scrutinio, Tim Beatty, and Martin Forster for valuable feedback on earlier drafts. The usual disclaimer applies: all errors are the responsibility of the authors.
Data statement: Analyses and interpretation were conducted independently of Kantar. Kantar can neither independently verify the findings nor endorse the views or findings of this study.

†Department of Economics, University of Bologna, Italy, Email: francesca.barigozzi@unibo.it.

‡Faculty of Public Health and Policy, London School of Hygiene & Tropical Medicine, 15-17 Tavistock Place, London WC1H 9SH, UK. Email: laura.cornelsen@lshtm.ac.uk

§Department of Statistics, University of Bologna, Italy. Email: m.mazzocchi@unibo.it

Non-technical summary

This paper investigates how government policies—specifically taxes—can serve not just as economic tools but also as communication devices. The authors study the 2016 UK announcement of a sugar tax on soft drinks to understand how consumers respond to information about health risks.

The Core Idea

People often do not have full information about the health effects of consuming sugar- beverages (SSBs). Governments use taxes to change behavior, but these tools also carry *signals*. The paper explores the idea that a tax doesn't just make sugary drinks more expensive—it tells people that these drinks are harmful.

Two Signals, Two Effects

The authors compare two types of signals:

- An *information campaign* led by celebrity chef Jamie Oliver in 2015, which raised public awareness about sugar.
- The UK *government's sugar tax announcement* in 2016, which specified that drinks with higher sugar content would be taxed more heavily.

The first signal was "cheap talk"—free but possibly vague information. The second was "costly signaling"—a credible action that gave consumers clearer information about sugar's health risks.

Key Findings

Using British household purchase data, the authors show that:

- After the *information campaign*, consumers reduced purchases across all sugary drinks.
- After the *tax announcement*, consumers selectively reduced purchases of high-sugar drinks that would be taxed, while continuing to buy untaxed or low-sugar drinks.

  Interestingly, these changes occurred *before* the tax was implemented and prices actually changed. This suggests that the announcement itself informed consumers and influenced their behavior.

Why Does This Matter?

The authors build a theoretical model to explain these patterns. They show that a tax can act as a credible signal, revealing information about health risks more effectively than words alone. The study also considers how people manage limited attention: it suggests that consumers only began checking nutrition labels after the tax announcement gave them a reason to do so.

Conclusion

This paper highlights the dual role of taxes: beyond changing prices, they shape beliefs. Thoughtfully designed tax policies can enhance public awareness and promote healthier choices—even before they take effect. The research suggests that policymakers should consider both economic and informational effects when crafting health-related interventions.

1 Introduction

In April 2018, the UK Government introduced a levy on soft drink producers as a policy to address the increasing prevalence of obesity and related health conditions by reducing sugar consumption. Since the levy was intended to reduce sugar intake primarily through reformulation by soft drink manufacturers, the tax was announced two years before its implementation, on March 16, 2016.[1] The two-tiered structure of the levy was made explicit in the announcement, indicating that products with less than 5 grams of added sugar per 100ml of drink would be exempt from the tax, and a lower levy would be applied to products with added sugar content between 5g and 8g/100ml, relative to those exceeding 8g/100ml. On the same day, the Office for Budget Responsibility forecast the two levy rates to be £0.18/liter and £0.24/liter, respectively.[2] The rates were formally confirmed one year later, on 8 March 2017, and subsequently implemented on 6 April 2018, as announced.

British mass media first reported on the health risks associated with the consumption of sugar-sweetened soft drinks and a potential sugar tax in the last week of August 2015, when TV chef Jamie Oliver (JO) launched a public petition to introduce a 7p charge per regular-sized can of sugar-sweetened beverages (SSBs) "to improve children's health." The petition quickly received 155,516 signatures—enough to trigger a parliamentary debate—but the Government responded on September 18, declaring it had no intention of introducing such a tax (see Buckton et al. (2019a)). Accordingly, the government's March 2016 announcement of the two-tiered Soft Drinks Industry Levy (SDIL) was largely unexpected.

These events motivate our paper. We leverage the *announcement* of the UK sugar levy's two-tiered structure, which followed the information campaign, to show that it served as an efficient signaling device that conveyed additional information to consumers. Specifically, we use a difference-in-differences strategy to study how information about the health risks of excessive sugar intake is transmitted through two types of policy: an information campaign and a tax announcement. We identify the causal impact of each on soft drink purchases using data from the Great Britain (GB) Kantar's Worldpanel take-home panel data covering household purchases between January 2014 and December 2017. Our empirical analysis reveals the following: (i) UK consumers responded to both the information campaign and the tax announcement, but their reactions differed depending on the type of policy; and (ii) after the tax announcement, the reduction in purchases was not generalized across all soft drinks, as observed after the information campaign, but aligned with the tiered tax structure. Despite the tax being announced but not yet implemented—implying no direct price or income effects—households reduced their purchases only of soft drinks announced to fall under the tax. In contrast, purchases of soft drinks exempt from the tax due to their low sugar content remained unchanged.

Our empirical strategy is guided by a theoretical model demonstrating that a tax policy can serve as an effective signaling device, conveying accurate information about the health effects of excessive sugar intake—even after an information campaign has occurred. The mechanism is explained below.

SSBs generate both internalities—health consequences that consumers may misperceive due to incomplete information and negative externalities stemming from the burden on public healthcare systems (e.g., from childhood obesity). Notably, public perception of the health risks from SSBs consumption remains vague. When he launched his petition in 2015, Mr. Oliver targeted fizzy drinks rather than other sugar sources (e.g., chocolate bars) because "people did not realize just how much sugar is in such drinks."[3]

[1] See the BBC News article "Sugar tax: How will it work?" by Nick Triggle, published on March 16, 2016, retrievable at https://www.bbc.com/news/health-35824071.

[2] https://cdn.obr.uk/March2016EFO.pdf.

[3] Statement made in Jamie Oliver's documentary, *Jamie's Sugar Rush*, first broadcast on Channel 4 in 2015. Available at: `https://www.youtube.com/watch?v=pLwcbHEuK44` (accessed 4 June 2025).

In our model, a representative consumer holds a *prior* about the negative effects of sugar in two substitutable soft drinks. She receives two types of signals: an information campaign and a tax policy. We interpret the information campaign as a cheap talk signal (Crawford and Sobel, 1982) and the tax policy as a costly signal (Barigozzi and Villeneuve, 2006; Mailath, 1987). The signals arrive sequentially: the campaign first, followed by the tax announcement. Only the drink with higher sugar content is announced to be taxed. After receiving each signal, the consumer updates her beliefs and adjusts her purchases of the two drinks.

The two senders—the campaigner and the government—adopt a paternalistic approach, aiming to maximize consumer utility based on the true health impact of sugar rather than the consumer's perceived risk. Both also internalize the negative externality that the consumer ignores. A key difference is that the government also values future tax revenue, which is irrelevant in the case of the information campaign.

In the information campaign, because of the externality, the sender's objective function diverges from that of the consumer. The sender may exaggerate the health effects to prompt a greater consumption reduction, inducing the consumer to internalize the externality. This aligns with Crawford and Sobel's results. When the externality (i.e., the mismatch between the sender's and the receiver's objective functions) is small enough, the information campaign transmits partial information via a semi-pooling equilibrium.

In the case of the tax policy, the government's objective includes both the externality and the revenue from the future tax. Because tax revenue accrues only after implementation, the government maximizes a two-period utility function. This creates opposing incentives: as with the information campaign, it may want to exaggerate sugar's health effects, but it may also understate them to maintain higher tax revenue. When the externality is small, the latter incentive dominates.

We show that a fully revealing equilibrium tax exists. The equilibrium tax increases with the true severity of health effects but is lower than what would be optimal if consumers were fully informed. Unlike the partial information conveyed through the campaign, the tax policy transmits accurate information about sugar's health effects.

Theory and evidence together show that consumers update their beliefs about sugar's health effects in two stages: first after the campaign, then after the tax announcement. The empirical analysis shows that consumers initially reduced their SSBs purchases in response to Jamie Oliver's campaign, suggesting that they were not fully aware of the risks before receiving the information. Later, they further reduced purchases following the tax announcement, supporting our interpretation of the tax as an informative signal.

Furthermore, consumer reactions varied by policy. While the information campaign led to an across-the-board reduction in SSBs purchases, the tax announcement triggered a more selective response: consumers did *not* reduce purchases of SSBs announced to be exempted from the tax. This can be explained through *rational inattention* (Maćkowiak et al., 2023). The optimal consumption of substitutable sugar-sweetened beverages (SSBs) requires two types of information: knowledge of the health risks associated with sugar, and knowledge of the sugar content in each beverage. As previously discussed, consumers are initially uninformed about sugar's health effects, which can be conveyed through a signaling mechanism by an informed sender. In contrast, information about sugar content is readily available on product labels due to mandatory disclosure. However, accessing this information involves a cognitive cost, creating a trade-off between information acquisition and mental effort.

Prior to the tax announcement, the perceived benefit of consulting nutrition labels was likely insufficient to justify the cognitive effort. The announcement of the tax, however, created a salient incentive to differentiate between taxed and untaxed SSBs, thereby encouraging consumers to engage in label-checking and become more aware of sugar content. Our model captures this dynamic: following the information campaign, consumers reduced consumption uniformly across drinks, updating beliefs about sugar's health effects without incurring the cost of processing label information. In contrast, after the tax announcement—but before implementation—consumers bore the cognitive cost of checking labels to identify which beverages would be taxed. They then internalized the signal conveyed by the tax and adjusted their consumption choices accordingly.

Before turning to the literature review, we note that Gruber and Kőszegi (2001) proposed a similar empirical approach to test forward-looking behavior in the context of addictive goods. They found that announced but not-yet-effective cigarette tax increases led to reduced smoking. In our case, an announced sugar tax also reduced soft drink purchases, but our interpretation emphasizes Bayesian updating among initially uninformed consumers.

In Section 7, we compare our empirical strategy with the test proposed by Gruber and Koszegi. While forward-looking behavior and information provision may operate jointly, several elements suggest that the latter may have been the dominant channel in the case of the UK sugar tax announcement. Most notably, the sugar tax was a new, largely unexpected policy in the UK, and consumer response to the preceding information campaign suggests that there was widespread misinformation about the health effects of sugar in soft drinks. In addition, we document a relatively strong response to the implementation of the tax in 2018, with effects that align with the tiered structure of the levy and likely reflect consumer adjustment to changes in relative prices. Nonetheless, we acknowledge that both mechanisms—forward-looking behavior and information provision—may jointly shape consumer responses to the tax announcement.

The remainder of the paper is organized as follows. The next subsection reviews the related literature. Section 2 presents the theoretical model, analyzing the information campaign and then the tax policy. Section 3 summarizes testable implications and introduces rational inattention. Section 4 describes the data, summary statistics, and identification strategy. Section 5 presents the findings and robustness checks. Section 6 discusses the economic mechanism, while Section 7 contrasts the forward-looking and information-based explanations. Section 8 concludes.

1.1 Related literature

This paper contributes to the extensive empirical literature on taxes on sin goods, particularly studies examining the impact of sugar taxes on consumer purchases of sugar-sweetened beverages (see, among others, Capacci et al. 2019; Dubois et al. 2020, and the review in Cawley et al. 2019). We are especially close to studies that emphasize the non-pecuniary effects of SSB policies—that is, effects not explained by price elasticities. Ahn and Lusk (2021) suggest that taxes can also serve as signals of prescriptive norms, conveying information about what consumers "should" be doing. In the case of cigarette taxes, Rees-Jones and Rozema (2023) argue that sin taxes influence behavior through information provision, persuasion, and other dissuasive mechanisms. Similarly, Cornelsen et al. (2020) and Cornelsen and Smith (2018) discuss the non-pecuniary effects of sugar-sweetened beverage taxes, emphasizing the role of information provision.

Taylor et al. (2019) suggest that the effects of SSB taxes may be largely driven by factors such as consumers' desire to conform to social norms or by belief updating regarding the health risks of sugar consumption. Other studies explore additional channels for non-pecuniary effects, such as reactance—where individuals respond in opposition to perceived external control (Debnam, 2017)—or resistance to paternalistic interventions (Just and Hanks, 2015).

While evidence indicates that non-pecuniary effects exist, their magnitude and direction remain ambiguous. Our paper contributes to this literature by formalizing the signaling effects of sin taxes through a theoretical model that informs the empirical analysis, exploiting the announcement of the UK sugar tax.

The information environment surrounding the UK Soft Drinks Industry Levy (SDIL) has been examined in several studies, some of which investigate anticipatory effects. A survey of approximately 3,000 UK adults conducted in December 2017 – 20 months after the SDIL announcement and four months before its implementation —- found that a large majority (around 90%) of respondents were aware of the link between frequent consumption of sugar-sweetened beverages (SSBs) and obesity. About half of the sample endorsed the social norm of avoiding SSBs (Pell et al., 2019). Follow-up surveys conducted 8 and 20 months after the SDIL came into force found no meaningful changes in knowledge, social norms, or policy support (Adams et al., 2021). A descriptive analysis by Bandy et al. (2020) identified a decline in volume sales of drinks that would become subject to the SDIL during 2016 and 2017, alongside an increase in sales of SSBs below the taxation threshold. Around the time of the SDIL announcement, Law et al. (2020) observed a significant—though short-lived—reaction in the stock prices of publicly listed soft drink companies. Additional research examining media coverage found that pro-health arguments dominated the discourse and received broader support than industry-led counterarguments (Bridge et al., 2020; Buckton et al., 2019b; Penney et al., 2023).

A key confounder when identifying the signaling effects of the SDIL is the possibility that beverage manufacturers reformulated products to reduce sugar content and thus avoid or minimize taxation. The two-year gap between the SDIL announcement and its implementation was explicitly intended to incentivize such reformulation. There is substantial evidence that many producers eventually reduced the sugar content of their beverages, although not immediately following the announcement. Dickson et al. (2023), using detailed point-of-sale data linked with nutritional information, find no evidence of reformulation prior to the end of 2016; according to their data, the first sugar-reducing reformulation occurred in February 2017[4]. Scarborough et al. (2020), using product data from the websites of six leading UK supermarkets, similarly report no observable reformulation activity before September–October 2016. In our empirical analysis, we therefore restrict the post-announcement sample to a 12-week window, ensuring that our estimates are not confounded by reformulation responses.

The theoretical model builds on the framework of Barigozzi and Villeneuve (2006), who first explored commodity taxes as fully informative signals. Unlike their single-good, single-period model with immediate tax implementation, our model introduces multiple goods, a tax announcement preceding implementation, and an information campaign. This sequential structure, combined with the information campaign, allows the model to align closely with the institutional setting of the UK SDIL.

2 The theoretical framework

A representative consumer derives utility from the consumption of two soft drinks, whose quantity is denoted as y and z, and a numeraire good, g, whose price is set to 1. The total sugar intake from y and z is given by $x = \alpha y + \beta z$, where α and β represent the grams of sugar per 100 ml contained in the respective soft drinks. We assume that soft-drink z contains more sugar than y, implying that $\beta > \alpha$.

The representative consumer's utility is:

$$V(y, z, g; \theta, \eta) = u(y, z) - \theta x - \eta \bar{x} + g; \tag{1}$$

where $u(y, z)$ is a function increasing and concave in the two arguments, $u_y(\cdot) > 0$, $u_z(\cdot) > 0$, $u_{yy}(\cdot) < 0$, $u_{zz}(\cdot) < 0$ and the cross derivative $u_{zy}(\cdot) < 0$ expresses some degree of substitutability between the two soft drinks. We first present the model without rational inattention[5] and then, in Section 3, we introduce rational attention.

[4] see Figure A1 in Dickson et al. (2023).

[5] Here, the consumer is aware of the sugar content of the two drinks, with $\alpha < \beta$, having incurred the small cognitive cost of reading

The parameter θ represents the negative impact of sugar intake on the consumer's health, which can translate into obesity, tooth decay, diabetes. Sugar also has a negative impact on the population's health. Hence, along with the negative internality θ, sugar generates a negative externality η, which is determined by the average sugar intake in the population, $\bar{x}$. The term $\eta\bar{x}$ thus represents the cost for the National Health System of treating health issues induced by the average sugar intake in the population (e.g., the cost of treating obesity). Notably, all consumers being identical, $\bar{x} = x$.

The budget constraint is $I = p_y y + p_z z + g$, where I is the per period income and p_y and p_z are the unit prices of the two soft-drinks. By substituting the budget constraint in the utility function (1) and setting the prices p_y and p_z to zero, one obtains the reduced-form of the consumer's per-period utility (where I is irrelevant for our analysis and then omitted):

$$V(y, z; \theta, \eta) = u(y, z) - (\theta + \eta)\,(\underbrace{\alpha y + \beta z}_{x}). \tag{2}$$

The crucial assumption of our model is that the side effect, θ, of consuming sugar, x, is not precisely known. The consumer knows the density of θ, f, defined over $\Theta \equiv \left[\underline{\theta}, \overline{\theta}\right]$, but its actual realization is not observable. The expected value of sugar's side effect is $E_f[\theta]$. The function f is assumed to be continuous and non-negative over its support.

In the absence of information provision, the representative consumer's choice depends on $E_f[\theta]$. In addition, assuming an infinite number of identical individuals, the consumer does not internalize the social consequences of her own sugar intake and the negative externality, $\bar{x}\eta = x\eta$, is neglected. The consumer's *objective function* thus writes:

$$U(y, z; f) = u(y, z) - E_f[\theta](\alpha y + \beta z), \tag{3}$$

where $E_f[\theta]$ indicates the *consumer's prior* about θ.

