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Evaluation of a plant-based meal campaign in workplace cafeterias. An interrupted time series analysis

The FSA prepared this report based on research conducted by Kantar Public.

September, 2023

DOI: https://doi.org/10.46756/sci.fsa.eds279

This report has been commissioned by the FSA as part of their role as an evidence generator. This is an independent research report and, as such, does not represent the views or policy advice of the FSA.

This research has been published by Kantar Public in the joural Behavioural Public Policy:

McPhedran, R., Zhuo, S., Zamperetti, L., & Gold, N. (2023). The effects of Veganuary on meal choices in workplace cafeterias: An interrupted time series analysis. Behavioural Public Policy, 1-20. doi:10.1017/bpp.2023.27

The report evaluates ‘Plant-Forward’ -the plant-based meal campaign implemented by Eurest, a national catering company. It was not the role of this research to verify any claims made by Eurest in their campaign and the FSA do not hold responsibility for the accuracy of the information used in the campaign.

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Acknowledgements

Profuse thanks go to

Rees Bramwell, Head of Nutrition and Sustainability, Eurest & 14Forty (Compass Group UK&I),

David Woodhead, EPOS analyst, Compass Group UK&I, and the rest of the workplace sector of Eurest & 14Forty (Compass Group UK&I) for their strong support. Thanks also go to Michael Ratajczak, Brian Cook and Paul Bateman for their methodological assistance. Additional immense thanks to Alice Rayner, Anya Mohideen, Harriet Pickles and Phil Jones for their contributions to this work.

1. Executive Summary

Background and aims

Choice and consumption of food is affected by a range of factors and dietary choices can change over time at both an individual and population level. One behaviour to have changed over the last few years is the purchasing of plant-based foods. UK sales of meat-free and plant-based dairy products have roughly doubled between 2016 and 2020 and in 2020 were worth close to £600m each (Glotz, 2021; Wunsch, 2021).

Food Standards Agency (FSA) data from 2022 found that 32% of respondents reported eating meat alternatives in the past, although the majority (66%) are not eating them frequently (Armstrong et al, 2022). Reflecting this, the consumption of red meat and pre-cooked meat has gradually fallen (Fuller et al., 2019). In 2021, 41% of respondents in an FSA survey said that they would like to eat less meat (Heard and Bogdan, 2021)

In the context of increased sales of plant-based foods, the study aimed to identify the impact of an annual plant-based meal campaign- ‘Plant-Forward’- conducted in cafeterias serviced by a large UK catering company. The campaign sought to influence consumer food choices by: 1) increasing the availability of plant-based meals to customers in a workplace cafeteria and 2) making plant-based meals more salient and attractive to consumers by using promotional materials. This included claims regarding health and sustainability of plant-based foods in general and newly-launched plant-based meals.

The study also aimed to determine the duration and speed of the deterioration of any significant treatment effect identified. To our knowledge, this is the first study to evaluate such campaigns which look at immediate as well as long-term effects in a cafeteria setting.

Method

The study analysed the large catering company’s sales dataset, which – following exclusions and imputation – encompassed 36 workplace cafeterias from five client companies that the catering company served from 2016 to 2022. Across the time series, 2,255,404 meals were sold, spanning 1,838 distinct products.

Analysis was conducted using Autoregressive Integrated Moving Average (ARIMA) models, including transfer functions to estimate the effects of annual promotional activity upon consumption. We built a model based on pre-campaign data (29/09/2016 to30/12/2018) that captured all the complex patterns over time, including seasonal fluctuations (for example, sales were higher during Christmas for each year) and long-run trends (for example, increasing consumption of plant-based meals over recent years). The model predicted the counterfactual time series of outcome variables after the campaign was introduced, which served as a modelled “control” to be compared to the actual data. ,.

