Investigating the efficacy of consumer interventions on sales of zero-calorie beverages

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Introduction

Strong evidence has linked habitual intake of sugar-sweetened beverages (SSBs) with weight gain and a higher risk of type 2 diabetes mellitus, cardiovascular diseases, and even cancer [2]. Multiple policy interventions to inhibit consumption of SSBs have been proposed [1], including taxation of SSBs, limiting access to SSBs in schools and healthcare facilities, and adding informative package labelling. As policymakers create potential interventions to limit SSB consumption, there is a need for data-driven methods of determining their efficacy.

This study aims to evaluate two groups of interventions which intend to shift consumers towards purchasing zero-calorie beverages instead of SSBs. Five separate interventions implemented at three hospitals are assessed. Three of these interventions utilize calorie-related messaging and the other two use price discounts to incentivize purchasing zero-calorie beverages.

The primary statistical question is whether these interventions are associated with differences in the average daily proportion of zero-calorie and sweetened beverage sales. Additional questions of interest include whether these interventions are equally effective at each hospital, and whether the effect of multiple simultaneous interventions is greater than the "sum of its parts".

Data Description and Summaries

The data come from an interrupted time-series multi-site quasi-experimental study on sales of sweetened and zero-calorie beverages at three United States hospitals over a 30-week period. The data consists of 631 observations aggregated across the three sites. Each observation represents the daily sales of bottled beverages among multiple storefronts per site. Sales are automatically recorded by point of sale terminals in one site, and manually by store employees at remaining sites. Beverage sales are recorded every day from the beginning of the experiment until the final day, including weekends and holidays.

The data includes the following variables: the day of the experiment, the corresponding weekday, the site, and the ongoing intervention. The day variable is a positive integer. The latter three are categorical variables which respectively have seven, three, and nine levels.

The data additionally contains the daily sales of bottled zero-calorie and sweetened beverages sold per site, and the total daily quantity of beverages sold per hospital. These are all non-negative integer values.

Some observations also include the daily sales of 100% juice, orange juice, and sports drinks, which are also non-negative integer values. These quantities are only consistently recorded at *CHOP* and hardly recorded at the other hospitals.

Quantities of bottled zero-calorie and sugared beverages are missing in nine observations, each containing missing data for every sales-related column. Of these nine observations, seven occur in the final week of the study at *HF*, and two occur mid-study at *NS*. One mid-study observation from *HF* does not report the total quantity of beverages sold, though the quantity of bottled zero-calorie and sugared beverage sales are provided.

Exploratory Analysis

Side-by-side boxplots of the proportion of total sales coming from zero-calorie drinks for each site for each day of the week were created. They showed a similar proportion for each site and day of the week across sites, though one of the sites differed slightly and seemed to have more variable sales. Boxplots of total drinks sold showed one site had a lot more sales than the other two sites. Sales were also much lower for all sites on weekends compared to weekdays

Spaghetti Plots

A plot of the proportion of total sugary and zero-calorie sales coming from zero-calorie drinks over counts (Figure 1), shows the trends of sales across each site over day. Surprisingly, two of the sites seem to have a downward trend, so the proportion of sales coming from zero calorie drinks is decreasing. This is not the expected trend, and will have to be formally tested.

Scatterplot Matrix

A scatterplot matrix comparing sugary, zero-calorie and total drink sales showed that they are all highly correlated with each other. The matrix also shows a positive linear relationship between zero-calorie, sugary and total sales, so for each pair, as sales of one type increase, the other tends to increase as well.

Missing Data Plot

A missing data plot showed that orange juice, 100% juice and sports drinks had many missing observations. A missing data table also showed this, additionally showing that some sites did not report some of these sales at all.