In period t_0, the optimal consumption levels, y_0^* and z_0^*, with $y_0^* > z_0^*$, are implicitly defined by the two equations:

$$y_0^* : u_y(\cdot) = \alpha E_f[\theta],$$
$$z_0^* : u_z(\cdot) = \beta E_f[\theta].$$

We use the following quadratic function to represent the consumer's utility:

$$u(y, z) = -\frac{1}{2}y^2 - \frac{1}{2}z^2 + y + z - \gamma yz, \tag{4}$$

where $\gamma \in [0, 1)$ is the degree of substitutability between the two drinks.

2.1 Strategic information transmission

Following the events that took place in the UK in 2015 and 2016, we aim to compare the impact on consumer choices of an information campaign and (the announcement of) a tax policy. To do so, we analyze two signaling games where the consumer is the receiver. Each sender has access to scientific reports and expert knowledge and thus observes sugar's side effect θ. The two games are separate and sequential, and the senders do not interact with each other. This theoretical approach is applicable because the representative consumer determines her consumption quantity in each period, and when the first sender launches the information campaign in period 1, he does not know that the tax will be announced in period 2.

their nutritional labels.

The events are the following. The first sender, Jamie Oliver (JO), launches an information campaign aimed at making consumers aware of the side effect of sugar contained in soft drinks y and z. Subsequently, the second sender (the government) announces a sugar tax specifically targeting soft drink z. As we will show, this tax may serve as a means of delivering information.

Each sender adopts a paternalistic approach, meaning they aim to maximize consumer utility by taking into account the realized value of θ, rather than the consumer's expectation f. Additionally, they consider the negative externality, η, associated with excessive sugar intake. However, it is important to note that while the second sender (the government) takes the tax revenue into account, the first one (JO) does not.

We look for Perfect Bayesian Equilibria (PBE) in pure strategies of the two games (see definitions in Appendix 9.1 and 9.5).

2.2 Information campaign

In his information campaign, Jamie Oliver makes statements like: "Health experts say sugar in soft drinks is as dangerous as alcohol and tobacco." From the consumer's perspective, this is cheap talk (Crawford and Sobel, 1982). Hence, JO's payoff function is: [6]

$$V^{S1}(y_1, z_1; \theta, \eta) = u(y_1, z_1) - (\theta + \eta)(\alpha y_1 + \beta z_1). \tag{5}$$

where the superscript $S1$ indicates "first sender." Expression (5) illustrates the paternalistic nature of $S1$, who maximizes the representative consumer's utility (2) while explicitly accounting for the negative externality.[7]

The timing of the cheap talk game is as follows. At the beginning of t_1, $S1$ observes the realization of θ and chooses a message $m(\theta)$. At the end of t_1, the consumer observes m, updates her beliefs on θ, and chooses consumption levels y_1 and z_1.

Hence, the consumer solves:

$$\max_{y_1, z_1} U_1(y_1, z_1; f|m) = u(y_1, z_1) - E_{f|m}[\theta](\alpha y_1 + \beta z_1) \tag{6}$$

where $E_{f|m}[\theta]$ is the *consumer's posterior* about θ after the information campaign.

Let us define $\hat{\theta}_m \equiv E_{f|m}[\theta]$, the consumer's posterior belief after the information campaign. The sender's program (5) can be rewritten as:

$$\max_m V^{S1}(\hat{\theta}_m; \theta) = u(y_1(\hat{\theta}_m), z_1(\hat{\theta}_m)) - (\theta + \eta)(\alpha y_1(\hat{\theta}_m) + \beta z_1(\hat{\theta}_m)). \tag{7}$$

By choosing a message m, a sender of type θ selects a belief $\hat{\theta}_m$. The belief indirectly affects the consumer's choice in period t_1 via its impact on the posterior. The presence of the externality η creates a misalignment between the objective function of $S1$ and that of the consumer. $S1$ has incentive to over-report side effects, as this would encourage the consumer to internalize the externality η.[8]

[6] Material costs associated with the information campaign, such as monetary expenses, time, and effort, remain unaffected by the realization of θ or by the quantity of y and z purchased by consumers. In other words, the effect of the sender's message and its impact on consumption are independent of the campaign's material costs. Therefore, we disregard them in our analysis.

[7] Note that, in addition to providing information, JO may have other reasons to launch an information campaign. These include supporting the introduction of a sugar tax, indirectly advertising his restaurants, and increasing his popularity. While these potential motives are not explicitly considered in the model, they do not affect JO's incentive to (mis)report θ, as they are independent of the consumption of y and z.

[8] Indeed, if the consumer is perfectly informed, optimal consumption levels for sender S1 and the representative consumer respectively

Remark 1 ***Incentives to misreport sugar side effects and the cheap-talk equilibrium.*** *(i) The sender seeks to over-report side effects to encourage the consumer to internalize the negative externality (its desired posterior belief is $\hat{\theta}_m = \theta + \eta > \theta$). (ii) If the externality is sufficiently low, partial information transmission is possible.*

The game is an application of Crawford and Sobel (1982). If η is sufficiently low, semi-pooling equilibria exist and partial information transmission is possible. As an example, in Appendix 9.1, we characterize a semi-pooling equilibrium with two partitions and a uniform distribution of θ.

For our purposes, the important conclusion is that if $E_{f|m}[\theta] > E_f[\theta]$, then sugar intake falls:

Remark 2 ***Information campaign, updating, and consumption.*** *(i) If the expected value of sugar side effect rises following Bayesian updating ($E_{f|m}[\theta] > E_f[\theta]$), sugar intake x falls. (ii) When considering the two soft drinks, consumption of z consistently decreases. However, depending on the degree of complementarity, γ, the consumption of y may either decrease or increase.*

See the last paragraph of Appendix 9.1 on point (ii) of Remark 2.

2.3 Tax announcement

We illustrate our argument using a single sugar-content threshold, κ, and a corresponding tax level. However, in the empirical analysis, we exploit the actual two-tiered structure of the levy to test the robustness of the theoretical implications. Let us assume that the sugar content in soft drink y is below the threshold, making it exempt from the tax, while the sugar content in soft drink z exceeds the threshold, resulting in the application of the tax: $\alpha < \kappa < \beta$. Hence, it is as if the following tax scheme is announced in period 2 and implemented in period 3:[9]

$$\tau_y = 0; \quad \tau_z = \tau > 0. \tag{8}$$

At the beginning of period t_2, the second sender observes the realization of θ and announces to the consumer both the sugar content threshold κ and the tax rate, thereby determining the tax scheme given in (8). Observing the sugar content threshold and the tax rate, the consumer further updates her belief on sugar side effects and chooses consumption levels y_2 and z_2, at the end of t_2. In t_3, the tax is implemented, and the representative consumer chooses consumption levels y_3 and z_3.

Let $\delta \in (0, 1]$ indicate the discount factor for the second sender ($S2$, i.e., the government). The government's payoff, V^{S2}, is:

$$V^{S2}(y_2, z_2, y_3, z_3, \tau; \theta, \eta, \lambda) = V_2(y_2, z_2; \theta, \eta) + \delta \left[V_3(y_3, z_3; \theta, \eta, \tau) + (1 + \lambda)\tau z_3\right], \tag{9}$$

where, $V_2(y_2, z_2; \theta, \eta)$ and $V_3(y_3, z_3; \theta, \eta, \tau)$ denote the consumer's utility in periods 2 and 3, respectively, as defined in equation 2—that is, utility with observable side effects and an internalized externality. In period t_3, the tax enters V_3 because the consumer pays τz_3 (see expression (12) below), and tax revenue, $(1 + \lambda)\tau z_3$ is generated.

The sender's objective function differs from the consumer's in three ways: $S2$ observes sugar's side effects, and it takes into account both the externality and the tax revenue. The parameter $\lambda \in [0, 1]$ indicates "love for tax

are:

$$y_1^{S1*} : u_y(\cdot) = \alpha(\theta + \eta); \quad z_1^{S1*} : u_z(\cdot) = \beta(\theta + \eta)$$
$$y_1^* : u_y(\cdot) = \alpha\theta; \quad z_1^* : u_z(\cdot) = \beta\theta.$$

[9] In Section 3.1, we discuss the announcement of the threshold κ and the tax rate in a setting where the representative consumer is rationally inattentive.

revenue."[10] From the point of view of $S2$, if $\lambda > 0$, the total benefit from raising the tax revenue, $(1+\lambda)\tau z_3$, more than compensates the corresponding consumer's utility loss τz_3. If $\lambda = 0$, the positive and negative effects of the tax cancel each other out, and the tax can no longer serve as a signal, since the sender's objective function becomes independent of the tax (see below).

Substituting V_2 and V_3 into (9) and rearranging yields:

$$V^{S2}(y_2, z_2, y_3, z_3, \tau; \theta, \eta, \lambda) = u(y_2, z_2) - (\theta + \eta)(\alpha y_2 + \beta z_2) \\ + \delta \left[u(y_3, z_3) - (\theta + \eta)(\alpha y_3 + \beta z_3) + \lambda \tau z_3 \right]. \tag{10}$$

After the tax announcement, the consumer updates her beliefs and chooses consumption levels in periods 2 and 3 by solving respectively:

$$\max_{y_2, z_2} U_2(y_2, z_2; f|_{m,\tau}) = u(y_2, z_2) - E_{f|m,\tau}[\theta](\alpha y_2 + \beta z_2), \tag{11}$$

$$\max_{y_3, z_3} U_3(y_3, z_3; f|_{m,\tau}, \tau) = u(y_3, z_3) - E_{f|m,\tau}[\theta](\alpha y_3 + \beta z_3) - \tau z_3. \tag{12}$$

where, $E_{f|m,\tau}[\theta]$ is the *consumer's posterior* about θ after the information campaign *and* the tax announcement. Thus, $E_{f|m,\tau}[\theta]$ indicates the cumulative effect of information transmission on the consumer's belief. Notably, while the "price effect" of the tax is only effective in period 3, the tax announcement conveys information on θ and thus already influences consumption in period 2.

2.3.1 Incentives to misreport side effects with a tax

The following definition is important to understand the signaling mechanism. The second-best tax $\tau^{SB}(\theta)$ is the tax that is optimal when the government cares about tax revenue, i.e., $\lambda > 0$, and the consumer observes side effects θ but still disregards the externality. The policy $\tau^{SB}(\theta)$ would thus enable the government to achieve the twofold objective of internalizing the externality and raising tax revenue, under the assumption that the consumer is already informed about the side effects. The second-best tax maximizes (9) when consumption levels derived from (11) and (12), with $E_{f|m,\tau}[\theta] = \theta$, have been incorporated. The following is established in Appendix 9.2:

Lemma 1 ***Second-best tax.*** *When the consumer observes θ and the tax is aimed at correcting the externality and raising tax revenue, its optimal value is:*

$$\tau^{SB}(\theta) = \frac{1}{1+2\lambda}\left[\lambda(1-\gamma) + (\beta - \alpha\gamma)(\eta - \lambda\theta)\right]. \tag{13}$$

Since the term $(\beta - \alpha\gamma)$ is positive, the tax is decreasing in θ.

Tax elasticity increases with θ, implying that consumption is more elastic at high values of θ. This explains why the tax is decreasing in sugar's side effect: some tax revenue for high θ can only be preserved by decreasing the tax.

Note that τ^{SB} does not depend on the discount rate δ. The reason is that, when consumers are informed, only the price effect of the tax matters (there is no updating of the consumer's belief). Since the tax is implemented in the third period, the latter remains the only relevant period for the government. Interestingly, if $\lambda = 0$, then tax revenue does not matter anymore, and the tax becomes the purely Pigouvian first-best tax $\tau^{FB} = \eta(\beta - \alpha\gamma)$,

[10] The parameter λ is related to the "shadow cost" of public funds. In the Ramsey model of taxation, λ would be the (endogenous) Lagrange multiplier associated with the government's budget constraint. In partial equilibrium models, λ is exogenous; see, for example, the Theory of Regulation (Laffont and Tirole, 1993).

which is now independent of θ. Intuitively, absent the incentive to increase tax revenue, curbing the externality created by sugar intake remains the only objective of the government.[11]

Since there is a one-to-one relationship between the tax level and the side effect parameter θ, the announcement of a particular second-best tax τ^{SB} implicitly reveals information about side effects. In particular, the consumer could, in principle, invert the policy function $\tau^{SB}(\theta)$ and recover the "true" value of θ from the observed tax level. This raises the question of whether τ^{SB} remains an implementable and incentive-compatible policy when consumers do not observe side effects, but may form beliefs on θ based on the announced tax.

A crucial condition for such an equilibrium to exist is the satisfaction of the single-crossing property. This property ensures that the sender's preferences over tax-announcement–belief pairs are monotonic in θ, thereby enabling the separation of the sender's types—i.e., the implementation of a credible signal for each possible value of θ. Verifying that the single-crossing condition holds is thus a necessary preliminary step to assess the implementability of a fully revealing tax under asymmetric information.

Proceeding as with the information campaign, let us define $\hat{\theta}_\tau \equiv E_{f|m,\tau}[\theta]$, the consumer's posterior belief after the information campaign *and* the tax announcement.

The government's objective function can be rewritten as:

$$\begin{aligned} V^{S2}(\theta, \hat{\theta}_\tau, \tau) = {} & u(y_2(\hat{\theta}_\tau), z_2(\hat{\theta}_\tau)) - (\theta + \eta)(\alpha y_2(\hat{\theta}_\tau) + \beta z_2(\hat{\theta}_\tau)) \\ & + \delta \left[u(y_3(\hat{\theta}_\tau, \tau), z_3(\hat{\theta}_\tau, \tau)) - (\theta + \eta)(\alpha y_3(\hat{\theta}_\tau, \tau) + \beta z_3(\hat{\theta}_\tau, \tau)) + \lambda \tau z_3(\hat{\theta}_\tau, \tau) \right]. \end{aligned} \tag{14}$$

By choosing a tax, a sender of type θ selects a belief-tax pair $(\hat{\theta}_\tau, \tau)$. Tax announcement affects *indirectly* the consumer's choice in periods t_2 and t_3 via its impact on beliefs; tax implementation instead *directly* affects consumption in period t_3 (the latter is the price effect). We are now in the position to check whether the single-crossing property holds. In Appendix 9.3, we derive the following lemma.

Lemma 2 ***Single-crossing.*** *$\left(\partial V^{S2}(\theta, \hat{\theta}_\tau, \tau)/\partial \tau\right) / \left(\partial V^{S2}(\theta, \hat{\theta}_\tau, \tau)/\partial \hat{\theta}_\tau\right)$ is a strictly monotonic function of θ.*

Since the single-crossing property is satisfied, the second-best tax schedule $\tau^{SB}(\theta)$ could, in principle, support a fully revealing equilibrium in the signaling game, where the consumer is initially uninformed and infers the true value of the side effect parameter θ from the observed second-best tax level.

However, we show in Appendix 9.4 that τ^{SB} does not constitute an equilibrium in this setting, as the consumer anticipates that the government has an incentive to misrepresent the true value of θ. Specifically, the government would like to implement the second-best tax $\tau^{SB}(\theta)$ as if it were the tax associated with a different value $\theta' \neq \theta$, thereby influencing the consumer's beliefs and behavior in a way that improves the government's payoff. This strategic misrepresentation violates the incentive compatibility condition required for full revelation. Although full revelation is not compatible with signaling through the second-best tax, it remains feasible because the single-crossing property is satisfied. However, any fully revealing mechanism must necessarily involve distortions relative to the second-best tax, as we show below.

The direction of mimicking depends on the (constant) sign of the derivative of $\left(\partial V^{S2}/\partial \tau\right) / \left(\partial V^{S2}/\partial \hat{\theta}_\tau\right)$. We focus on the case where the derivative is negative; see Appendix 9.4 and 9.5.

Remark 3 ***The second-best tax and incentives to misreport the sugar side effect.*** *The second-best tax τ^{SB} is not an equilibrium of the signaling game. (i) When $\lambda > 0$ and $\eta = 0$, the government aims to under-report*

[11] When the consumer observes θ, the first-best tax allows for decentralization of the first-best allocation because it successfully addresses the externality generated by sugar overconsumption.

side effects (the desired belief is $\hat{\theta}_\tau < \theta$) through the tax policy to boost tax revenue. (ii) When $\lambda = 0$ and $\eta > 0$, the government seeks to over-report side effects (the desired belief is $\hat{\theta}_\tau > \theta$), but the tax is no longer informative. (iii) When $\lambda, \eta > 0$, incentives to misreport side effects are influenced by two opposing forces: boosting tax revenue and mitigating the negative externality. If η is sufficiently low, the government's incentive to discourage consumption is secondary to its desire to increase tax revenue, resulting in a prevailing incentive to under-report side effects.

Let's begin by considering a scenario where the externality is zero ($\eta = 0$), but tax revenue matters ($\lambda > 0$). To increase tax revenue, the government could report that sugar is less harmful to the consumer's health than it actually is. Since the second-best tax τ^{SB} decreases as θ increases, an optimistic message ($\hat{\theta}_\tau < \theta$) would imply setting a tax larger than the second-best one ($\tau > \tau^{SB}$).