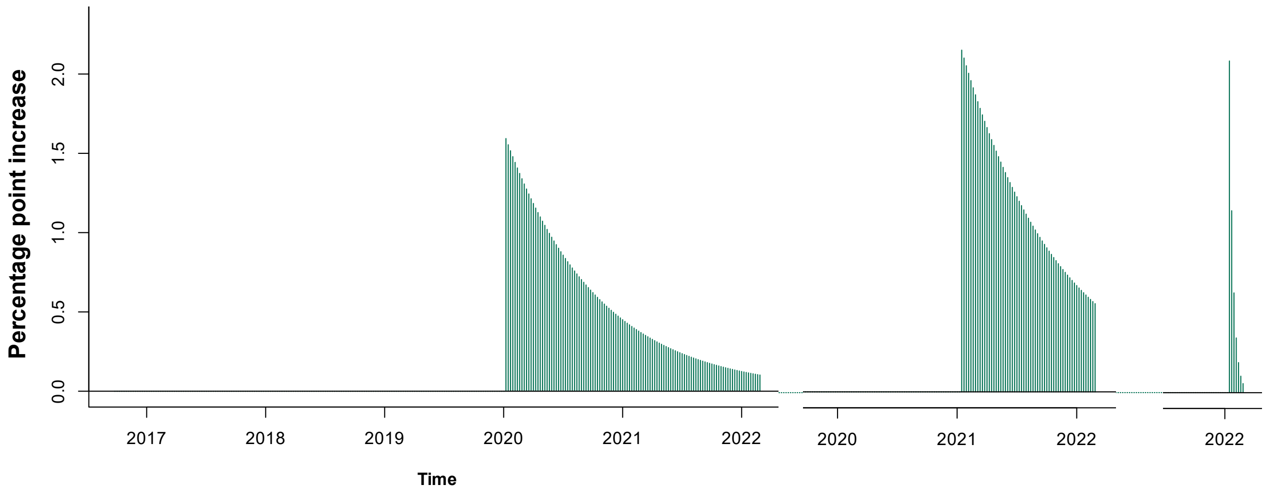
The method provided us with two outcome measures:

1. An estimation of the immediate campaign effect: this is the impact of the campaign on proportion of plant-based sales (out of total sales) for each week.
2. An estimation of the longer-term effect of the campaign (the decay of the immediate effect over time).

Results

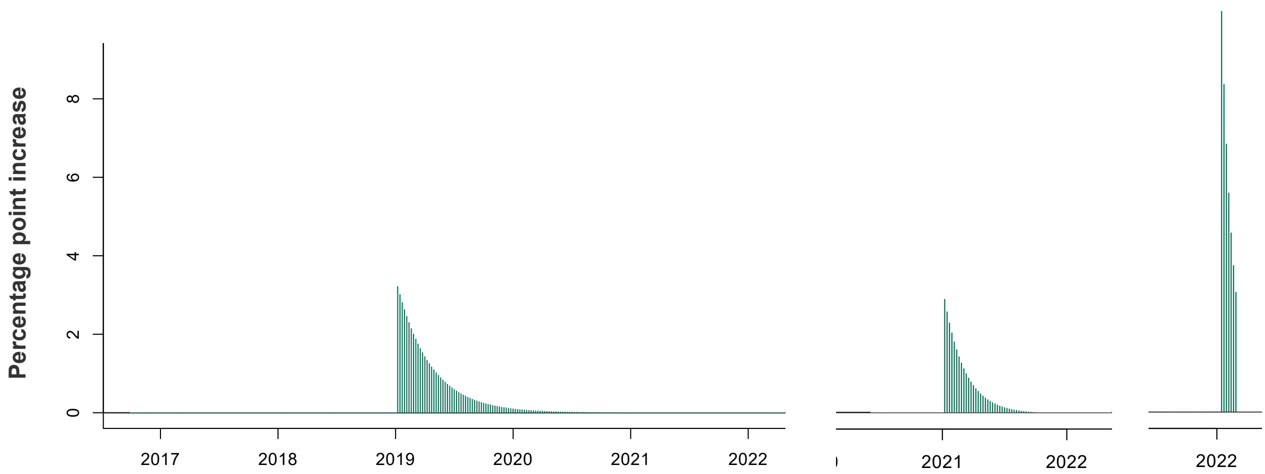
There were positive effects of the campaigns on weekly purchase of vegan and vegetarian products in most years during the campaign period. For vegan meals, significant campaign effects were observed in 2020 (ω_1 2020 = 0.016, $p < 0.01$), 2021 (ω_1 2021 = 0.021, $p < 0.001$) and 2022 (ω_1 2022 = 0.021, $p < 0.001$). This translates to increases of 1.6 percentage points in 2020 and 2.1 percentage points in 2021 and 2022, compared to the modelled counterfactual. The effects were perseverant in the 2020 and 2021 campaigns, with a gradual decay following the initial peak, and positive impact around one third of the initial size still present one year after the campaign. No effects were observed for the 2019 campaign. (See Figure 1.)

Figure 1: Estimated absolute treatment effects (vegan products)



For vegetarian products, significant campaign effects were observed in 2019 (ω_1 2019 = 0.032, $p < 0.01$), 2021 (ω_1 2021 = 0.028, $p < 0.01$) and 2022 (ω_1 2022 = 0.097, $p < 0.001$) campaign periods. This translates to increases of 3.2 percentage points in 2019, 2.8 percentage points 2021, and 9.7 percentage points in 2022 compared to the modelled counterfactual. No significant effects were found for the 2020 campaign. A small positive impact was present after one year for the 2019 campaign, while for 2021, the effects appeared to be present until the end of that year. (See Figure 2).