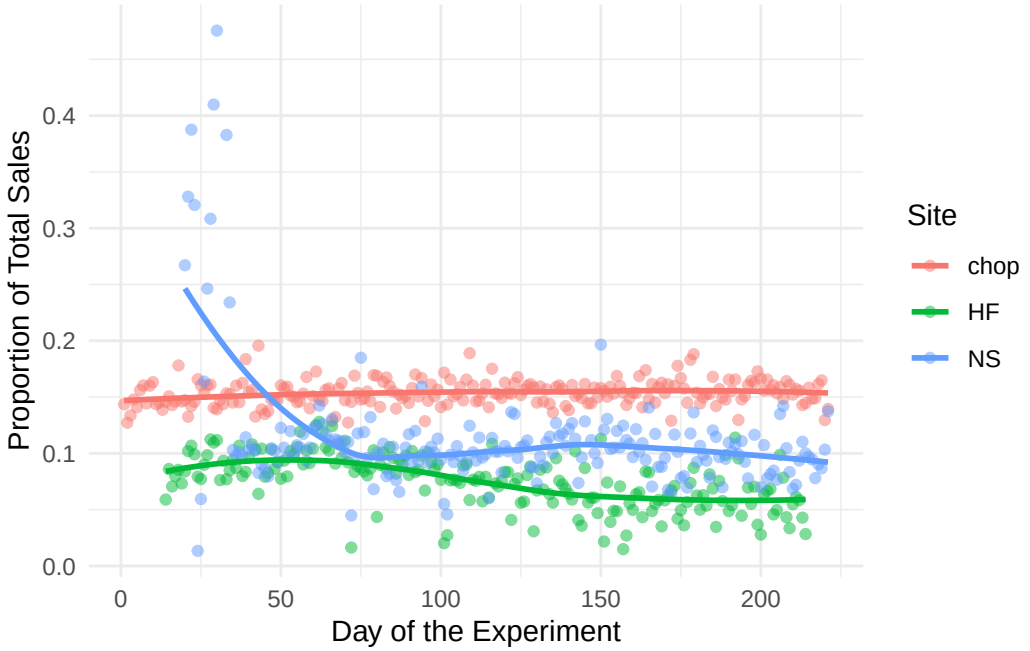

Figure 1: Proportion of total sugary and zero-calorie drink sales coming from zero-calorie drinks over time

Formal Analysis

To answer the statistical questions, we formally assessed the relative effects of the interventions on the average daily proportion of both zero calorie and sugary bevarage sales. The intervention groups had a statistically significant effect on the daily sales of both zero calorie and sugary bevarage sales – likelihood-ratio test (LRT) p <0.0001 in both cases. Table 1 and Figure (N) show the pairwise group comparisons for zero calorie sales. The same comparisons for sugary bevarage sales are shown in Table (N2) and Figure (N2). In all cases, relative effects are represented as relative percentage changes.

Table 1: Pairwise group comparisons on average zero calorie sales.

Comparison	Relative change (95% CI)	Adjusted p-value
Discount vs. Baseline	9.4% (-2.11% — 20.88%)	0.516
Discount and messaging vs. Baseline	38.6% (24.02% — 53.19%)	0.0001
Exercise messaging vs. Baseline	-7.8% (-17.61% — 2.01%)	0.516

Caloric content messaging vs. Baseline	-8% (-17.68% — 1.63%)	0.516
Combination messaging vs. Baseline	-13.2% (-22.27% — -4.03%)	0.028
Discount and messaging vs. Discount	26.7% (12.95% — 40.48%)	0.001
Combination messaging vs. Exercise messaging	-5.8% (-16.19% — 4.58%)	0.546
Combination messaging vs. Caloric content messaging	-5.6% (-15.85% — 4.71%)	0.546

Conclusion

To accurately assess the efficacy of the interventions, it is best to create a statistical model which explains how these interventions affect the proportion of zero-calorie beverages. This response variable is less prone to variation than the overall sales of zero-calorie drinks, and it still provides an easily-interpretable metric for consumer purchasing behaviours.

Therefore, we recommend fitting a Poisson GLMM to the log-transformed sales to predict the proportion of zero-calorie beverage sales, and determining which effects are most relevant using the likelihood ratio test. However, the Poisson GLMM assumes that the underlying data follows a Poisson distribution. If this assumption is not met, we recommend utilizing robust Poisson regression, as the robust Poisson model does not require this distributional assumption. Both analyses employ the zero-calorie beverage sales as the primary outcome with the log of the sum of zero-calorie beverage sales and sugary beverage sales as an offset.

References

[1] James Krieger et al. "Sugar-Sweetened Beverage Reduction Policies: Progress and Promise". In: *Annual Review of Public Health* 42.1 (2021). ISSN: 1545-2093. DOI: 10.1146/annurev-publhealth-090419-103005. URL: http://dx.doi.org/10.1146/annurev-publhealth-090419-103005.

[2] Vasanti S. Malik and Frank B. Hu. "The role of sugar-sweetened beverages in the global epidemics of obesity and chronic diseases". In: *Nature Reviews Endocrinology* 18.4 (2022). ISSN: 1759-5037. DOI: 10.1038/s41574-021-00627-6. URL: http://dx.doi.org/10.1038/s41574-021-00627-6.

Statistical Appendix

[1] James Krieger et al. "Sugar-Sweetened Beverage Reduction Policies: Progress and Promise". In: *Annual Review of Public Health* 42.1 (2021). ISSN: 1545-2093. DOI: 10.1146/annurev-publhealth-090419-103005. URL: http://dx.doi.org/10.1146/annurev-publhealth-090419-103005.

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