Conversely, when tax revenue is irrelevant ($\lambda = 0$), but the externality exists ($\eta > 0$), the government aims to reduce sugar over-consumption by sending a pessimistic message regarding side effects ($\hat{\theta}_\tau = \theta + \eta > \theta$), as in the cheap-talk game. However, in this case, the optimal tax becomes the first-best tax $\tau^{FB} = \eta(\beta - \alpha\gamma)$ and no longer conveys information on sugar's side effect.

When both the externality and tax revenue are relevant, the incentive to misreport side effects lies between these two extremes. To align with empirical findings suggesting that the information campaign conveys some information, we focus on a scenario in which the externality is relatively low, such that the cheap talk equilibrium is partially informative (see also Remark 1). Consequently, we focus on the scenario in which the incentive to under-report side effects prevails—namely, when η is sufficiently low (so that condition (33) holds) and the single-crossing condition is negative (see Appendix 9.4 and 9.5). Here, a government of type θ has an incentive to mimic a lower type $\theta' < \theta$ by setting the tax $\tau^{SB}(\theta') > \tau^{SB}(\theta)$, thereby attempting to signal a lower level of side effects.

2.3.2 The fully revealing tax

We characterize the fully revealing tax in the following proposition (see Appendix 9.5).

Proposition 1 *The fully revealing tax satisfies the following ordinary differential equation:*

$$\frac{d\tau^*(\theta)}{d\theta} = \frac{(1+\lambda)(\beta - \alpha\gamma)\tau^*(\theta) - \frac{1+\delta}{\delta}(\alpha^2 + \beta^2 - 2\alpha\beta\gamma)\eta}{(1+2\lambda)(\tau^{SB}(\theta) - \tau^*(\theta))}.$$

For values of the externality sufficiently low, the tax is monotonically increasing and the boundary condition is $\tau^*(\bar{\theta}) = \tau^{SB}(\bar{\theta})$.

Observing the fully revealing tax, the consumer infers the true value of side effects θ and chooses consumption of the two drinks accordingly. Consumption of z is always decreasing with θ. Depending on the degree of complementarity, γ, the consumption of y may either decrease or increase with θ.

To understand the shape of the fully revealing tax, recall that both $\alpha^2 + \beta^2 - 2\alpha\beta\gamma$ and $\beta - \alpha\gamma$ are positive. When the externality is sufficiently small and condition (33) holds, the government has an incentive to underreport side effects in order to increase tax revenue. The consumer anticipates that a government of type θ has an incentive to mimic a lower type $\theta' < \theta$ by setting the tax $\tau^{SB}(\theta') > \tau^{SB}(\theta)$, thereby attempting to signal a lower level of side effects. As a result, to remain credible, the government must distort the fully revealing tax downward relative to τ^{SB}.

Condition (33) ensures that the numerator of the differential equation governing the fully revealing tax is positive. Therefore, the tax increases monotonically in θ, provided that the denominator is also positive. This is consistent

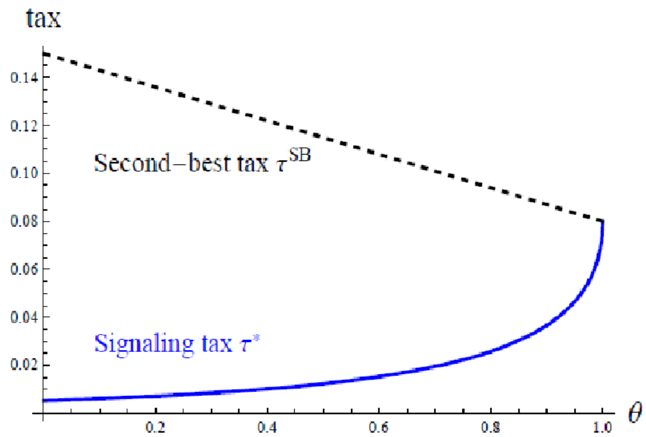

Figure 1: The second-best tax τ^{SB} and the fully revealing tax τ^* are represented for $\theta \in [0, 1]$ and the following parameters: $\eta = 0$, $\delta = 1$, $\lambda = 0.5$, $\gamma = 0.4$, $\alpha = 0.3$, $\beta = 0.4$.

with the required downward distortion from the second-best level, τ^{SB}.

The boundary condition $\tau^*(\bar{\theta}) = \tau^{SB}(\bar{\theta})$ corresponds to *no distortion at the top*: since the government has an incentive to *under-report side effects*, the consumer infers that the sender is truthfully reporting θ when it reports the worst possible case, corresponding to $\theta = \bar{\theta}$.

When $\eta = 0$, the differential equation simplifies to:

$$\frac{d\tau^*(\theta)}{d\theta} = \frac{(1+\lambda)(\beta - \alpha\gamma)\tau^*(\theta)}{(1+2\lambda)(\tau^{SB}(\theta) - \tau^*(\theta))}. \tag{15}$$

Here, the fully revealing tax does not depend on the discount factor because the sender only cares about consumption levels in the period in which tax revenue is collected, i.e., t_3. Figure 1 depicts the second-best and the fully revealing tax (15) when $\theta \in [0, 1]$, $\eta = 0$, and $\lambda = 0.5$.

The following remark is the counterpart of Remark 2 and states that, once she learns the value of side effects by observing the fully revealing tax, the consumer decreases sugar intake if the realized side effect θ is larger than the expected value $E_{f|m}[\theta]$:

Remark 4 ***Tax announcement, updating, and consumption.*** *In t_2, after the tax announcement, the consumer is fully informed on side effects ($E_{f|m,\tau}[\theta] = \theta$). (i) If the realized θ is larger than the consumer's expected value ($\theta > E_{f|m}[\theta]$), sugar intake x falls. (ii) When considering the two soft drinks, consumption of z consistently decreases. However, depending on the degree of complementarity, γ, the consumption of y may either decrease or increase.*

3 Testable implications

Remarks 2 and 4 imply that, under the two influence games, the consumer acquires partial information about sugar side effects in period t_1 and becomes fully informed in period t_2. This leads to the following testable implication:

Corollary 1 ***Testable implications: information.*** *(i) Following the information campaign in period t_1, the tax announcement in period t_2 acts as an additional informative signal to the consumer. (ii) If sequential Bayesian* *updating satisfies $E_{f|m,\tau}[\theta] = \theta > E_{f|m}[\theta] > E_f[\theta]$, then sugar intake from soft drinks decreases in period t_1 and further decreases in period t_2.*

Corollary 1 states that the tax announcement provides consumers with additional and valuable information, which can lead to a reduction in sugar intake from soft drinks. We now introduce an additional assumption that will affect the specific consumption of the two soft drinks following the information campaign and the tax announcement. Taken together, Points (ii) in Remarks 2 and 4 imply that, after the information campaign and after the tax announcement, the consumption pattern is qualitatively the same and depends on the degree of substitutability between the two products. To account for the distinct consumption responses observed after the two policy interventions, we extend the framework with rational inattention—an addition that captures variation in consumer reactions while preserving the model's informational structure.[12]

3.1 Rational inattention

The theory of rational inattention assumes that agents cannot process all available information, but they can choose which pieces of information to process; see Maćkowiak et al. (2023). Consumers always face the fundamental trade-off between processing more information to improve decisions and saving on the cognitive effort of doing so. Following this idea, assume that checking nutrition facts tables to verify the sugar content of soft drinks entails a cognitive cost.[13] In this case, the consumer may rationally choose to remain unaware of the exact sugar content (α and β) of the two drinks if the benefit of acquiring this information does not outweigh the effort required—particularly when their prior belief about sugar's side effects is minimal.

Let us define $\hat{\alpha}$ and $\hat{\beta}$ as the *perceived* sugar contents. The consumer's objective function (3) becomes:

$$U(y, z; f) = u(y, z) - E_f[\theta](\hat{\alpha}y + \hat{\beta}z). \tag{16}$$

Additionally, we assume that, before reading the nutritional information on their packaging, the consumer perceives the two drinks as having similar sugar content: $\hat{\alpha} = \hat{\beta}$. Hence, the first Bayesian updating of the parameter θ following the information campaign in period t_1 occurs while the consumer remains unaware of the actual sugar content of the two drinks. However, the tax policy in period t_2 involves the announcement of a sugar content threshold κ, along with a tax to be implemented in period t_3 on drinks exceeding this threshold.

The announcement of the two-tiered sugar tax introduces a direct incentive to distinguish between taxed and untaxed beverages.[14] This shift in incentives pushes the consumer to check nutritional facts, thereby becoming aware of the sugar content of the two drinks. In other words, the consumer in period t_2 incurs the cognitive cost of reading the nutritional information and learning the sugar content to determine whether either of the two drinks will be taxed in period t_3: the sugar content of beverages gained saliency due to this tax announcement.[15]

[12] We introduce rational inattention at this stage for expository clarity, having first presented the baseline signaling mechanisms to highlight the informational content of each intervention and the resulting Bayesian updates.

[13] Many studies suggest that the cognitive effort required to interpret detailed nutritional information can lead to consumer inattention; see, among others, Kiesel and Villas-Boas (2013). Recently, Barahona et al. (2023) analyzed the impact of the 2016 Chilean Food Act—the first mandatory nationwide food labeling regulation—focusing on the breakfast cereal market. The policy requires warning labels on packaged products exceeding thresholds for sugar, calories, sodium, or saturated fat. Unlike standard nutrition facts, the labels are salient symbols that facilitate information acquisition. The authors show that consumers substituted away from labeled products, with demand responses primarily driven by belief updating. Labeling effects are stronger for products about which consumers were initially more misinformed.

[14] Recall that, in the signaling mechanism, the consumer must infer the government's objective function, which includes tax revenue, in order to anticipate the government's potential incentives to misreport sugar side effects.

[15] In line with this interpretation, a robustness check reveals that the tax announcement reduced purchases of taxable drinks across both more and less popular soft drink brands, indicating that consumers learned about the sugar content of less familiar products as well—likely by consulting nutrition labels rather than relying solely on brand visibility or media coverage; see Section 6.

In Appendix 9.6, we show that the results stated in Remark 1 remain valid when the consumer is inattentive. If the externality is sufficiently low, the information campaign still allows for partial information transmission on θ. The notable difference is that, when the consumer is inattentive and perceives both drinks as having the same sugar content, after the information campaign, the decrease in consumption is equal for both drinks (substitution effects are not relevant). The impact of the tax policy, however, remains unchanged, as the announcement of the sugar threshold and corresponding tax renders the sugar content salient, prompting consumers to become aware of it despite the associated cognitive cost. As a result, Remark 4 continues to hold even under inattentive consumers, whereas point (ii) in Remark 2 requires adjustment:

Remark 5 ***Information campaign, updating, and consumption when the consumer is inattentive.*** *(i) If the expected value of side effect rises following Bayesian updating ($E_{f|m}[\theta] > E_f[\theta]$), sugar intake x decreases. (ii) The consumption of both soft drinks, y and z, decreases in a similar manner.*

From Remarks 4 and 5:

Corollary 2 ***Testable implications: consumption pattern when the consumer is inattentive.*** *If the consumer learns that the side effect is worse than expected ($E_{f|m,\tau}[\theta] = \theta > E_{f|m}[\theta] > E_f[\theta]$), (i) after the information campaign, the consumption of both soft drinks, y and z, decreases in a similar manner. (ii) After the tax announcement, consumption of z always decreases; however, depending on the degree of complementarity, γ, the consumption of y may either decrease or increase.*

Table 1. Testable Implications for Periods t_1 and t_2.

	$\mathbf{t}_1$	$\mathbf{t}_2$
Sugar intake from drinks $= x$	$\downarrow$	$\downarrow$
Untaxed drinks ($<$ **5g/100ml**) $= y$	$\downarrow$	$\downarrow\uparrow$
Taxed drinks ($\geq$ **5g/100ml**) $= z$	$\downarrow$	$\downarrow$

As established in Corollary 1, sugar intake, x, decreases during periods t_1 and further decreases during period t_2. We now move to the consumption of the two drinks. As established in Corollary 2, considering an inattentive consumer influenced by an information campaign, both drinks decrease similarly during t_1. On the other hand, the sugar threshold and corresponding tax announcement allow for a different consumption pattern for taxed and exempted drinks in t_2.

What accounts for the differing consumer responses to the information campaign and the tax announcement with respect to the exempted drink y, as shown in Table 1? Following the information campaign, the consumer updates her beliefs about the negative effects of sugar and reduces consumption of both drinks, which she initially perceives as having similar sugar content. In contrast, after the tax policy is announced—specifying the threshold κ and the tax rate—she pays the cost of attention and learns the actual sugar content of each drink. This enables her to identify which drink will be taxed, anticipate the period-t_3 budget constraint, and infer the government's objective function, which is necessary for interpreting the signal. A second belief update follows as a result of the signaling game.

While total sugar intake from drinks declines in both periods, the relative consumption of y and z may shift depending on their degree of substitutability. If y and z are strong substitutes, the consumer may find it optimal to replace the taxed, high-sugar drink z with the exempted, low-sugar drink y, possibly increasing consumption of y. This aligns with our empirical findings: consumption of exempted drinks declines during t_1 but slightly increases (or remains stable) during t_2.

4 Data

Our primary analysis is based on home scanner data between 2014 and 2016, collected within the Great Britain (GB) Kantar's Worldpanel Take-Home panel, 156 weeks, ending 31st December 2016. The panel is a representative live consumer panel of food and beverage purchases made by households in GB (i.e., England, Wales, and Scotland) and brought into the home. Purchases are made in a variety of outlets, including major retailers, supermarkets, butchers, greengrocers, and corner shops. Data are collected from each participating household using hand-held scanners provided by Kantar's Worldpanel, which are used to scan barcodes of purchased products. The panel is a sample of approximately 30,000 GB households each year, stratified by household size, number of children, occupational socio-economic status, geographical region, and age group.

The raw dataset comprises individual transactions, including information on the date of purchase, outlet, amount spent, and purchased volume. The unit value paid by the household for each product is calculated as expenditure divided by quantity. At the universal product code (UPC) level, this unit value corresponds to the shelf price. In addition, the dataset includes socio-demographic characteristics of the household: household size and composition, age, ethnicity, highest qualification of the main shopper. It also contains information on postcode area, household income group, tenure, occupational socio-economic status and body mass index (BMI) of the HRP. Nutritional information is provided by Kantar's Worldpanel either through direct measurement in stores or via product images supplied by Brandbank, a third-party provider. The basic unit of observation is an individual transaction at the UPC level (e.g. cans and bottles of the same brand are recorded separately).

A relevant consideration when working with such detailed data is that many households purchase soft drinks only occasionally, resulting in natural data sparsity that needs to be addressed in the modelling approach. Because the sugar tax targets high-volume consumers of high-sugar soft drinks (SSBs), we restrict the sample to households whose purchases of SSBs with sugar content above 5g/100ml (i.e. drinks subject to the 2018 tax) fall within the top quartile during the 52 weeks prior to the JO petition in August 2015 (i.e. from 27 August 2014 to 26 August 2015). Table 2 presents descriptive statistics comparing the full panel sample with our selected sub-sample of heavy SSB purchasing (HP) households. We further restrict our HP sample to households that remained in the panel both at the time of the JO petition (August 2015) and the government tax announcement (March 2016), yielding a final sample comprising 22.9% of all panel households (slightly less than one quarter due to attrition).

This HP subpopulation is especially relevant from a public health perspective. The sugar content of their total food and drink purchases is 42% higher (20% on a per capita basis) than that of the average GB household. The contribution of sugar from SSBs is also higher: 9.8% of total dietary sugar in HP households comes from SSBs, compared to 5.2% in the full sample. HP households also differ socio-demographically—they are, on average, larger (3.2 vs. 2.7 members) and have more children (0.86 vs. 0.64). The main shopper in these households tends to have lower educational attainment and is less likely to have a higher socio-occupational status. The recommended reference intake for total sugar in the UK is 90g per day per person, but HP households exceed this threshold on average (117g/day per capita).[16] Sugar from purchased SSBs alone accounts for 41% of the recommended maximum daily intake.

[16]These figures are consistent with the National Diet and Nutrition Survey data from the same period: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/699242/NDNS_yr_7_to_8_statistics.xlsx

Table 2. Household sample descriptives.

		Household sample			
		All households		Heavy purchasing households[a]	
	Unit	Mean	(S.D.)	Mean	(S.D.)
Number of households		35,156		8,056	
Age of the main shopper	Years	49.36	(15.40)	48.69	(13.07)
Household size		2.73	(1.34)	3.24	(1.37)
Number of children		0.64	(0.98)	0.86	(1.09)
Household income[b]	,000 £per year	32.14	(19.65)	33.27	(18.91)
Education level of the main shopper					
Degree or higher	%	30.39		27.26	
Higher education	%	16.11		16.44	
A Level	%	14.22		15.68	
GCSE	%	22.37		25.24	
Other	%	8.47		8.12	
None	%	8.44		7.26	
Occupational socio-economic status of the HRP[c]					
Class AB	%	21.28		19.54	
Class C1	%	37.98		36.97	
Class C2	%	17.82		20.02	
Class D	%	14.00		15.69	
Class E	%	8.92		7.79	
Body Mass Index HRP		22.61	(11.51)	22.46	(11.81)
Food expenditure	£per week per hh	44.25	(23.54)	56.80	(25.52)
Expenditure in non-alcoholic drinks	£per week per hh	1.96	(2.06)	3.64	(2.54)
Total quantity of non-alcoholic drinks purchased	Litres per week per hh	2.89	(3.16)	5.11	(3.80)
Sugar content of total food and drink purchases	grams per day per hh	267.30	(187.22)	380.50	(211.52)
Sugar content of drink purchases only	grams per day per hh	13.98	(19.92)	37.24	(28.84)
Average price of soft drinks	£per liter	1.12	(0.22)	1.11	(0.21)

Notes:

[a] The sub-sample of heavy purchasing (HP) households includes households whose purchases of SSBs with sugar content above 5g/100ml fall within the top quartile during the 52 weeks prior to 27 August 2015. Only households that remained in the panel until 2016 were retained.