Figure 2: Estimated absolute treatment effects (vegetarian products)



There are suggestions that the impact of the campaign may differ across workplace cafeterias. We found that when looking at the data of one randomly selected branch no campaign effects were found for proportion of vegan sales, in contrast to the findings from the aggregate data across 36 branches.

In relative terms, we estimated that the campaign resulted in an initial increase of between 86% and 113% in the proportion of total weekly sales for vegan products relative to the modelled counterfactual, depending on the year. The relative increases for vegetarian products were smaller, between 23% and 79%. Sales of vegetarian products showed a higher percentage point rise than sales of vegan products, but a smaller relative rise due to the higher level of vegetarian consumption before the introduction of the campaigns.

Conclusion

The results of this study indicate that this annual campaign has had a significant positive impact on the sales of both vegan and vegetarian products during the campaign period, aggregating across branches, although its success has differed according to year.

Consistent with findings of other recent studies, our results suggest that when used in collaboration with promotional material, increasing the availability and salience of vegan and vegetarian items in cafeteria menus can have a pronounced positive impact on sales. Furthermore, given the lack of exploration of the longevity of such effects in the literature, the current study contributes unique new evidence regarding the potential endurance of similar interventions.

2. Introduction

2.1 Background

Food choices can change over time at both an individual and population level. One of the choices to have changed over the last few years is the consumption of plant-based foods. UK sales of meat-free and plant-based dairy products have roughly doubled between 2016 and 2020 and in 2020 were worth close to £600 million each (Glotz, 2021; Wunsch, 2021). FSA data from 2022 found that 32% of respondents reported eating meat alternatives in the past, although the majority (66%) are not eating them frequently (Armstrong et al, 2022) . Correspondingly, the consumption of red meat and pre-cooked meat has gradually fallen (Fuller et al., 2019). In 2021 41% of respondents in an FSA survey said that they would like to eat less meat (Heard and Bogdan, 2021).

Choice and consumption of food is affected by a range of factors, including those which are external (for example, availability of foods in the environment and social norms) and internal to the consumer (for example, habits and beliefs).

The external environment of food choices has changed significantly in the last few years with regards to plant-based foods. Plant-based food products are now more accessible to consumers with increased availability in supermarkets and food businesses, and there is a greater range of products and brands on offer. According to Mintel in 2019, 23% of all new UK food launches were vegan (Mintel Press Team, 2020). Correspondingly, as mentioned above, in the UK in 2020 sales of meat-free and plant-based dairy products were worth close to £600 million each (Glotz, 2021; Wunsch, 2021).

People's beliefs also affect their food choices. The majority (87%) of people say that it is important to them to eat a healthy diet and most people (73%) say it is important to them to buy food which has a low environmental impact/ is more sustainable (Heard and Bogdan, 2021). However, people's knowledge and beliefs about what constitutes healthy and sustainable diets differ. For example, only 48% of people report that they know what a sustainable/ environmentally friendly diet consists of and qualitative research indicates that marketing, 'spin' and 'dietary tribalism' can make it difficult for consumers to determine the 'correct' diet for minimising environmental impact (Connors et al., 2021; Heard and Bogdan, 2021).

In the context of increased interest in plant-based foods, alongside the reported importance of healthy and sustainable diets to consumers, this project evaluates the effects of a campaign, implemented in canteens run by a UK catering company which sought to influence consumer food choices by: 1) increasing the availability of plant-based meals to customers in a workplace cafeteria and 2) making plant-based meals more salient and attractive to consumers by using promotional materials, which included claims regarding health and sustainability of plant-based foods.

2.2 Research context

A large contract catering company in the UK, which services numerous local and national businesses, launched an internal 'Plant-Forward campaign in 2019- a plant-based food concept- and has repeated it annually since. This promotion is compliant with the company's net zero commitments: specifically, to replace 40% of the animal-based foods throughout its supply chain with alternative proteins by 2030. The mechanism of the campaign is two-fold.

1. Increasing availability: The company launched new plant-based products throughout the campaign period, increasing the number of plant-based options on the menu, thereby increasing the availability of such products (see Section 4.4 for details on product availability).