[b] Household income is provided in the original data as seven categories of £10,000 intervals from £0 to £70,000, plus a top category for incomes above £70,000. Average income is calculated by assigning each category its midpoint value and £80,000 to the top category.

[c] Occupational socio-economic status is classified using the NRS Social Grade system: A (higher managerial, administrative, or professional), B (intermediate managerial, administrative, or professional), C1 (supervisory or clerical, junior managerial), C2 (skilled manual workers), D (semi- and unskilled manual workers), and E (state pensioners, casual or lowest-grade workers, unemployed). `https://nrs.co.uk/nrs-print/lifestyle-and-classification-data/social-grade/`

Source: Author's own analysis of Kantar's Worldpanel Take-Home panel, 52 w/e 26 August 2015.

Given the structure of the tax, Table 3 breaks down descriptive statistics for the HP household sample over the year preceding the JO announcement. The high-tax category for drinks containing more than 8g/100ml of sugar is the most frequently purchased: it accounts for nearly half of the household budget for soft drinks and contributes 80% of the sugar from household soft drink purchases. On average, households in our sample purchased 5.11 litres of soft drinks per week, of which 4.12 litres contained some sugar. SSBs that would become subject to the 2018 levy represent 45% of the total volume of soft drink purchases and 56% of total household expenditure on soft drinks, as they were already more expensive than other products even before the tax.

Table 4 shows changes in purchasing behaviour around the time of the two key announcements, comparing the 12 weeks before and after each date. Both events are associated with a decrease in the proportion of households purchasing soft drinks. Since the JO announcement was made at the end of August and schools reopened the following week, part of this drop may reflect seasonal effects. A relatively large decline (4%) is observed even in the proportion of purchasers of sugar-free drinks. On average, households reduced their SSB purchases by

Table 3. Sample descriptive statistics by product sugar content.

	Households	Heavy-purchasing household sample[a] Expenditure	Volume	Price	Sugar content
	% purchasing	£/week	Litres/week	£/litre	grams/day
No sugar	81.90	0.59	0.99	0.83	0.00
		(1.15)	(1.84)	(0.53)	(0.00)
Sugar < 5g/100ml	98.56	0.93	1.80	0.83	2.85
		(0.95)	(2.13)	(0.24)	(3.52)
Sugar > 5g/100ml (taxed)	100.00	2.03	2.32	1.46	32.53
		(1.57)	(1.83)	(0.36)	(25.12)
Sugar 5–8g/100ml (tier 1)	84.57	0.33	0.33	1.75	2.91
		(0.53)	(0.56)	(0.63)	(4.78)
Sugar > 8g/100ml (tier 2)	99.74	1.70	2.00	1.17	29.62
		(1.41)	(1.69)	(0.19)	(24.19)
Total soft drinks	100.00	3.64	5.11	1.11	37.24
		(2.54)	(3.80)	(0.21)	(28.84)

Notes: Figures on expenditure and volumes are mean values for households purchasing a product from the category at least once, considering only the weeks a household is in the sample. Prices are postcode-level weekly averages of unit values. Sugar content is the daily average amount of sugar in products purchased from each category. Standard deviations in parentheses.

[a] The sub-sample of heavy purchasing (HP) households includes households whose purchases of SSBs with sugar content above 5g/100ml fall within the top quartile during the 52 weeks prior to 27 August 2015. Only households that remained in the panel until 2016 were retained.

Source: Author's own analysis of Kantar's Worldpanel Take-Home panel, Soft Drinks, 52 w/e 26 August 2015.

39.4 centilitres after the JO announcement, while total SSB volume increased by 38.7 centilitres following the government's announcement. For the latter, the increase was larger for non-taxed drinks (+38.7 centilitres) than for those subject to tax (+15.7 centilitres). Moreover, the proportion of purchasers of taxed drinks remained stable, while it increased for non-taxed categories.

The table also reports average weekly stock levels, defined as a discounted sum of purchases in the previous four weeks:

$$\text{stock}_t = \sum_{p=1}^{4} \frac{1}{p} \times \text{purchases}_{t-p} \tag{17}$$

In the JO case, changes in stocks mirror those in volumes and remain small, suggesting limited substitution between current purchases and consumption from stock. The modest increases in stocks after the government announcement (+3 centilitres of SSBs per household per week) were close to zero for taxed drinks.

The JO event is also associated with a slight decrease in average prices across all categories, while following the government announcement there was a minor increase (+3 pence/litre) in the average price of drinks expected to be taxed. In our study, prices are calculated as the average unit value (expenditure divided by volume) across households purchasing a given drink in the same week and postcode area. While we cannot determine whether announcements led to strategic price changes or other price-related promotional campaigns by SSB manufacturers, we treat households as price takers in our empirical analysis.

4.1 Identification strategy

Our causal identification strategy aims to provide evidence on the testable implications discussed in Section 1, by examining the effects of the announcements on household purchases, controlling for observable (e.g. prices) and unobservable exogenous factors. The outcomes of interest are the purchased volumes of SSBs (y, z in Table 1)

Table 4. Changes at announcement date.

	No sugar	Total SSBs	<5g/100ml	>5g/100ml	5-8g/100ml	> 8g/100ml
	Jamie Oliver's petition launched (27 August 2015)					
Purchases (%)	-4.032	-1.046	-3.677	-3.378	-5.934	-3.964
	(0.776)	(0.183)	(0.465)	(0.389)	(0.790)	(0.473)
Volume (Lt/week)	-0.070	-0.394	-0.184	-0.210	-0.042	-0.167
	(0.032)	(0.056)	(0.039)	(0.034)	(0.012)	(0.031)
Stocks (Lt/week)	-0.019	-0.086	-0.036	-0.050	-0.007	-0.043
	(0.006)	(0.012)	(0.008)	(0.007)	(0.002)	(0.006)
Price (£/Lt)	-0.029	-0.073	-0.015	-0.102	-0.164	-0.034
	(0.007)	(0.008)	(0.005)	(0.011)	(0.019)	(0.005)
Expenditure (£/week)	-0.034	-0.267	-0.084	-0.182	-0.043	-0.137
	(0.020)	(0.038)	(0.018)	(0.030)	(0.010)	(0.027)
Sugar (g/day)	0.000	-3.054	-0.365	-2.681	-0.346	-2.321
	(0.000)	(0.497)	(0.069)	(0.477)	(0.107)	(0.455)
	Government announcement on levy and two-tiered structure (16 March 2016)					
Purchases (%)	2.916	0.013	1.487	-0.014	-0.098	0.390
	(0.788)	(0.238)	(0.516)	(0.468)	(0.803)	(0.542)
Volume (Lt/week)	0.137	0.387	0.230	0.157	0.014	0.142
	(0.032)	(0.055)	(0.040)	(0.033)	(0.010)	(0.030)
Stocks (Lt/week)	0.011	0.031	0.034	-0.002	-0.004	0.001
	(0.007)	(0.011)	(0.008)	(0.007)	(0.002)	(0.006)
Price (£/Lt)	-0.001	0.012	-0.023	0.031	0.065	-0.010
	(0.006)	(0.008)	(0.006)	(0.012)	(0.020)	(0.007)
Expenditure (£/week)	0.092	0.224	0.099	0.126	0.013	0.111
	(0.021)	(0.037)	(0.017)	(0.028)	(0.009)	(0.026)
Sugar (g/day)	0.000	2.670	0.194	2.484	0.143	2.322
	(0.000)	(0.528)	(0.069)	(0.510)	(0.102)	(0.486)

Notes: Twelve weeks before and after the announcement are considered. Figures on purchases refer to the change in the % of households purchasing the product category at least once between the time windows before and after the announcement. Volumes refer to the change in average purchased volumes per week. Weekly stocks are defined as purchases for a household during the previous 4 weeks considering increasing discount factors (0, 0.25, 0.50, 0.75). Prices reflect changes in the average weekly prices of products within the category. Expenditure is the total weekly expenditure in each specific drink category. Sugar is the total daily sugar content of drinks purchased by the household. Standard deviations in parentheses.
Source: Author's own analysis of Kantar's Worldpanel Take-Home panel, Soft Drinks, 104 w/e 31 December 2016.

and total sugar content of purchased SSBs (x in Table 1). We begin by outlining the causal inference model for purchased volumes, as purchases of sugar-free drinks provide a natural reference category. Since this reference group contains no sugar, identifying the impact of announcements on sugar intake requires an adaptation of the volume model.

Impact on volumes

For each household and week, all soft drink purchases are grouped into the following categories:

1. Sugar-free (zero sugar) soft drinks;
2. SSBs that are not taxed (sugar content strictly below 5g/100ml, y in Table 1);
3. SSBs belonging to the taxed categories (sugar content 5g/100ml and above, z in Table 1).

The first category serves as a reference good, based on the assumption that many relevant exogenous factors — such as temperature, overall inflation, and public holidays — exert similar influence on all soft drink categories. Thus, a parallel trends assumption across categories prior to the announcement appears plausible. We expect, however, that the tax announcements influence purchasing behaviour differently across the three categories, as they signal varying health implications associated with sugar content. This may trigger substitution toward lower-sugar or sugar-free alternatives, potentially breaking pre-existing parallel trends.

This parallel trends assumption — which is later tested and relaxed — applies after controlling for household and category-specific time-invariant effects, category-specific price dynamics, and week-specific time effects. We therefore specify a difference-in-differences panel regression as follows:

$$v_{hct} = \mu_{hc} + \eta_t + \beta_1 A_t \mathbb{1}_{c=1} + \beta_2 A_t \mathbb{1}_{c=2} + \psi \mathbf{X}_{hct} + \epsilon_{hct} \tag{18}$$

where v_{hct} is the volume of soft drink category c purchased by household h in week t, with $c = 1, 2, 3$ indexing sugar-free drinks, SSBs with less than 5g/100ml, and SSBs with more than 5g/100ml of sugar, respectively. A_t is a binary variable equal to 1 after the announcement, and 0 otherwise. $\mathbf{X}_{hct}$ is a vector of time-varying covariates, μ_{hc} are household-category fixed effects, η_t are week fixed effects, and ϵ_{hct} is a random error.

The covariate vector $\mathbf{X}_{hct}$ includes the average weekly price faced by the household for each drink category, stock levels for the corresponding drink category (as in equation (17)), and total weekly household food expenditure, excluding drink expenditure to mitigate endogeneity concerns. We assume that the announcements have no impact on prices, stocks and food expenditure, or - at least - that they act similarly on the three drink categories.

The coefficients β_1 and β_2 estimate the relative effect of the announcement on purchases of each SSB category compared to sugar-free soft drinks. As the reference group may not be entirely unaffected — households could increase sugar-free drink purchases in response to the signal — our estimates should not be interpreted as absolute changes, but as differences in the change in volume relative to sugar-free beverages. This differential measure is, in our view, a more sensitive indicator of the signaling effects of the announcements.

Our approach allows comparison between the signals arising from the JO announcement (which predated the tax structure) and the GOV announcement (which explicitly introduced a two-tiered levy). The earlier announcement likely conveyed a general message about health risks associated with sugar, while the GOV announcement provided a threshold-based signal exempting SSBs with less than 5g/100ml — making them, along with sugar-free drinks, a potential control group.

Impact on sugar from purchased drinks

The total amount of added sugar from SSBs (x in Table 1) reflects the net effect of the announcement, after accounting for within-household substitution. Here, using sugar-free drinks as a reference category is not viable, as they contain no sugar. Instead, we construct an artificial reference sugar amount by multiplying the volume of sugar-free drinks by a constant sugar content — the average sugar concentration in SSBs across all households over the 52 weeks before the JO announcement. This average is 4.66g per 100ml.

For example, a household purchasing 2 litres of sugar-free drinks in a week would be assigned a control sugar amount of $4.66 \times 20 = 93.2$ grams. These artificial control values are calculated for every household-week observation, before and after the announcements.

Our identification assumption is that a reduction in actual sugar reflects a reduction in purchased SSB volumes (relative to sugar-free drinks) and/or substitution toward lower-sugar SSBs. As the difference-in-differences structure is preserved, the scaling factor becomes a mere conversion coefficient, allowing effect estimates in grams of sugar.

We therefore estimate the following regression:

$$\ln(s_{hdt}) = \mu_{hd} + \eta_t + \gamma A_t \mathbb{1}_{d=1} + \psi \mathbf{X}_{hdt} + \epsilon_{hdt} \tag{19}$$

where $\ln(s_{hdt})$ is the natural logarithm of the sugar amount from SSB purchases by household h in week t, with $d = 1$ for actual sugar and $d = 0$ for the artificial control[17]. μ_{hd} are household-type fixed effects, and the explanatory variables $\mathbf{X}_{hdt}$ are defined as in equation (18). The coefficient γ captures the average relative effect of the announcement on sugar purchases.

Accounting for zero purchases in estimation

Although our sample includes heavy-purchasing households and aggregates products into broad drink categories, using weekly data for non-perishable goods results in frequent zero purchases. To address this, we estimate an alternative specification based on the two-stage procedure proposed by Semykina and Wooldridge (2010), which adjusts for sample selection bias due to non-purchases.

Equation (18) is modified as:

$$y_{hct} = \mu_{hc} + \eta_t + \beta_1 A_t \mathbb{1}_{c=1} + \beta_2 A_t \mathbb{1}_{c=2} + \psi \mathbf{X}_{hct} + \rho \hat{\lambda}_{hct} + \zeta_t \hat{\lambda}_{hct} T_{hct} + \epsilon_{hct} \tag{20}$$

Two additional terms incorporate the augmented inverse Mills ratio (IMR) $\hat{\lambda}_{hct}$ to control for selection bias. T_{hct} is a week indicator (equal to 1 if the observation is from week t). The IMR is obtained from a first-stage selection model estimated separately for each week $t = 1, \ldots, W$ using the following probit model:

$$P(p_{hct} = 1 \mid \mathbf{Z}_{hct}) = \Phi(\delta_t \mathbf{Z}_{ht} + \xi_t \bar{\mathbf{Z}}_{hc}) \tag{21}$$

Here, $\mathbf{Z}_{hct}$ includes the covariates in $\mathbf{X}_{hct}$, indicators in A_t, and at least one exclusion restriction (instrument) affecting selection but not directly influencing the outcome equation (20). $\bar{\mathbf{Z}}_{hc}$ denotes the time-average of $\mathbf{Z}_{hct}$. The instruments include household demographics (e.g. age, education, social class, BMI, children, size, income) that do not vary over time.

[17] We apply a (natural) logarithmic transformation so that the impact of the announcement can be interpreted as a percentage change rather than an absolute difference—an approach that is preferable given the artificial nature of the reference amount.

Based on these first-stage estimates, the IMR is computed as $\hat{\lambda}_{hct} = \lambda(\delta_t \mathbf{Z}_{ht} + \xi_t \bar{\mathbf{Z}}_{hc})$, and enters the second-stage regression both as a standalone term and interacted with time dummies.

The selection model in equation (21) is estimated on all observations, while equation (20) is estimated only on positive purchases. The coefficients β_c (one for each drink category) continue to consistently estimate the treatment effects, provided the covariates $\mathbf{X}_{hct}$ are strictly exogenous conditional on the fixed effects μ_{hc} (Wooldridge, 1995). This two-step correction is also applied to the sugar regression in equation (19).

5 Results

We apply models (18) and (19) separately to the JO and GOV announcements. The estimation sample includes the 12 weeks before and after each announcement. Coefficients are estimated both without and with the SW selection correction for non-purchases, as described in (20). Additionally, an aggregate estimate of the announcement impact on all SSBs is obtained from a separate model in which SSB purchases are collapsed into a single category, irrespective of sugar content.

The estimation results, reported in Table 5, are broadly consistent with the signaling mechanism outlined in the theoretical model and summarized in Table 1. The JO announcement led to reductions in the purchased volumes of both untaxed (y) and taxed (z) SSBs, as well as a reduction in the total sugar intake from SSBs (x). Estimates are robust across specifications, with and without the SW correction, although the latter are less efficient. On average, the total reduction in SSB volume is around 8 centilitres per household per week—roughly equivalent to one can per month.

When distinguishing between low-in-sugar (LS, <5g/100ml) and taxed (TX, >5g/100ml) drink categories, the response is larger for LS drinks. However, this difference is not statistically significant under the SW correction, as shown in the bottom portion of Table 5. The reduction in total sugar is more pronounced: based on the log-transformed dependent variable and the artificial reference group, we estimate a roughly 10% decrease in sugar from SSB purchases. This exceeds what might be expected from the volume reductions alone, indicating a compositional shift toward SSBs with lower sugar content after the announcement.

By contrast, the GOV announcement affected only the taxed category. The size of this effect varies depending on whether the SW correction is applied. The estimated reduction in taxed SSBs ranges from 5.3 to 11.9 centilitres per week, corresponding to 25 to 50 centilitres per month. For the non-taxed category, the model without selection correction suggests an increase in purchases, while the corrected model yields an estimate close to zero. In either case, the null hypothesis of equal treatment effects between y and z is strongly rejected (see last row of Table 5).

Consistent with these patterns, the overall impact of the GOV announcement on sugar intake is smaller—about 2.6%—and becomes statistically insignificant without the SW correction. These findings align with the interpretation that the JO petition, which advocated for a generic sugar tax without specifying thresholds, affected all SSBs similarly. In contrast, the GOV announcement delivered a more targeted signal, impacting only high-in-sugar drinks (z), while the exempted drinks (y) remained unaffected.

5.1 Robustness checks

We conduct two robustness checks to assess the validity of our identification strategy. First, we examine the plausibility of the parallel trends assumption across drink categories. Second, we estimate placebo models around hypothetical announcement dates occurring in the year preceding the first actual announcement.

From a purely intuitive perspective, there is little reason to believe that seasonal effects or other external shocks

Table 5. Estimates of announcement impact.

	Jamie Oliver		Government	
Selection correction	No	Yes	No	Yes
	Purchased volumes (L/week)			
Total SSBs × announcement	-0.081	-0.070	-0.008	-0.057
	(0.015)	(0.052)	(0.014)	(0.053)
y: Untaxed SSBs (<5g/100ml) × announcement (1)	-0.132	-0.098	0.073	0.025
	(0.022)	(0.062)	(0.020)	(0.062)
z: Taxed SSBs (>5g/100ml) × announcement (2)	-0.053	-0.047	-0.053	-0.119
	(0.015)	(0.052)	(0.014)	(0.054)
	Sugar from SSBs (Δ log)			
x: Total sugar × announcement	-0.150	-0.103	0.012	-0.026
	(0.015)	(0.015)	(0.014)	(0.013)
Number of households	8,052	6,720	8,051	6,625
t-statistics for treatment equality test H_0: Effect on untaxed = taxed SSBs (p-values in brackets)				
(1) = (2)	17.51	1.28	52.58	10.07
	(0.001)	(0.26)	(0.001)	(0.002)

Notes: Robust standard errors clustered by household and drink category in parentheses.
Source: Author's own analysis of Kantar's Worldpanel Take-Home panel, Soft Drinks, 104 w/e 31 December 2016.

would differentially impact taxed SSBs, low-sugar drinks, and sugar-free beverages. However, public discourse around sugar consumption—especially among children—had already gained traction in the UK prior to the JO petition. For instance, Briggs et al. (2013) simulated the potential effects of a UK soft drink tax in the *British Medical Journal*. In June 2014, Public Health England (PHE) published a report[18] highlighting the risks of excessive sugar intake and outlining policy options. Although taxation was listed as one of the options, the report downplayed its expected effectiveness and received limited media coverage. There were also sporadic media reports as early as 2013 suggesting that some medical bodies were calling for a soft drink tax.[19]

To test for any potential confounding effect of these earlier information events, we examine whether a divergence in purchasing trends across categories was already emerging prior to the JO announcement.

Parallel trends

Our difference-in-difference specifications rely on the assumption that, after conditioning on prices, stock levels, and food expenditure, there are no diverging time trends in drink volumes or total sugar intake across categories that could be driven by unobservable factors. As a first test of this assumption, we follow the method proposed by Rambachan and Roth (2023) (hereinafter RR), estimating confidence intervals under the assumption of smooth differential linear trends. Table 6 reports the confidence intervals under their least conservative assumption—namely, that these differential trends remain stable following the intervention.

Incorporating the "honest" assumption of differential linear pre-trends and RR's adjusted confidence sets weakens our findings for both JO and GOV announcements. However, comparison with conventional confidence intervals under the parallel trends assumption suggests that the attenuation is primarily due to RR's conservative adjustment,

[18] https://assets.publishing.service.gov.uk/media/5a75c0d7e5274a545822df4d/Sugar_Reduction_Responding_to_the_Challenge_26_June.pdf

[19] See BBC News: https://www.bbc.com/news/health-21228122

rather than actual violations of parallel trends. While the confidence sets are wider, the direction and magnitude of the average effects remain largely consistent with those estimated under the parallel trends assumption.

A visual inspection of the plausibility of the parallel trend assumption and the evolution of the treatment effects can be gained through an event study specification, defined as:

$$y_{hct} = \mu_{hc} + \eta_t + \sum_{t=-12}^{-2} \beta_t \mathbb{1}_{c=k} + \sum_{t=0}^{11} \beta_t \mathbb{1}_{c=k} + \psi \mathbf{X}_{hct} + \rho \hat{\lambda}_{hct} + \zeta_t \hat{\lambda}_{hct} T_{hct} + \epsilon_{hct} \tag{22}$$

This event study model generalizes equation (20). The coefficients β_t capture deviations in purchases of the treated drink category k from the baseline trend η_t in each period t, using $t = -1$ (the week before the announcement) as the reference. As in equation (20), we account for sample selection using the augmented inverse Mills ratio. We estimate this model separately for each drink category k (All SSBs, LS, HS), using sugar-free soft drinks as the control group. Similarly, we extend equation (19) into an event study framework to evaluate pre-existing trends in the (log of) total sugar purchases.

Figure 2 shows the β_t coefficients for the six weeks preceding and following each announcement. Visually, no strong evidence emerges of pre-existing differential trends across the treated and control categories. Although only a few time periods yield statistically significant coefficients (mostly for the GOV announcement), in all volume plots the post-announcement estimates lie consistently below the baseline, suggesting persistent reductions in purchases. By contrast, the event study model for sugar intake does not indicate any significant effects.

On balance, we are reasonably confident that our main estimates are not biased by pre-existing differential trends. The event study analysis provides supportive—though not definitive—evidence that the announcements, particularly the one by the government, contributed to a reduction in purchases. Given the relatively modest size of these effects, a period-by-period analysis may lack sufficient power to detect significant changes. However, under conservative assumptions, the direction of the effects remains negative in nearly all post-announcement periods, and our baseline difference-in-difference models yield sufficiently precise estimates to consider the effects statistically meaningful.

Table 6. Robustness: Pre-existing differential linear trend.

	Jamie Oliver		Government	
Selection correction	No	Yes	No	Yes
	Purchased volumes (Lt/week)			
All SSBs × announcement	-0.050 – 0.088	-0.401 – 0.091	-0.091 – 0.035	-0.454 – 0.027
	(-0.108 – 0.012)	(-0.366 – 0.064)	(-0.069 – 0.044)	(-0.413 – -0.003)
y - (SSBs < 5g / 100ml) × announcement (1)	-0.109 – 0.090	-0.587 – -0.004	-0.193 – -0.017	-0.501 – 0.058
	(-0.158 – 0.010)	(-0.456 – 0.043)	(-0.082 – 0.081)	(-0.416 – 0.065)
z - Taxed SSBs (> 5g / 100ml) × announcement (2)	-0.033 – 0.104	-0.288 – 0.205	-0.056 – 0.071	-0.464 – 0.028
	(-0.094 – 0.027)	(-0.330 – 0.111)	(-0.075 – 0.038)	(-0.445 – -0.026)
	Sugar content of purchased SSBs (Δ log)			
x - Total sugar from SSBs × announcement	0.190 – 0.325	-0.077 – 0.062	-0.213 – -0.084	0.003 – 0.133
	(-0.128 – -0.009)	(-0.137 – -0.013)	(-0.083 – 0.032)	(-0.053 – 0.063)

Notes: The test for pre-existing differential linear trends is based on the confidence intervals proposed by Rambachan and Roth (2023). The reported confidence intervals reflect estimates that allow for a pre-existing linear trend in the differences between treated and control units, interpolated over the pre-event period and based on an event-study model. Confidence intervals under the assumption of parallel trends are shown in parentheses.
Source: Author's own analysis of Kantar's Worldpanel Take-Home panel, Soft Drinks, 30 w/e 29 June 2018.

Placebo tests

As a further validity check, we estimate the volume models using placebo dates—specifically, the same calendar day and month as the JO and GOV announcements but one year earlier. This strategy aims to address potential concerns that the observed effects might be driven by seasonality rather than the announcements themselves.

Table 7 presents the results. The estimated effects on total SSB purchases are close to zero and not statistically significant, offering some reassurance. However, some category-specific estimates (e.g., the JO placebo effect on high-sugar drinks, the GOV placebo effect on low-sugar drinks) are unexpectedly positive. Notably, we also observe relatively large negative effects for high-sugar drinks in the GOV placebo case. These patterns suggest that there is enough variability in the data to occasionally produce spurious significant estimates.

In summary, our robustness checks do not offer unequivocal confirmation of the announcement effects. While they support the plausibility of our identification strategy, they also highlight the importance of statistical noise and potential heterogeneity. Further validation may be obtained by restricting the sample to specific subgroups, as discussed in Section 6.

Table 7. Robustness check: Announcement impact on placebo dates one year earlier.

	Jamie Oliver		Government	
Selection correction	No	Yes	No	Yes
	Purchased volumes (L/week)			
All SSBs × announcement	-0.003	0.063	0.009	-0.026
	(0.016)	(0.057)	(0.016)	(0.058)
y - Untaxed SSBs (<5g/100ml) × announcement (1)	-0.136	-0.122	0.082	0.086
	(0.023)	(0.066)	(0.023)	(0.069)
z - Taxed SSBs (>5g/100ml) × announcement (2)	0.071	0.191	-0.031	-0.105
	(0.016)	(0.060)	(0.016)	(0.058)
	Sugar content of purchased SSBs (Δ log)			
x - Total sugar from SSBs × announcement	0.145	0.013	0.030	-0.017
	(0.015)	(0.015)	(0.015)	(0.014)
Number of households	7,878	6,482	8,049	6,707

Notes: Placebo dates are 27 August 2014 for the JO announcement and 16 March 2015 for the GOV announcement. Robust standard errors clustered by household and drink category are shown in parentheses.
Source: Author's own analysis of Kantar's Worldpanel Take-Home panel, Soft Drinks, 104 w/e 31 December 2015.

6 Validation of the economic mechanism

Our results provide (weak) evidence that the tax announcements had an impact on the target population, identified as those households in the top quartile of taxed SSB purchases.

Additional analyses may help clarify whether the signaling effect of the JO and GOV announcements genuinely altered consumption behaviour. We consider three sets of validation checks.

First, we examine whether the observed effects differ between the most popular soft drink brands—those more likely to be mentioned in the media—and less frequently purchased brands. The rationale is that if announcements served as health signals, one would expect consumers to react regardless of brand popularity, based on checking the sugar content on labels. However, if only top brands are affected, the response might be more attributable to media visibility than to the processing of nutritional information.

Second, we investigate heterogeneous effects by subgroup, focusing on households with children and those in which the main shopper is living with obesity. These groups may be more responsive to health-related messaging.

Third, we explicitly test for differential effects between the low and high tax tiers, as the magnitude of the response might depend on the sugar content thresholds.

Fourth, we also examine household behaviour at the time of the actual tax implementation.

Minor versus major brands

We define major brands as those whose market share—measured as the proportion of total household expenditure on soft drinks—exceeds 1% prior to the announcement. We define minor brands as those with a market share below 0.5%. Our dataset includes 471 distinct brands,[20] resulting in 21 major brands (accounting for 69.2% of total expenditure) and 430 minor brands (accounting for 17.2%).

The estimates reported in Table 8 reinforce our earlier finding that the GOV announcement significantly reduced purchases of taxable drinks. Notably, the effect on less popular soft drinks is of similar magnitude to that observed for major brands[21]. In contrast, the JO announcement appears to have had limited impact on volumes when brands are considered separately, and no impact at all on less popular soft drinks. Nonetheless, we do observe a reduction in sugar content, suggesting that substitution occurred towards products with lower sugar density within each brand category.

Impact on population sub-groups

As a second validation check, we restrict the sample to two relevant sub-groups within the target population: *i*) households with children and *ii*) households in which the main shopper is living with obesity (i.e. has a body mass index above 30). Estimates are reported in Table 9.

We find that the JO announcement had a relatively larger impact on both sub-groups. This result is consistent with the messaging of the campaign, which explicitly targeted excessive sugar consumption among children. Despite the fact that households with children account for less than half of the original sample, we observe a significant reduction in purchases. Similarly, for households with main shopper living with obesity (around one-quarter of the original sample), the estimated reductions in both volume and sugar content of purchased drinks following the JO announcement remain substantial.

The evidence from households with children supports our interpretation of the announcements as signaling devices. Notably, purchases of low-in-sugar SSBs (exempted from the tax under the government's announcement) responded to the JO campaign—which targeted all sugary drinks indiscriminately—but not to the subsequent announcement of the two-tiered tax structure.

The impact of the GOV announcement is less clear-cut. Among households with children, the reduction in purchases of taxed SSBs appears even larger than that observed for the JO campaign, while untaxed drinks remain unaffected. As a result, the overall decline in sugar purchases is of a similar magnitude across the two interventions. By contrast, we find no evidence that the GOV announcement affected households with a main shopper living with

[20]Brand names refer uniquely to a drink type. For instance, a diet cola is treated as a separate brand from the standard cola, even if produced by the same manufacturer.

[21]Interestingly, many of these products may have eventually been exempted from the SDIL, which does not apply to small producers that produced fewer than one million litres of liable drinks in the previous 12 months. However, consumers were unlikely to be aware of or respond to this distinction.

Table 8. Announcement impact on product sub-samples.

	Jamie Oliver		Government	
Selection correction	No	Yes	No	Yes
	Less popular soft drinks			
	Purchased volumes (Lt/week)			
All SSBs × announcement	0.055	0.067	-0.074	-0.084
	(0.013)	(0.056)	(0.012)	(0.061)
y - (SSBs $<$ 5g / 100ml) × announcement	0.049	0.105	-0.050	-0.012
	(0.015)	(0.075)	(0.014)	(0.084)
z - Taxed SSBs ($>$ 5g / 100ml) × announcement	0.058	0.037	-0.088	-0.138
	(0.013)	(0.055)	(0.012)	(0.060)
	Sugar content of purchased SSBs (Δ log)			
x - Total sugar from SSBs × announcement	-0.027	-0.027	-0.054	-0.044
	(0.013)	(0.019)	(0.012)	(0.021)
Number of households	8,052	5,626	8,051	5,357
	Most popular soft drinks			
	Purchased volumes (Lt/week)			
All SSBs × announcement	-0.022	-0.027	-0.049	-0.109
	(0.014)	(0.051)	(0.013)	(0.054)
y - (SSBs $<$ 5g / 100ml) × announcement	-0.032	-0.006	-0.013	-0.056
	(0.017)	(0.057)	(0.016)	(0.061)
z - Taxed SSBs ($>$ 5g / 100ml) × announcement	-0.017	-0.041	-0.069	-0.148
	(0.014)	(0.054)	(0.013)	(0.056)
	Sugar content of purchased SSBs (Δ log)			
x - Total sugar from SSBs × announcement	-0.134	-0.093	-0.012	-0.042
	(0.015)	(0.015)	(0.014)	(0.014)
Number of households	8,052	6,571	8,051	6,393

Notes: Robust standard errors clustered by household and drink category in parentheses.
Source: Author's own analysis of Kantar's Worldpanel Take-Home panel, Soft Drinks, 104 w/e 31 December 2016.

obesity. Although the point estimates for taxed SSBs are negative—and broadly comparable to those in the full sample—they are not statistically or economically meaningful. This suggests that this subgroup did not respond more strongly to the GOV announcement, and may have been less attentive to the informational signal it conveyed.

Government tax tiers

In March 2016, the government announced a tiered levy on sugar-sweetened beverages (SSBs), applying a higher tax to products with added sugar content exceeding 8g/100ml compared to those containing between 5g and 8g/100ml. Model (18) can be extended to incorporate a third SSB category, $c = 3$, representing high-sugar drinks. This adjustment implies estimating an additional treatment effect, β_3. Table 10 reports estimates of the impact of the government announcement on SSB purchase volumes, distinguishing between the low-tax tier (LT: 5–8g/100ml) and the high-tax tier (HT: >8g/100ml).

The results suggest a stronger reduction in purchases within the LT category relative to the HT category.

Table 9. Announcement impact on population sub-samples.

	Jamie Oliver		Government	
Selection correction	No	Yes	No	Yes
	Households with children			
	Purchased volumes (Lt/week)			
x - All SSBs × announcement	-0.072	-0.119	-0.010	-0.112
	(0.023)	(0.075)	(0.021)	(0.076)
y - (SSBs < 5g / 100ml) × announcement	-0.117	-0.150	0.070	-0.060
	(0.032)	(0.088)	(0.031)	(0.089)
z - Taxed SSBs (> 5g / 100ml) × announcement	-0.047	-0.097	-0.055	-0.148
	(0.022)	(0.076)	(0.021)	(0.078)
	Sugar content of purchased SSBs (Δ log)			
Total sugar from SSBs × announcement	-0.027	-0.087	-0.045	-0.055
	(0.021)	(0.022)	(0.021)	(0.020)
Number of households	3,775	3,270	3,815	3,129
Households in which the main shopper is living with obesity				
	Purchased volumes (Lt/week)			
x - All SSBs × announcement	-0.130	-0.124	0.005	0.005
	(0.036)	(0.107)	(0.032)	(0.113)
y - (SSBs < 5g / 100ml) × announcement	-0.218	-0.112	0.098	0.075
	(0.051)	(0.128)	(0.045)	(0.137)
z - Taxed SSBs (> 5g / 100ml) × announcement	-0.082	-0.130	-0.046	-0.052
	(0.036)	(0.110)	(0.032)	(0.113)
	Sugar content of purchased SSBs (Δ log)			
Total sugar from SSBs × announcement	-0.218	-0.116	0.011	0.021
	(0.032)	(0.029)	(0.030)	(0.028)
Number of households	1,765	1,574	2,132	1,675

Notes: Robust standard errors clustered by household and drink category in parentheses.
Source: Author's own analysis of Kantar's Worldpanel Take-Home panel, Soft Drinks, 104 w/e 31 December 2016.