2. Promoting plant-based meals by increasing the salience of and informing beliefs around plant-based foods. This was done at a general level – promoting plant-based foods in general- and a specific level- promoting newly-launched plant-based products. The company used on-site materials such as posters which included claims on the environmental and health benefits of the products and messaging/ design which aimed to make the meals seem attractive and tasty., for example
   - saying ‘plant-based meals are associated with reduced risk of heart disease and cancers’
   - giving information about the carbon savings from a meat-free day each week
   - trying to make the meals in general look exciting and delicious (‘nom, nom, nom’ pictorial posters)
   - saying the meal is ‘better for you, better for the planet’.
   - giving the protein content of the meal

Examples of promotional materials can be seen in Figure 3. They used a number of behavioural change techniques (from the Behavioural Change Technique Taxonomy (Michie et al., 2013)), such as Information about social and environmental consequences, Information about health consequences, Information about emotional consequences. Salience of consequences, and Prompts/cues (see Table 1).

Figure 3: An example of the company's on-site campaign materials

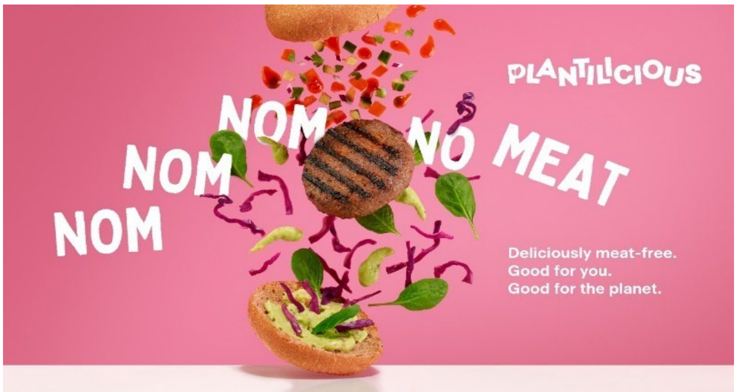


Table 1: Behavioural components of the interventions to increase purchases of plant-based meals

Intervention strategy	Behaviour Change Technique (BCT)*	COM-B domain
Increasing the proportion of plant-based options	Adding objects to the environment	Physical opportunity
Posters promoting plant-based meals in general and newly launched products.	Information about social and environmental consequences Information about health consequences Information about emotional consequences Salience of consequences Prompts/cues	Reflective Motivation Physical opportunity

The 'Plant-Forward' campaign activities start on the first working Monday in January and last until February 1st. Meals served during the campaign continue for 3-months until the end of March, posters promoting the new plant-based meals stop in March. The company promotes plant-based eating all year round, but at a lower frequency and focus compared to in January. During January, the campaign is implemented consistently across the business sites, although messaging and food offers differ slightly across business sites and industry environments to ensure the differing needs of the workforces are accommodated.

After the initial launch of the campaign in January 2019, the same concept and similar approaches were used in January of the following years. New recipes were added each year, and new promotional materials were added in different campaign periods focusing on a variety of food products and messages.

The Behavioural Practice was provided with access to the catering company's sales data from 2016 to 2022 which allowed assessment of both the immediate and longer-term effects of the annually repeated campaign.

2.3 Research hypotheses

This study aimed to test the following two primary hypotheses:

Hypothesis 1: The 'Plant-Forward' campaign increased the proportion of vegan meals sold during the annual campaign periods.

Hypothesis 2: The 'Plant-Forward' campaign increased the proportion of vegetarian meals sold during the annual campaign periods.

In addition, given the identification of significant treatment effects across multiple years, we performed further analyses to determine the "shape" and duration of the impact.

3. Materials and Methods

3.1 The sales dataset

Initial dataset

The main dataset initially comprised daily sales of main meals[1] from 29/09/2016 to 02/03/2022, in 131 workplace cafeterias[2] (henceforth referred to as "branches") of 11 client companies that the catering company served in the UK. Sales here in the report refer to number of meals sold, i.e., unit sales, rather than the monetary value of sales.

There were 1,975 dates in total during the study time period. Over this period, 4,677,540 meals were sold, with 2,396 distinct meal products (henceforth "products" refer to "meal products"). A separate dataset contained indicators for each of the meal products that denoted whether they were vegetarian or vegan options.

[1] We focused on main meals, with sandwiches and snacks not included, because the campaign activities were designed around main meal products mostly.

[2] The majority of these cafeterias served mostly blue-collar workers.

There were 1,411 weekdays in the dataset. Weekends were excluded from the dataset, as many branches do not operate over the weekend. If selective set of branches with data for weekends were included, it would have been detrimental to the intended approach to analysis.

Exclusions and missing data

Following Velicer and Colby (2005), the study initially excluded branches that had no data for more than 20% of the weekdays in the period. There were 57 branches with at least 80% of the weekdays (>1129). Further nine branches that had missing data for two consecutive weeks were excluded, because imputation with consecutive missing values has been shown to be more inaccurate (Wongoutong, 2020). 43 of the remaining 48 branches had data until 23/02/2022; one had data until 22/02/2022; and another had data until 21/02/2022. The other three branches whose data ended before February 2022 were removed, which left 45 branches that spanned the total study period.

Finally, due to high variance in the raw data and low absolute volumes of vegetarian and vegan sales, the results of imputation (the process for which is described below) for a 45 branch set were inaccurate, particularly for vegan sales.[3] Consequently, a further nine branches with more than 5% missing data were removed, which left 36 branches from five client companies the catering company served in the final dataset.

Note that since the data covered the COVID-19 period, if workplace cafeterias shut during COVID-19 then that would have led to missing data for a branch. Since we excluded branches based on amount of missing data, only branches that opened consistently during the COVID-19 lockdown periods could have remained in the final dataset. These branches might differ systematically from other branches, affecting the generalisability of the results (see further discussion on this as a limitation in Section 6).

Imputation procedure

We used Kalman smoothing on the state space representation of an ARIMA model for imputation of missing data, applied via the *imputeTS* package in R Statistical Software.

[3] A correlation coefficient of 0.55

Imputation was conducted for each branch, using a two-step approach. If data were missing for the whole week, the imputation at a weekly level was conducted; otherwise, data were imputed at a daily level.

To examine the quality of this imputation, checks were ran where 10% of existing data as missing where randomly replaced, imputed missing values, and calculated the correlation coefficients of imputed values and actual values. The study explored different imputation methods (for example, seasonally decomposed missing value imputation, seasonally splitted missing value imputation interpolation, interpolation, last observation carried forward) and imputation with different seasonality settings in attempt to improve imputation quality.

With the final dataset, for imputation at a daily level, Kalman smoothing on the state space representation of a weekly ARIMA model gave the best results, with correlation coefficients of 0.89, 0.65, 0.66 for total sales, vegetarian sales and vegan sales respectively. For imputation at a weekly level, Kalman smoothing on the state space representation of an ARIMA model with a yearly seasonality gave the best results, with correlation coefficients of 0.94, 0.80, 0.78 for total sales, vegetarian sales and vegan sales respectively.

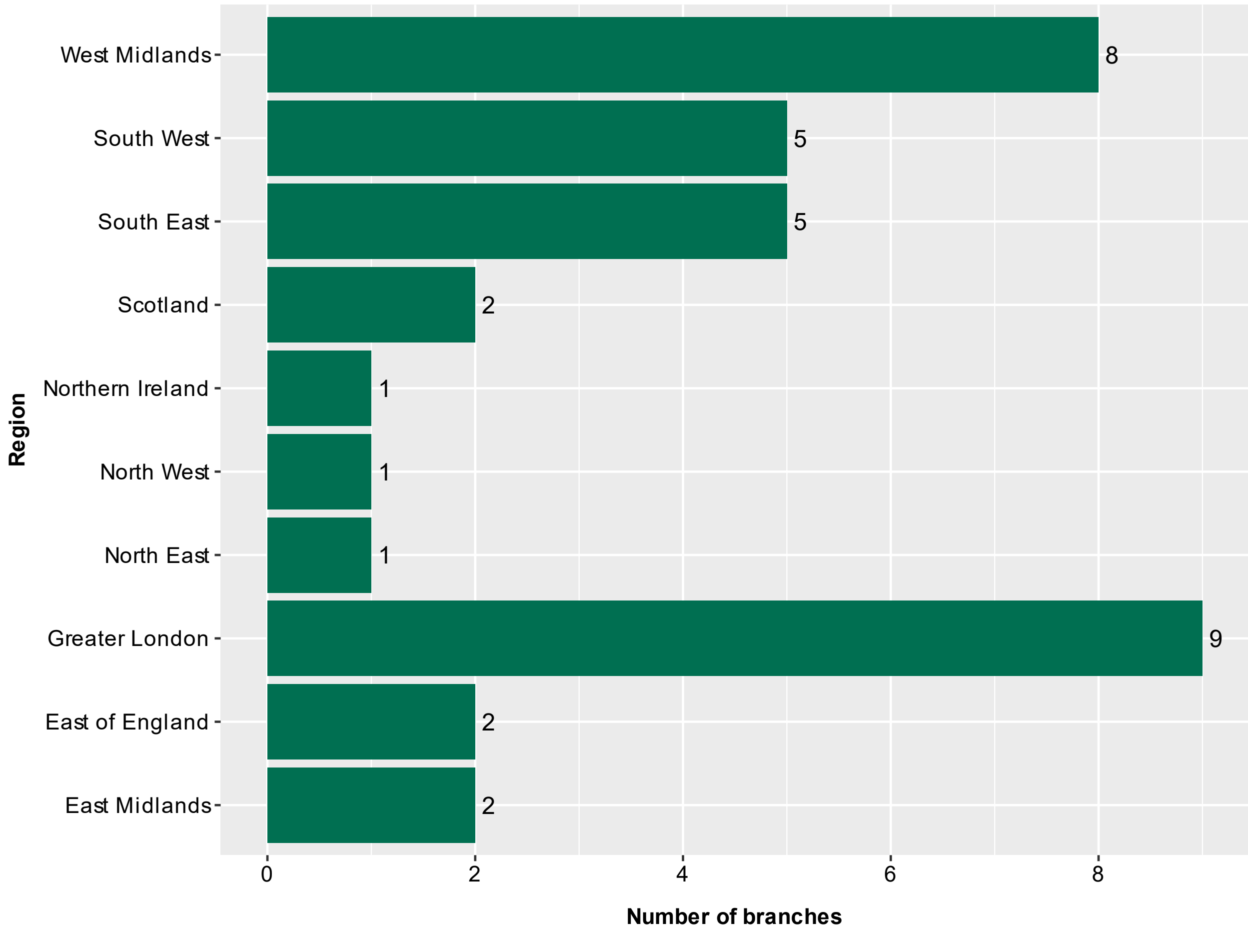
These correlation coefficients are roughly comparable to those seen elsewhere in the literature; nevertheless, data completeness and imputation remains a limitation of this study (Hadeed et al., 2020).