However, the difference in response is not statistically significant when the SW selection correction for non-purchases is applied. We find no clear evidence that the higher levy induces a stronger behavioural response in terms of reduced purchased volumes. One possible explanation is that high-sugar drinks may be more preferred by consumers, and reducing their consumption could involve higher adjustment costs—for example, due to limited acceptable substitutes or stronger taste preferences.

The theoretical model can be naturally extended to allow for three drinks with different sugar contents, two of which are subject to a sugar tax that increases with sugar concentration. In our baseline theoretical framework, drinks with different sugar levels yield the same baseline utility but differ in their associated health side effects, which are proportional to their sugar content (see utility function in Equation (4)).

However, if consumers have heterogeneous preferences across drinks, substitution patterns would depend not only on the sugar content parameters α and β and the substitutability parameter γ (see Equations (3) and (4)),

Table 10. Government announcement effects on purchased volumes, separate tier-effects.

	Government announcement Purchased volumes (Lt/week)	
Selection correction	No	Yes
(SSBs $<$ 5g / 100ml) $\times$ announcement (1)	0.073	0.026
	(0.020)	(0.062)
(SSBs 5-8g / 100ml) $\times$ announcement (2)	-0.098	-0.168
	(0.014)	(0.066)
(SSBs $>$ 8g / 100ml) $\times$ announcement (3)	-0.017	-0.107
	(0.017)	(0.056)
Number of households	8,051	6,625
t-statistics on treatment coefficients H0: effect on non-taxed SSBs = high tier tax SSBs (p-values in brackets)		
(1) = (3)	96.88	7.87
	(0.001)	(0.001)
t-statistics on treatment coefficients H0: effect on low tier tax SSBs = high tier tax SSBs (p-values in brackets)		
(2) = (3)	32.58	1.35
	(0.001)	(0.246)

Notes: Robust standard errors clustered by household and drink category in brackets.
Source: Author's own analysis of Kantar's Worldpanel Take-Home panel, Soft Drinks, 52 w/e 31 December 2016.

but also on taste preference parameters.[22]

The interplay between taste preferences, product substitutability, and the relative magnitude of health side effects can generate consumption responses consistent with those reported in Table 10.

Tax implementation

The UK government implemented the sugar levy on April 6, 2018, and this was followed by a noticeable increase in soft drink prices. Table 11 reports the changes in average prices for mineral water and soft drinks, classified by sugar content and tax tier, comparing the 12 weeks before and after implementation.

Relative to the stable price of mineral water, the average prices of all soft drink categories increased following the levy, including those not directly affected by the tax. Price increases were positively correlated with sugar content: for drinks in the upper tax tier (sugar >8g/100ml), the average price rose by 10.7 pence per litre, well below the statutory levy of 24 pence per litre. For drinks in the lower tier (5–8g/100ml), prices rose by 8.3 pence per litre, again below the 18 pence per litre levy. An incomplete pass-through is also reported in Scarborough et al. (2020).

Interestingly, prices also increased for untaxed sugar-sweetened beverages (by 7.2 pence per litre) and sugar-free soft drinks (by 6.2 pence per litre). These results suggest potential strategic pricing behaviour: producers operating across product categories may have opted to distribute the tax burden across their full portfolio. This interpretation aligns with findings from Dickson et al. (2023), who observed similar pricing patterns among major brands offering

[22] A preference for higher-sugar drinks can be incorporated into the model via a modified utility function (a variation of Equation (4)):

$$u(y, z) = -\frac{1}{2}y^2 - \frac{1}{2}z^2 + ay + bz - \gamma yz,$$

where $a, b > 0$, and $b > a$ implies that drink z is preferred over drink y.

both diet and sweetened versions of their flagship drinks.

Table 11. Price changes after implementation.

	Average prices (£/Lt)			Test on differences
	Before	After	Difference	t-statistic
Mineral water	0.555	0.548	-0.007	
	(0.004)	(0.003)	(0.005)	
No sugar	0.908	0.970	0.062	
	(0.010)	(0.010)	(0.014)	
SSBs < 5g/100ml	0.831	0.903	0.072	0.394
	(0.006)	(0.005)	(0.008)	(0.694)
SSBs 5–8g/100ml	1.958	2.041	0.083	0.053
	(0.022)	(0.027)	(0.035)	(0.958)
SSBs > 8g/100ml	1.468	1.576	0.107	2.673
	(0.007)	(0.007)	(0.010)	(0.008)

Notes: Prices are averaged by postcode and drink category over 12 weeks before and after the implementation date (April 6, 2018). Values in parentheses are standard errors. The final column reports t-statistics comparing each category's price change with the change for sugar-free soft drinks. P-values are shown in parentheses.
Source: Author's own analysis of Kantar's Worldpanel Take-Home panel, Soft Drinks, 24 w/e 29 June 2018.

To assess household responses, we apply models (18) and (19) to purchase data collected around the implementation date, retaining the same sample of heavy-purchasing households used in the announcement analysis.[23]

Table 12 presents the results. The implementation of the tax had a substantially greater effect than either of the announcements. The most pronounced impact is observed in the high tax tier: when applying the SW correction for non-purchases, the decline in purchases reaches 86 centilitres per household per week—approximately eight times the size of the reduction observed following the government announcement. This estimate is much higher than the 14 centilitres reported for the same tax tier by Rogers et al. (2023), who used the same dataset but considered all households in the panel over a longer period (2014–2019). While our analysis focuses on short-term effects, the restriction to a sub-sample of heavy purchasers suggests that the SDIL had a more substantial impact on the policy's primary target group.

Substantial reductions are also observed for the lower tax tier (approximately 27 centilitres/week), while non-taxed sugar-sweetened drinks show a smaller but positive response (14 centilitres/week). When aggregating all taxed SSBs into a single category, the net reduction in volume ranges from 12 to 25 centilitres/week, depending on whether the model accounts for selection.

In terms of sugar content, the tax implementation produces a notable effect: household purchases of added sugar from soft drinks fall by 15.6% to 18.6%, compared to just 2.6% or less for the announcement period.

These results provide clear evidence that households responded to the price change induced by the levy. The difference in behavioural responses between non-taxed and taxed drinks, and across the two tax tiers, is large and statistically significant (see bottom panel of Table 12). The salience of the price increase—relative to typical price fluctuations—may have amplified this effect. However, a structural demand model would be necessary to disentangle this salience response from pure price elasticity.

[23] The 2018 sample includes 6,855 households, fewer than the 8,052 in the earlier analysis, reflecting changes in panel composition over time.

Table 12. Estimates of implementation impact.

SDIL implementation		
Selection correction	No	Yes
	Purchased volumes (Lt/week)	
(SSBs < 5g / 100ml) × implementation (1)	0.171	0.138
	(0.025)	(0.068)
(SSBs 5-8g / 100ml) × implementation (2)	-0.188	-0.273
	(0.017)	(0.072)
(SSBs > 8g / 100ml) × implementation (3)	-0.420	-0.859
	(0.021)	(0.068)
(SSB > 5g / 100 ml (taxed)) × implementation	-0.338	-0.762
	(0.018)	(0.063)
All SSBs × implementation	-0.122	-0.248
	(0.018)	(0.059)
	Sugar content of purchased SSBs (Δ log)	
Total sugar from SSBs × implementation	-0.186	-0.156
	(0.016)	(0.016)
Number of households	6,855	5,184
	t-statistics on treatment coefficients (p-values in brackets)	
	H0: non-taxed = low tier tax	
(1) = (2)	251.11	219.64
	(0.001)	(0.001)
	H0: low tier tax = high tier tax	
(2) = (3)	231.86	78.38
	(0.001)	(0.001)

Notes: Robust standard errors clustered by household and drink category in brackets.
Source: Author's own analysis of Kantar's Worldpanel Take-Home panel, Soft Drinks, 30 w/e 29 June 2018.

7 Information vs forward-looking behaviors

Gruber and Kőszegi (2001) provide a compelling framework for examining forward-looking behavior in the consumption of addictive goods. Their study shows that announced but not yet implemented increases in cigarette taxes lead to reductions in cigarette consumption, supporting the hypothesis that smokers anticipate future price changes. In contrast, our paper examines whether the announcement of the UK sugar tax—announced in 2016 and implemented two years later—served as a signal that informed consumers about the health risks of sugar consumption. While both nicotine and sugar exhibit addictive properties, making forward-looking behavior plausible in both contexts,[24] our focus is on the informational role of the announcement rather than on intertemporal price effects for rationally addicted consumers.

Our theoretical analysis shows that belief updating in response to a tax announcement can generate behavioral patterns similar to those predicted by models of rational addiction. In practice, observed consumer responses may

[24] For evidence of habit formation in sugar-sweetened beverages, see Zhen et al. (2011).

reflect the influence of either mechanism—or a combination of both. Nonetheless, several features of our empirical setting provide a useful opportunity to explore the informational role of fiscal policy announcements, offering a perspective that complements the forward-looking interpretation advanced by Gruber and Kőszegi.

i) *Preceding information campaign.* We provide empirical evidence that consumers reacted to the information campaign launched six months prior to the tax announcement by reducing their purchases of sugar-added beverages. This suggests that consumers were previously uninformed or under-informed about the health risks of sugar in soft drinks, and likely remained at least partially uninformed even after the campaign—indicating room for further belief updating in response to the tax announcement.

ii) *Policy novelty.* The UK sugar tax was an unexpected new policy and received substantial political and media attention. Its novelty and unpredictability likely enhanced its salience. By contrast, cigarette taxes in the US had existed for decades; the marginal tax changes analyzed by Gruber and Kőszegi were less likely to convey new information to consumers.

iii) *Post-implementation response.* Our analysis of consumer behavior following tax implementation (Table 12) shows further and notable reductions in purchases of high-sugar drinks, particularly in the high-tax tier. This pattern appears consistent with a strong price effect triggered by the actual implementation of the tax. Evidence in Gruber and Kőszegi (2001) points to a smaller price effect, consistent with rational addiction theory, as consumers partially internalize the anticipated increase and adjust their behavior accordingly in advance.

Additionally, the quality of our dataset may contribute to enhancing the credibility of our empirical analysis. First, we utilize granular household-level purchase data, which enables a more precise identification of behavioral responses. Second, by distinguishing between drinks based on sugar content and tax tier, we can detect heterogeneous reactions to the announcement. Third, we explicitly control for price changes and household stockpiling behavior, helping to isolate consumption patterns.

In summary, while both forward-looking behavior and the signaling of side effects can give rise to similar empirical predictions—namely, a decline in consumption following the announcement of a price increase but prior to its implementation—our findings appear more consistent with the view that the UK sugar-tax announcement may have functioned, at least in part, as an *information mechanism.*

In this respect, additional insights can be gained by breaking down the impact of the announcement across population subgroups. Table 9 shows that households with children are slightly more responsive to both the information campaign and the tax announcement, suggesting that parents may be more attentive to health-related messages and more inclined to react to policies perceived as protecting their children's well-being.[25]

The interpretation of the response by households in which the main shopper is living with obesity is less straightforward, as we observe no detectable reaction to the government announcement. One possible explanation is that this group may exhibit a form of *irrational* addiction to sugar in soft drinks, which could dampen their responsiveness to informational cues and inhibit forward-looking behavior. These households appear to have responded to the JO information campaign, as their behaviour aligns with that of households with children. However, there is no evidence of a second Bayesian update following the government's tax announcement, possibly because the strength of their irrational addiction prevents them from further reducing their consumption of sugar-added soft drinks.

[25]Recall that Jamie Oliver launched his information campaign against sugar-sweetened beverages with the explicit goal of "improving children's health."

8 Conclusion

This study investigates the signaling function of sugar taxes compared to information campaigns in raising awareness about the health risks of sugar consumption and triggering behavioral change. We focus on the UK Soft Drinks Industry Levy (SDIL), examining consumer responses to its *announcement* in March 2016.

While an information campaign can be interpreted as a cheap talk signal—transmitting partial information—our theoretical model shows that a tax policy serves as a costly signal that can credibly convey more precise information. In this framework, the tax announcement induces a fully revealing equilibrium: consumers update their beliefs about the side effects of sugar and adjust their consumption accordingly.

Empirically, using household-level panel data from Great Britain, we find that consumers responded to Jamie Oliver's information campaign in August 2015 by reducing their purchases of sugar-sweetened beverages (SSBs), suggesting that they were initially unaware of the health implications of sugar contained in soft drinks. Several months later, the announcement of the two-tiered tax policy prompted a further reduction in sugar purchases, consistent with the theoretical mechanism of a second belief updating.

Importantly, consumer responses differed between the two interventions. Jamie Oliver's campaign led to a broad-based reduction in soft drink consumption, whereas the government's tax announcement prompted more targeted changes—primarily affecting purchases of beverages explicitly identified as subject to the forthcoming tax.

In addition to the subsequent belief updating triggered by the two policies, this asymmetry in consumer behavior can be explained by rational inattention: prior to the tax announcement, consumers may have chosen not to process nutritional labels—a pattern that may help explain the broad-based reduction observed following the campaign. In contrast, the tax announcement made sugar content more salient. The announcement of the two-tiered levy created a concrete incentive to process nutritional information and distinguish between drinks that would be taxed and those that would not, prompting the second belief updating and more deliberate product choices.

Our study highlights how tax policy, even prior to implementation, can function as an effective informational tool. Our identification strategy necessarily relies on relatively short time windows (12 weeks before and after announcements), with gaps between the two announcements and between the government announcement and the tax implementation. This limits our ability to assess the persistence or dissipation of the signaling effects over longer periods.

Overall, our findings underscore the dual role of fiscal interventions in public health: beyond creating price incentives, taxes on harmful goods can act as credible signals, enhancing consumer awareness and facilitating healthier choices—even in populations prone to addiction or inattentiveness. These results suggest that the design and communication of fiscal policies should consider not only price elasticities but also the potential for signaling and informational spillovers.

Future research could explore the longer-term dynamics of these informational effects, how they interact with product reformulation and broader shifts in consumer awareness, and whether they result in spillover effects on other sugary foods or unintended substitution towards untaxed products.

References

Adams, J., Pell, D., Penney, T. L., Hammond, D., Vanderlee, L., and White, M. (2021). Public acceptability of the UK Soft Drinks Industry Levy: Repeat cross-sectional analysis of the International Food Policy Study (2017–2019). *BMJ Open*, 11(9).

Ahn, S. and Lusk, J. L. (2021). Non-pecuniary effects of sugar-sweetened beverage policies. *American Journal of Agricultural Economics*, 103(1):53–69.

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

Barahona, N., Otero, C., and Otero, S. (2023). Equilibrium effects of food labeling policies. *Econometrica*, 91(3):839–868.

Barigozzi, F. and Villeneuve, B. (2006). The signaling effect of tax policy. *Journal of Public Economic Theory*, 8(4):611–630.

Bridge, G., Flint, S. W., and Tench, R. (2020). An exploration of the portrayal of the UK Soft Drinks Industry Levy in UK national newspapers. *Public Health Nutrition*, 23(17):3241–3249.

Briggs, A. D., Mytton, O. T., Kehlbacher, A., Tiffin, R., Rayner, M., and Scarborough, P. (2013). Overall and income specific effect on prevalence of overweight and obesity of 20% sugar sweetened drink tax in UK: Econometric and comparative risk assessment modelling study. *British Medical Journal*, 347.

Buckton, C. H., Fergie, G., Leifeld, P., and Hilton, S. (2019a). A discourse network analysis of UK newspaper coverage of the "sugar tax" debate before and after the announcement of the Soft Drinks Industry Levy. *BMC Public Health*, 19(1):490.

Buckton, C. H., Fergie, G., Leifeld, P., and Hilton, S. (2019b). A discourse network analysis of UK newspaper coverage of the "sugar tax" debate before and after the announcement of the Soft Drinks Industry Levy. *BMC Public Health*, 19:1–14.

Capacci, S., Allais, O., Bonnet, C., and Mazzocchi, M. (2019). The impact of the French soda tax on prices and purchases: An ex post evaluation. *PLOS ONE*, 14(10):e0223196.

Cawley, J., Thow, A. M., Wen, K., and Frisvold, D. (2019). The economics of taxes on sugar-sweetened beverages: A review of the effects on prices, sales, cross-border shopping, and consumption. *Annual review of nutrition*, 39(1):317–338.

Cornelsen, L., Quaife, M., Lagarde, M., and Smith, R. D. (2020). Framing and signaling effects of taxes on sugary drinks: A discrete choice experiment among households in great britain. *Health Economics*, 29(10):1132–1147.

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

Crawford, V. P. and Sobel, J. (1982). Strategic information transmission. *Econometrica*, 50(6):1431–1451.

Debnam, J. (2017). Selection effects and heterogeneous demand responses to the Berkeley soda tax vote. *American Journal of Agricultural Economics*, 99(5):1172–1187.

Dickson, A., Gehrsitz, M., and Kemp, J. (2023). Does a spoonful of sugar levy help the calories go down? An analysis of the UK Soft Drinks Industry Levy. *The Review of Economics and Statistics*, 105(3):651–666.