Final dataset

The 36 branches in the dataset were located in eight of nine regions in England (all regions except for Yorkshire and The Humber), Scotland and Northern Ireland (See Figure 4). The majority of the customers of the 36 branches were blue-collar workers, such as lorry/bus drivers and staff at distribution centres, while some branches also served white collar customers, such as office workers.

In these 36 branches, 2,255,404 meals were sold in the time series, spanning 1,838 distinct meal products. The average number of meals sold per branch per week (after imputation) was 221.379 (SD = 156.080), while the number for vegan meals was 3.887 (SD = 10.433) and 27.644 (SD = 34.569) for vegetarian meals.

Figure 4: Location of branches in the final dataset



3.2 Computation of outcome variables

To abstract away from daily variation (which might be an artefact of logistic issues, or otherwise), the conducted analysis was at a weekly level. To obtain the final time series data for analyses, the following were firstly aggregated: the total sales, the vegan sales, and the vegetarian sales for each branch over each calendar week respectively, then aggregated over all 36 branches included in the final dataset for each of the three variables. This gave the time series data of the total sales, the vegan sales and the vegetarian sales. Finally, we used them to create the two primary outcomes, which were the proportion of vegan sales (out of the total sales) for each week and the proportion of vegetarian sales (out of the total sales) for each week.[4]

3.3 Autoregressive Integrated Moving Average (ARIMA)

Intervention analysis

The annual campaign effects of the "Plant-Forward" campaign upon vegan and vegetarian sales were estimated using Autoregressive Integrated Moving Average (ARIMA) intervention analysis, following the general processes outlined in Box et al. (2015) and Cryer and Chan (2008).

The immediate campaign effect is defined as the impact of the campaign on proportion of plant-based sales (out of total sales) for each week.

ARIMA models

ARIMA models are used in interrupted time series analysis when data have properties that render them difficult to model using simpler approaches – for example, segmented regression – such as residuals with complex autocorrelation structures (Schaffer et al., 2021). In this case, data spanned several years, and a cursory examination of the time series plots for the selected outcome variables suggested non-stationarity and the potential for seasonal patterns; therefore, ARIMA intervention analysis was chosen for use.

ARIMA models combine four separate components to predict the value of a given outcome Y at time t (Y_t) (Hyndman and Athanasopoulos, 2018). A brief summary of these components follows:

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[4] We focused on sales in terms of quantity (i.e., unit sales) rather than monetary value of the sales because it was quantity that captured the shift in consumption of meals. Price could be a factor that affected unit sales. In the final dataset, consumers on average paid £2.56 for a vegan meal and £2.40 for a vegetarian meal, while paying £2.71 per meal when all types of meals were included. See Appendix Table 9 for more information on price.

1. **Autoregressive (AR)**: in which Y_t is predicted by regression including one or more lagged values of Y_t.

2. **Moving average (MA)**: in which Y_t is predicted by one or more lagged values of the regression error.

3. **Differencing**: in which a non-stationary time series is transformed using differencing (a calculation of the difference between consecutive time points).

4. **Seasonality**: in which Y_t is predicted by lagged values that occur at a recurring periodicity (season).

ARIMA models are typically written as ARIMA (p,d,q) where p represents the order of the AR component, q represents the order of the MA component, and d represents the order of differencing for stationarity to be achieved (Zheng et al., 2013).

Determination of ARIMA model form

In this study, several different ARIMA models - two for vegan sales and two for vegetarian sales - were used to estimate the campaign effects associated with 'Plant-Forward' campaign activity each year. If effective, each period of activity was assumed to act as an exogenous factor that disrupted the trend or mean function of vegan/vegetarian sales at the branches (Cui et al., 2020). The patterns of these disruptions were estimated using transfer functions.

The form of each of these ARIMA models – including the intervention effects – was fitted using the same general process. This process comprised the steps outlined in Cryer and Chan (2008) and pre-registered on OSF (https://osf.io/3zwhs).

1. The first step in determining the ARIMA models was to specify the models for the pre-campaign period (29/09/2016 to 30/12/2018). The *auto.arima* function within the *forecast* package in R Statistical Software was used for this purpose, with best fit determined on the basis of Akaike Information Criteria (AIC). If the model selected by *auto.arima* included a differencing term (indicated non-stationarity), the augmented Dickey-Fuller test was used for confirmation.

2. The second step was to test the adequacy of the pre-campaign ARIMA model by examining diagnostic statistics, including examining the Ljung-Box statistic,

autocorrelation function (ACF) plot and partial autocorrelation function (PACF) plot alongside interrogation of the parameter estimates.

3. The third step was to extend the tentative pre-campaign ARIMA model to the full dataset, including the inclusion of four transfer functions denoting each of the Veganuary campaign periods. These transfer functions were initially specified as having the form:

$$_t = \omega_0 P_t^{(T)} + \frac{\omega_1}{1 - \delta B} P_t^{(T)}$$

   where $\omega_0 P_t^{(T)}$ represents the immediate positive impact upon sales of vegan and vegetarian products associated with the intervention, and $\frac{\omega_1}{1-\delta B} P_t^{(T)}$ represents campaign effect in the weeks following the intervention. The *arimax* function within the *TSA* R package was used to estimate models in this step.

4. The fourth step was to test the adequacy of the full time series ARIMA model, using the same steps of diagnostic statistics as in Step 2 alongside interrogation of the parameter estimates. In addition, at this juncture, additive (AO) and innovative outliers (IO) were identified using the *detectAO* and *dectectIO* functions in the *TSA* package (both of which use the $lambda_{2,t}$ test statistic) (Chang et al., 1988) or via interrogation of model residuals.

5. Improved models – in which changes to the model and transfer function specifications were made on the basis of Step 4 – were fitted, if needed.

Interpretation of estimated effects

Due to the complex pattern of the level of outcome variables over time, the campaign effects could not be estimated by simply comparing the level of outcome variables during the campaign periods to that of non-campaign periods. In fact, given the inherent fluctuation of the outcome variables over time, it is possible to have a lower level of vegan and vegetarian sales during the campaign periods compared to non-campaign periods, while still having positive campaign effects.

Step 1 and 2 above aimed to build a model based on pre-campaign data that captured all the complex patterns over time, including seasonal fluctuations (for example, sales were higher during Christmas for each year) and long-run trends (for example, increasing consumption of plant-based meals over recent years).The model would predict the counterfactual time series of outcome variables after the first campaign was introduced, which would serve as the "control" to be compared to the actual data to estimate the campaign effects. It is with this constructed "control" we were able to relatively cleanly identify the effects of the campaigns. The model for predicting the counterfactual was further adjusted in Steps 3 to 5 to incorporate extra information in the longer time series.

Note that as mentioned in Step 3, the effects of the four campaign periods were modelled separately from each other; therefore, the estimated effect of one campaign at any time point was in addition to any estimated effect of other campaigns. The analysis was able to estimate the longer-term effects beyond the campaign periods due to the way the study modelled the intervention effects in Step 3: instead of modelling the campaign effects as a one-shot change of level, the study modelled them in the shape of an initial level change followed by a gradual decay of the initial change over time. No assumption about how quickly the effect would decay were made. Therefore, ex ante, the effects could decrease to zero right at the end of the campaign period or persist over years; the duration of the effects would be estimated from the data. However long the effects persist, the analysis can attribute a set of estimated effects over time to a specific campaign period because those effects were modelled as function purely of the timing of the specific campaign and the initial effect of that specific campaign.