Dubois, P., Griffith, R., and O'Connell, M. (2020). How well targeted are soda taxes? *American Economic Review*, 110(11):3661–3704.

Gruber, J. and Kőszegi, B. (2001). Is addiction "rational"? Theory and evidence. *The Quarterly Journal of Economics*, 116(4):1261–1303.

Just, D. R. and Hanks, A. S. (2015). The hidden cost of regulation: Emotional responses to command and control. *American Journal of Agricultural Economics*, 97(5):1385–1399.

Kiesel, K. and Villas-Boas, S. B. (2013). Can information costs affect consumer choice? Nutritional labels in a supermarket experiment. *International Journal of Industrial Organization*, 31(2):153–163.

Laffont, J.-J. and Tirole, J. (1993). *A theory of incentives in procurement and regulation*. MIT press.

Law, C., Cornelsen, L., Adams, J., Penney, T., Rutter, H., White, M., and Smith, R. (2020). An analysis of the stock market reaction to the announcements of the UK Soft Drinks Industry Levy. *Economics & Human Biology*, 38:100834.

Mailath, G. J. (1987). Incentive compatibility in signaling games with a continuum of types. *Econometrica*, 55(6):1349–1365.

Maćkowiak, B., Matějka, F., and Wiederholt, M. (2023). Rational inattention: A review. *Journal of Economic Literature*, 61(1):226–273.

Pell, D., Penney, T., Hammond, D., Vanderlee, L., White, M., and Adams, J. (2019). Support for, and perceived effectiveness of, the UK Soft Drinks Industry Levy among UK adults: Cross-sectional analysis of the International Food Policy Study. *BMJ Open*, 9(3).

Penney, T. L., Jones, C. P., Pell, D., Cummins, S., Adams, J., Forde, H., Mytton, O., Rutter, H., Smith, R., and White, M. (2023). Reactions of industry and associated organisations to the announcement of the UK Soft Drinks Industry Levy: Longitudinal thematic analysis of UK media articles, 2016-18. *BMC public health*, 23(1):280.

Rambachan, A. and Roth, J. (2023). A more credible approach to parallel trends. *The Review of Economic Studies*, 90(5):2555–2591.

Rees-Jones, A. and Rozema, K. (2023). Price isn't everything: Behavioral response around changes in sin taxes. *National Tax Journal*, 76(1):5–35.

Rogers, N. T., Pell, D., Mytton, O. T., Penney, T. L., Briggs, A., Cummins, S., Jones, C., Rayner, M., Rutter, H., Scarborough, P., Sharp, S., Smith, R., White, M., and Adams, J. (2023). Changes in soft drinks purchased by British households associated with the UK Soft Drinks Industry Levy: A controlled interrupted time series analysis. *BMJ Open*, 13(12).

Scarborough, P., Adhikari, V., Harrington, R. A., Elhussein, A., Briggs, A., Rayner, M., Adams, J., Cummins, S., Penney, T., and White, M. (2020). Impact of the announcement and implementation of the UK Soft Drinks Industry Levy on sugar content, price, product size and number of available soft drinks in the UK, 2015-19: A controlled interrupted time series analysis. *PLoS medicine*, 17(2):e1003025.

Semykina, A. and Wooldridge, J. M. (2010). Estimating panel data models in the presence of endogeneity and selection. *Journal of Econometrics*, 157(2):375–380.

Taylor, R. L., Kaplan, S., Villas-Boas, S. B., and Jung, K. (2019). Soda Wars: The effect of a soda tax election on university beverage sales. *Economic Inquiry*, 57(3):1480–1496.

Wooldridge, J. M. (1995). Selection corrections for panel data models under conditional mean independence assumptions. *Journal of Econometrics*, 68(1):115–132.

Zhen, C., Wohlgenant, M. K., Karns, S., and Kaufman, P. (2011). Habit formation and demand for sugar-sweetened beverages. *American Journal of Agricultural Economics*, 93(1):175–193.

9 Appendix

9.1 Proof of Example 3

Recall the sender's objective function (7):

$$V^{S1}(\hat{\theta}_m;\theta) = u(y_1(\hat{\theta}_m), z_1(\hat{\theta}_m)) - (\theta+\eta)\left(\alpha y_1(\hat{\theta}_m) + \beta z_1(\hat{\theta}_m)\right);$$

by choosing a message m, a sender of type θ selects a belief $\hat{\theta}_m$. The belief affects the consumer's choice in periods t_1, y_1 and z_1.

A Perfect Bayesian Equilibrium is a message m with associated belief $\hat{\theta}_m$, and a consumption rule ($y_1(\hat{\theta}_m)$, $z_1(\hat{\theta}_m)$) such that: (i) $\hat{\theta}_m$ maximizes $V^{S1}(\hat{\theta}_m;\theta)$; (ii) belief $\hat{\theta}_m = E_{f|m}[\theta]$ is updated using Bayes' rule; (iii) consumption ($y_1(\hat{\theta}_m)$, $z_1(\hat{\theta}_m)$) is optimal given $\hat{\theta}_m$, i.e., it solves consumer program 6. Beliefs for off-equilibrium actions are not restricted by Bayes rule.

Let us assume that θ is uniformly distributed in $\Theta \equiv [0,1]$ and that $m \in M \equiv \Theta$. In equilibrium, when θ belongs to the first partition, $S1$'s optimal strategy must be message $m_1^* \in [0,\tilde{\theta}]$. When instead θ belongs to the second partition, $S1$'s optimal strategy must be message $m_2^* \in [\tilde{\theta},1]$. Consumer observes the message and uses Bayes rule to correctly infer which partition θ belongs to. Then, consumer solves:

$$\max_{y_1,z_1} u(y_1,z_1) - \hat{\theta}_{m_k}(\alpha y_1 + \beta z_1);\ k=1,2.$$

As a result, y_1 and z_1 are:

$$y_1^*(\hat{\theta}_{m_k^*}) = \frac{1-\gamma-\hat{\theta}_{m_k^*}(\alpha-\beta\gamma)}{1-\gamma^2}; \tag{23}$$

$$z_1^*(\hat{\theta}_{m_k^*}) = \frac{1-\gamma-\hat{\theta}_{m_k^*}(\beta-\alpha\gamma)}{1-\gamma^2};\ k=1,2, \tag{24}$$

where the expected value of θ is:

$$\hat{\theta}_{m_1^*} = \frac{\int_0^{\tilde{\theta}} \theta f_\theta d\theta}{\int_0^{\tilde{\theta}} f_\theta d\theta} = \frac{1}{2}\tilde{\theta} \tag{25}$$

$$\hat{\theta}_{m_2^*} = \frac{\int_{\tilde{\theta}}^1 \theta f_\theta d\theta}{\int_{\tilde{\theta}}^1 f_\theta d\theta} = \frac{1}{2}(1+\tilde{\theta}). \tag{26}$$

When $\theta = \tilde{\theta}$, the sender must be indifferent between the two messages m_1^* and m_2^*. Thus, the following equation must hold:

$$V^{S1}(\hat{\theta}_{m_1^*};\tilde{\theta}) = V^{S1}(\hat{\theta}_{m_2^*};\tilde{\theta});$$

which writes:

$$u(y_1^*(\hat{\theta}_{m_1^*}), z_1^*(\hat{\theta}_{m_1^*})) - \left(\tilde{\theta} + \eta\right)(\alpha y_1^*(\hat{\theta}_{m_1^*}) + \beta z_1^*(\hat{\theta}_{m_1^*})) = u(y_1^*(\hat{\theta}_{m_2^*}), z_1^*(\hat{\theta}_{m_2^*})) - \left(\tilde{\theta} + \eta\right)(\alpha y_1^*(\hat{\theta}_{m_2^*}) + \beta z_1^*(\hat{\theta}_{m_2^*})).$$

Substituting the expressions for $y_1^*(\hat{\theta}_{m_k^*})$ and $z_1^*(\hat{\theta}_{m_k^*})$, $k = 1, 2$, and solving for $\tilde{\theta}$, one obtains:

$$\tilde{\theta} = \frac{1}{2} - 2\eta.$$

Note that the partition equilibrium is feasible iff $\tilde{\theta} > 0$ or $\eta < \frac{1}{4}$.

Plugging $\tilde{\theta}$ into updated beliefs (25) and (26):

$$E_{f|m_1^*}[\theta] = \frac{1}{4} - \eta;$$
$$E_{f|m_2^*}[\theta] = \frac{3}{4} - \eta.$$

Consumer's choices are:

$$y_1^*(\hat{\theta}_{m_1^*}) = \frac{4(1-\gamma) - (1-4\eta)(\alpha - \beta\gamma)}{4(1-\gamma^2)}; \tag{27}$$
$$z_1^*(\hat{\theta}_{m_1^*}) = \frac{4(1-\gamma) - (1-4\eta)(\beta - \alpha\gamma)}{4(1-\gamma^2)}; \tag{28}$$

and

$$y_1^*(\hat{\theta}_{m_2^*}) = \frac{4(1-\gamma) - (3-4\eta)(\alpha - \beta\gamma)}{4(1-\gamma^2)}; \tag{29}$$
$$z_1^*(\hat{\theta}_{m_2^*}) = \frac{4(1-\gamma) - (3-4\eta)(\beta - \alpha\gamma)}{4(1-\gamma^2)}. \tag{30}$$

Therefore, since $\beta - \alpha\gamma > \alpha - \beta\gamma$, $y_1^*(\hat{\theta}_{m_k^*}) > z_1^*(\hat{\theta}_{m_k^*})$, $k = 1, 2$, holds.

We already showed above that the receiver uses Bayes' rule to update beliefs and then chooses her best reply to the sender's message. One can check that, when $\theta \in [0, \frac{1}{2} - 2\eta]$, the sender prefers consumption levels $y_1^*(\hat{\theta}_{m_1^*})$ and $z_1^*(\hat{\theta}_{m_1^*})$ to $y_1^*(\hat{\theta}_{m_2^*})$ and $z_1^*(\hat{\theta}_{m_2^*})$; whereas, when $\theta \in [\frac{1}{2} - 2\eta, 1]$, the opposite holds. This means that the sender's strategy is the best reply to the receiver's consumption choice. The intuition is that optimal consumption from the sender's perspective is systematically lower than optimal consumption from the consumer's point of view, or $\frac{\partial}{\partial\theta} V^{S1}\left(y_1^*(\hat{\theta}_{m_k^*}), z_1^*(\hat{\theta}_{m_k^*}); \eta, \theta\right) > 0 \ \forall k = 1, 2$.

Example 3 *Assume that θ is uniformly distributed in $[0, 1]$ and that $M \equiv \Theta = [0, 1]$. An equilibrium with two messages, m_i^*, $i = 1, 2$, exists if $\eta < \frac{1}{4}$ and is characterized as follows. For $\theta \in [0, \frac{1}{2} - 2\eta)$, $S1$ sends message $m_1^* \in [0, \frac{1}{2} - 2\eta)$, the representative consumer infers that $E_{f|m_1^*}[\theta] = \frac{1}{4} - \eta$ and chooses consumption levels $y_1^*(\hat{\theta}_{m_1^*})$ and $z_1^*(\hat{\theta}_{m_1^*})$ in (27) and (28). For $\theta \in [\frac{1}{2} - 2\eta, 1]$, $S1$ sends message $m_2^* \in [\frac{1}{2} - 2\eta, 1]$, consumer infers that $E_{f|m_2^*}[\theta] = \frac{3}{4} - \eta$ and chooses consumption levels $y_1^*(\hat{\theta}_{m_2^*})$ and $z_1^*(\hat{\theta}_{m_2^*})$ in (29) and (30).*

This equilibrium is sustained by the following out-of-equilibrium beliefs: if the consumer observes a deviation message $m^d \in [0, \frac{1}{2} - 2\eta)$ with $m^d \neq m_1^*$, she infers that $E_{f|m^d}[\theta] = \frac{1}{4} - \eta$; if she observes a deviation message $m^d \in [\frac{1}{2} - 2\eta, 1]$ with $m \neq m_2^*$, she infers that $E_{f|m^d}[\theta] = \frac{3}{4} - \eta$.

Note that the out-of-equilibrium beliefs chosen in the above Proposition assure that the sender is indifferent between playing the equilibrium strategy or deviating from it.

Since $\alpha < \beta$ and $0 < \gamma < 1$, the inequality $\beta - \alpha\gamma > 0$ always holds, but $\alpha - \beta\gamma \lesseqgtr 0$. Hence, z_1^* is always decreasing in θ. Conversely, a large γ implies $\alpha - \beta\gamma < 0$ and, as a result, y_1^* is increasing in θ for $\alpha - \beta\gamma < 0$ (see expressions in (23)). Therefore, if the expected value of θ increases after Bayes updating ($E_{f|m}[\theta] > E_f[\theta]$), $z_0^* > z_1^*$ always holds, while it can be $y_0^* \lesseqgtr y_1^*$ according to the value of γ. This last observation explains Remark 2 in the main text.

9.2 Proof of Lemma 1

Consumption levels in period 2 are obtained from the objective function (11) when the consumer observes θ:

$$\begin{aligned} y_2^{SB} &= \frac{1-\gamma-\theta(\alpha-\beta\gamma)}{1-\gamma^2}; \\ z_2^{SB} &= \frac{1-\gamma-\theta(\beta-\alpha\gamma)}{1-\gamma^2}; \end{aligned} \tag{31}$$

where the superscript SB indicates the second-best consumption level obtained when consumers are informed on θ.

Similarly, consumption levels in period 3 are obtained from objective function (12) when the consumer observes θ:

$$\begin{aligned} y_3^{SB} &= \frac{1-\gamma(1-\tau)-\theta(\alpha-\beta\gamma)}{1-\gamma^2}; \\ z_3^{SB} &= \frac{1-\gamma-\theta(\beta-\alpha\gamma)-\tau}{1-\gamma^2}. \end{aligned} \tag{32}$$

Since $\alpha < \beta$ and $0 < \gamma < 1$, the inequality $\beta - \alpha\gamma > 0$ always holds, but the sign of $\alpha - \beta\gamma$ is ambiguous. Hence, z_t^{SB}, $t = 2, 3$, is always decreasing in θ. Conversely, a large γ implies that $\alpha - \beta\gamma < 0$ and, as a result, y_t^{SB}, $t = 2, 3$, becomes increasing in θ for $\alpha - \beta\gamma < 0$.

Substituting the four consumption levels in government payoff (9) and maximizing with respect to τ, one obtains the $\tau^{SB}(\theta)$ in Lemma 1.
Tax elasticity writes $\frac{-\tau}{1-\gamma-\theta(\beta-\alpha\gamma)-\tau}$ and is decreasing in θ.

9.3 Proof of Lemma 2

Let us substitute consumption levels (31) and (32) into the government's objective function (14). One can check that:

$$\frac{\partial}{\partial\theta}\left(\frac{\partial V^{S2}(\theta,\hat{\theta}_\tau,\tau)}{\partial\tau}\Big/\frac{\partial V^{S2}(\theta,\hat{\theta}_\tau,\tau)}{\partial\hat{\theta}_\tau}\right) = \frac{\delta\left[\left(\alpha^2+\beta^2-2\alpha\beta\gamma\right)(1+\delta)\left((\beta-\alpha\gamma)\lambda\hat{\theta}_\tau+\tau(1+2\lambda)-\lambda(1-\gamma)\right)-(\beta-\alpha\gamma)^2\delta(1+\lambda)\tau\right]}{\left[(\alpha^2+\beta^2-2\alpha\beta\gamma)(1+\delta)(\eta+\theta-\hat{\theta}_\tau)-(\beta-\alpha\gamma)\delta(1+\lambda)\tau\right]^2}$$

where the denominator is always positive and the numerator does not depend on θ. Hence, the sign of the derivative is constant, meaning that the single-crossing property is satisfied.

9.4 Proof of Remark 3

We first show that $\tau^{SB}(\theta)$ is not an equilibrium. To do so, we plug consumption levels (31), (32), and the expression for the second-best tax (13) into (14). Then we maximize government's payoff $V^{S2}(\theta,\hat{\theta}_\tau,\tau^{SB})$ w.r.t. to $\hat{\theta}_\tau$. Let us define $\hat{\theta}^o = \arg\max_{\hat{\theta}_\tau} V^{S2}(\theta,\hat{\theta}_\tau,\tau^{SB})$.

One can verify that $\hat{\theta}^o$ differs from the true value of side effects, i.e., $\hat{\theta}^o \neq \theta$. In words, when the government applies the second-best tax, it has an incentive to misreport the magnitude of sugar-related side effects. Only in the special case where $\eta = \lambda = 0$, the equality $\hat{\theta}^o = \theta$ holds.

We now return to the general function $V^{S2}(\theta,\hat{\theta}_\tau,\tau)$—i.e., the government payoff when the tax rate is not constrained. One can verify that the government's optimal belief is given by:

$$\hat{\theta}^o_\tau = \theta - \frac{(\beta-\alpha\gamma)\,\delta\,(1+\lambda)\,\tau_z}{(\alpha^2+\beta^2-2\alpha\beta\gamma)\,(1+\delta)} + \eta,$$

where the fraction takes a positive value.

Consistency with the analysis of the information campaign requires that η be small. Therefore, the expression above suggests that when the externality is sufficiently limited, the government has an incentive to under-report the side effects and convey an overly optimistic message to consumers. Specifically:

$$\eta < \frac{(\beta-\alpha\gamma)\,\delta\,(1+\lambda)\,\tau_z}{(\alpha^2+\beta^2-2\alpha\beta\gamma)\,(1+\delta)} \quad \Leftrightarrow \quad \hat{\theta}^o_\tau < \theta. \tag{33}$$

The previous condition clearly holds even when $\tau_z = \tau^{SB}$.

9.5 Proof of Proposition 1

The proof follows Mailath (1987) and Barigozzi and Villeneuve (2006). We report here the sender's payoff (14):

$$\begin{aligned} V^{S2}\left(\theta,\hat{\theta}_\tau,\tau(\hat{\theta}_\tau)\right) &= u(y_2(\hat{\theta}_\tau),z_2(\hat{\theta}_\tau)) - (\theta+\eta)\left(\alpha y_2(\hat{\theta}_\tau)+\beta z_2(\hat{\theta}_\tau)\right) + \\ \delta\Big[u(y_3(\hat{\theta}_\tau,\tau(\hat{\theta}_\tau)),z_3(\hat{\theta}_\tau,\tau(\hat{\theta}_\tau))) &- (\theta+\eta)\left(\alpha y_3(\hat{\theta}_\tau,\tau(\hat{\theta}_\tau))+\beta z_3(\hat{\theta}_\tau,\tau(\hat{\theta}_\tau))\right) + \lambda\tau z_3(\hat{\theta}_\tau,\tau(\hat{\theta}_\tau))\Big], \end{aligned} \tag{34}$$

where the expected value of side effects after the tax announcement represents the consumer's belief: $\hat{\theta}_\tau = E_{f|m,\tau}[\theta]$.

Hence, we can define a Perfect Bayesian Equilibrium as a tax with associate beliefs $(\hat{\theta}_\tau,\tau(\hat{\theta}_\tau))$, and a consumption rule $(y_2(\hat{\theta}_\tau),\ z_2(\hat{\theta}_\tau),\ y_3(\hat{\theta}_\tau,\tau(\hat{\theta}_\tau)),\ z_3(\hat{\theta}_\tau,\tau(\hat{\theta}_\tau)))$ such that: (i) $(\hat{\theta}_\tau,\tau(\hat{\theta}_\tau))$ maximizes $V^{S2}\left(\theta,\hat{\theta}_\tau,\tau(\hat{\theta}_\tau)\right)$; (ii) belief $\hat{\theta}_\tau = E_{f|m,\tau}[\theta]$ is updated using Bayes' rule; (iii) consumption $(y_2(\hat{\theta}_\tau),\ z_2(\hat{\theta}_\tau),\ y_3(\hat{\theta}_\tau,\tau(\hat{\theta}_\tau)),\ z_3(\hat{\theta}_\tau,\tau(\hat{\theta}_\tau)))$ is optimal given $(\hat{\theta}_\tau,\tau(\hat{\theta}_\tau))$. Beliefs for off-equilibrium actions are not restricted by Bayes rule.

Note that

$$\frac{\partial^2 V^{S2}\left(\theta,\hat{\theta}_\tau,\tau(\hat{\theta}_\tau)\right)}{\partial\tau^2} = -\frac{\delta(1+2\lambda)}{1-\gamma^2} < 0$$

and

$$\frac{\partial^2 V^{S2}\left(\theta,\hat{\theta}_\tau,\tau(\hat{\theta}_\tau)\right)}{\partial\theta\,\partial\tau} = \frac{(\beta-\alpha\gamma)\,\delta\lambda}{1-\gamma^2} > 0$$

In words, the government's payoff is concave in the tax τ, and the cross-partial derivative with respect to the type and the tax is positive (monotonicity condition). The latter sign implies the fully revealing tax is strictly increasing in θ.

From Theorem 1 in Mailath (1987), the fully revealing tax policy satisfies:

$$\frac{d\tau}{d\theta} = -\frac{\frac{\partial}{\partial\theta}V^{S2}\left(\theta,\theta,\tau(\theta)\right)}{\frac{\partial}{\partial\tau}V^{S2}\left(\theta,\theta,\tau(\theta)\right)}. \tag{35}$$

As an intuition for the result in (35), note that the senders' payoff can be rewritten as $V^{S2}\left(\hat{\theta}_\tau, \tau(\hat{\theta}_\tau); \theta\right)$, making it explicit that the "true" side effect θ enters as a parameter in the sender's objective. Hence, the optimal belief, $\hat{\theta}_\tau$, solves:

$$\frac{d}{d\hat{\theta}_\tau}V^{S2}\left(\hat{\theta}_\tau, \tau(\hat{\theta}_\tau); \theta\right) = 0;$$

which can be rewritten as:

$$\frac{\partial}{\partial\hat{\theta}_\tau}V^{S2}\left(\hat{\theta}_\tau, \tau(\hat{\theta}_\tau); \theta\right) + \frac{\partial}{\partial\tau}V^{S2}\left(\hat{\theta}_\tau, \tau(\hat{\theta}_\tau); \theta\right)\frac{d\tau}{d\hat{\theta}_\tau} = 0, \tag{36}$$

where the first term indicates the direct effect of the consumer's beliefs on the sender's payoff and the second term indicates the mediated effect via the tax. From (36):

$$\frac{d\tau}{d\hat{\theta}_\tau} = -\frac{\frac{\partial}{\partial\hat{\theta}_\tau}V^{S2}\left(\hat{\theta}_\tau, \tau(\hat{\theta}_\tau); \theta\right)}{\frac{\partial}{\partial\tau}V^{S2}\left(\hat{\theta}_\tau, \tau(\hat{\theta}_\tau); \theta\right)}.$$

In a fully revealing equilibrium, $\hat{\theta}_\tau = \theta$ must hold. Hence, the fully revealing tax solves:

$$\frac{d\tau}{d\theta} = -\left.\frac{\frac{\partial}{\partial\hat{\theta}_\tau}V^{S2}\left(\hat{\theta}_\tau, \tau(\hat{\theta}_\tau); \theta\right)}{\frac{\partial}{\partial\tau}V^{S2}\left(\hat{\theta}_\tau, \tau(\hat{\theta}_\tau); \theta\right)}\right|_{\hat{\theta}_\tau=\theta};$$

which corresponds to the differential equation(35).

From Theorem 3 in Mailath (1987), we also know that $\frac{\partial V^{S2}(\theta,\hat{\theta}_\tau,\tau)}{\partial\hat{\theta}_\tau}$ can have either positive or negative sign (belief monotonicity) and that its sign affects the initial value of the signaling mechanism. Given the monotonicity condition illustrated above and condition (33) in Section 9.4, we study the following case:

$$\frac{\partial V^{S2}(\theta,\hat{\theta}_\tau,\tau)}{\partial\hat{\theta}_\tau} < 0 \Leftrightarrow \tau^{SB}(\bar{\theta}) = \tau^*(\bar{\theta}),$$

implying a negative sign for the single-crossing condition and *no distortion at the top*—that is, a situation in which the only type with no incentive to misreport its θ is the highest type, $\theta = \bar{\theta}$.

Plugging the quadratic function (4) into $V^{S2}\left(\theta, \hat{\theta}_\tau, \tau(\hat{\theta}_\tau)\right)$ and rearranging (35), we obtain:

$$\frac{d\tau^*(\theta)}{d\theta} = \frac{(1+\lambda)(\beta-\alpha\gamma)\tau^*(\theta) - \frac{1+\delta}{\delta}\left(\alpha^2+\beta^2-2\alpha\beta\gamma\right)\eta}{(1+2\lambda)\left(\frac{1}{1+2\lambda}\left[\lambda(1-\gamma)+(\beta-\alpha\gamma)(\eta-\lambda\theta)\right]-\tau^*(\theta)\right)}, \tag{37}$$

where $\frac{1}{1+2\lambda}\left[\lambda(1-\gamma)+(\beta-\alpha\gamma)(\eta-\lambda\theta)\right]$ is the second-best tax.

Condition 33 implies that the numerator is positive. The equilibrium tax is therefore monotonically increasing provided that the denominator of equation 37 is also positive. This, in turn, requires that the equilibrium tax remain below τ^{SB}.

As an example, in the main text we report the solution to the differential equation (37) when $\eta = 0$. A larger η leads the government to set a higher base tax but to respond more gradually to increases in θ, making the tax schedule less steep overall.

The following out-of-equilibrium beliefs sustain this equilibrium: if the consumer observes a deviation tax $\tau^d > \tau^{SB}\left(\bar{\theta}\right)$, she infers that the sender's type is $\bar{\theta}$. If she observes a deviation message $\tau^d < \tau^{SB}\left(\underline{\theta}\right)$, she infers that the sender's type is $\underline{\theta}$. Intuitively, those beliefs make deviations from the equilibrium not attractive because they represent major departures from the sender's preferred tax-belief pairs, i.e. the second-best tax with a belief slightly lower than the true type θ (see condition 33).

For more technical details on the fully revealing tax, the reader is referred to Barigozzi and Villeneuve (2006), who solve a version of the model with a single good and a single period (where the tax is implemented immediately). Although the two frameworks differ in several respects, they share similar economic mechanisms: when the externality is small, the signaling taxes display comparable shapes and structural properties across both models.

Considering consumption choices, expressions (31) and (32) hold in equilibrium since the tax is fully revealing.

Specifically, in period t_2, if the expected value of θ increases after Bayesian updating—i.e., $\theta = E_{f|m,\tau}[\theta] > E_{f|m}[\theta]$—then $z_1^* > z_2^*$ always holds. By contrast, the ranking between y_1^* and y_2^* may go in either direction, depending on the value of γ.

In period t_3, the price effect of the tax materializes. The tax exerts an additional negative impact on z_3^*, resulting in the ordering $z_1^* > z_2^* > z_3^*$. However, due to the substitutability between the two drinks, the tax has a positive effect on y_3^* (see expression (32)).

9.6 Information campaign with inattentive consumer

Suppose that reading the soft drinks' label entails a small cost for the consumer. Hence, after the information campaign, she does not learn y and z's sugar content and continues to perceive the two drinks as equivalent: $\hat{\alpha} = \hat{\beta}$. Then, the consumer chooses y and z by solving:

$$\max_{y_1, z_1} u(y_1, z_1) - \hat{\theta}_{m_k^{**}} \hat{\alpha}(y_1 + z_1); \;\; k = 1, 2,$$

where m_k^{**} is the equilibrium message when consumer is inattentive.

If $\hat{\alpha} = \frac{\alpha+\beta}{2}$, then the incentive to misreport θ is the same as without inattention (see 9.1). In general, If the consumer is inattentive, the best message from $S1$ perspective is $m = \frac{\alpha+\beta}{2}\frac{\theta+\eta}{\hat{\alpha}}$. Hence, the sender has incentive to over-report θ if $\hat{\alpha} \leq \frac{\alpha+\beta}{2}\frac{\eta+\theta}{\theta}$.

To obtain a two-partition equilibrium, the proof is the same as in 9.1. We directly reports results below.

The new threshold defining the two-partition equilibrium is

$$\tilde{\theta}' = \frac{2(\alpha+\beta)\eta - \hat{\alpha}}{2(\hat{\alpha} - \alpha - \beta)}.$$

Note that the partition equilibrium is feasible iff $\tilde{\theta}' > 0$ or $\eta < \frac{\hat{\alpha}}{2(\alpha+\beta)}$.

Substituting the expression for $\tilde{\theta}'$ in updated beliefs, we observe that:

$$E_{f|m_1^{**}}[\theta] = \frac{2(\alpha+\beta)\eta - \hat{\alpha}}{4(\hat{\alpha}-\alpha-\beta)};$$
$$E_{f|m_2^{**}}[\theta] = \frac{\hat{\alpha} - 2(\alpha+\beta)(1-\eta)}{4(\hat{\alpha}-\alpha-\beta)}.$$

Consumer's choices are:

$$y_1^{**}(\hat{\theta}_{m_1^{**}}) = z_1^{**}(\hat{\theta}_{m_1^{**}}) = \frac{\hat{\alpha}(\hat{\alpha}+4) + 2(\alpha+\beta)(2-\hat{\alpha}\eta)}{4(\hat{\alpha}-\alpha-\beta)(1+\gamma)};$$

and

$$y_1^{**}(\hat{\theta}_{m_2^{**}}) = z_1^{**}(\hat{\theta}_{m_2^{**}}) = \frac{\hat{\alpha}(4-\hat{\alpha}) - (2-\hat{\alpha}+\hat{\alpha}\eta)2(\alpha+\beta)}{4(\hat{\alpha}-\alpha-\beta)(1+\gamma)};$$

where y_1^{**} and z_1^{**} are the equilibrium consumption choices when consumer is inattentive.
Under the quadratic utility function (4), y and z generate the same utility. In addition, their price has been assumed to be equal and set to zero. Hence, when sugar content is perceived to be the same ($\hat{\alpha} = \hat{\beta}$), the consumer chooses the same amount of both drinks and $y_1^*(\hat{\theta}_{m_k^{**}}) = z_1^*(\hat{\theta}_{m_k^{**}})$, $k = 1, 2$. Therefore, one observes that, if the expected value of θ increases after Bayes updating ($E_{f|m^{**}}[\theta] > E_f[\theta]$), $y_0^* = z_0^* > y_1^* = z_1^*$ always holds, irrespective of the value of γ. In addition, the change in consumption levels generated by the information campaign is the same for the two drinks.

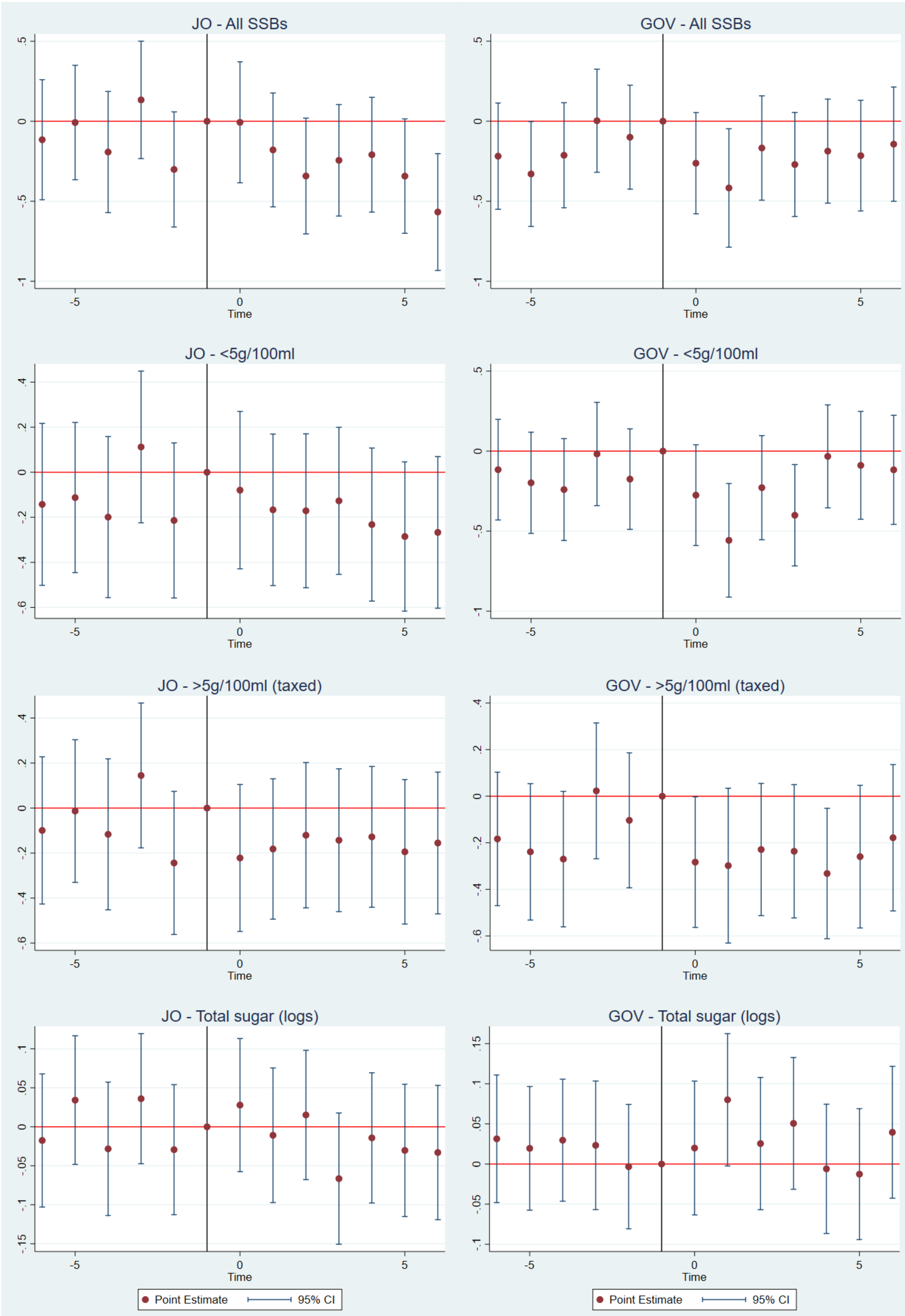

Figure 2: Event study estimates of treatment effects (baseline: week before announcement)

Alma Mater Studiorum - Università di Bologna

DEPARTMENT OF ECONOMICS

Strada Maggiore 45
40125 Bologna - Italy
Tel. +39 051 2092604
Fax +39 051 2092664
http://www.dse.unibo.it