3.4 Range of vegan and vegetarian products

To facilitate the interpretation of results, the proportion of the weekly products that vegan/vegetarian products accounted for were calculated (see Figure 5).[5]

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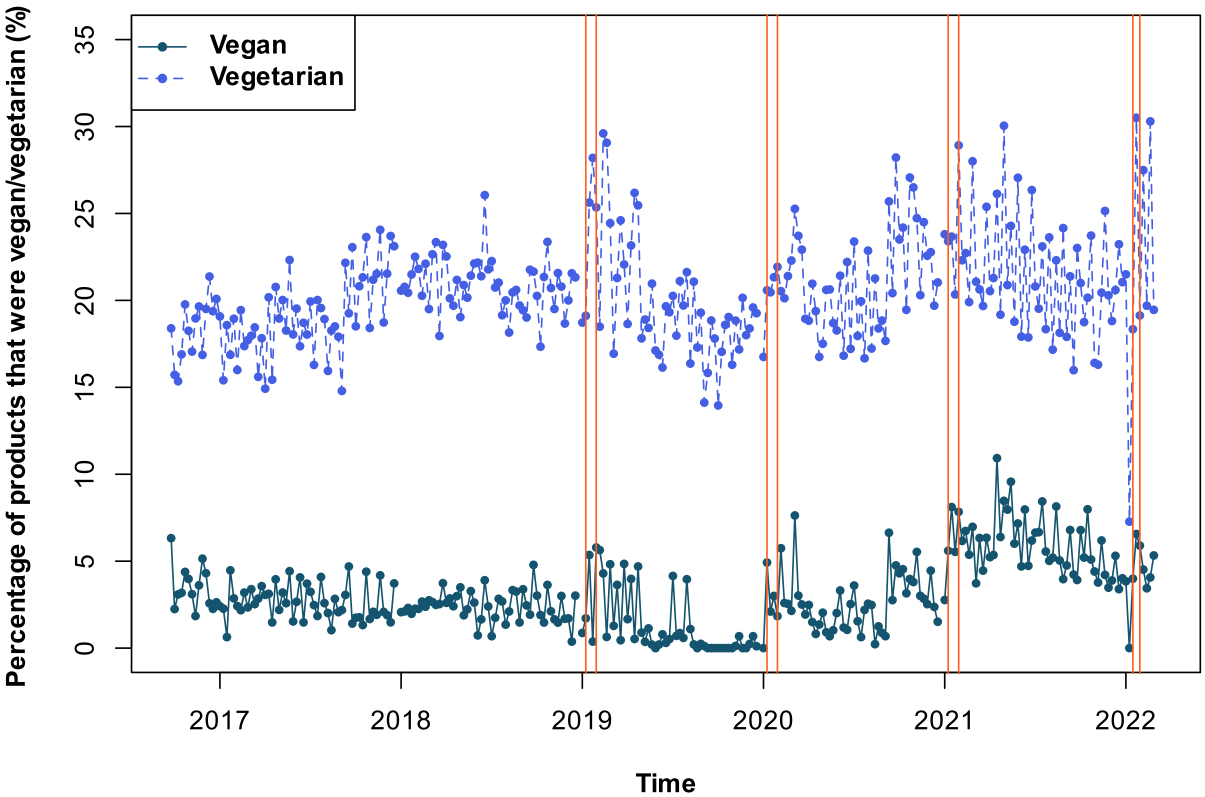
[5] Numbers in this subsection were calculated using the sales data in the final dataset instead of the official menu. The proportion was calculated across all 36 branches included in the final dataset for each week to match the way the outcome variables were calculated. One caveat is that products that were available but not bought did not show up in the dataset, however, we expect this to have happened rarely. A second caveat is that we didn't perform imputation for these numbers, so if sales data was missing for a branch for a specific date, it was treated as no products were available for that branch for

Figure 5: Vegan/Vegetarian products (weekly), proportion of total products



Note: The vertical lines mark the beginning and end of each campaign period.

Vegan products accounted for a higher proportion of the total number of products in the campaign periods in 2021 and 2022 (6.77% and 5.24% respectively), compared to pre campaign (2.63%). A similar pattern was observed for vegetarian products: they accounted for a higher proportion in 2021 and 2022 (24.08%, 23.87% respectively), again compared topre campaign (19.79%). See Table 8 in the Appendix for more details on this.

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that date. This would result in lower absolute number of (all/vegan/vegetarian) products, however, the influence on proportion of vegan/vegetarian products out of all products should be relatively small. Overall, the proportions calculated should be treated as imperfect proxies of actual product availability.

Additionally, analysis of the relationship between product proportion and proportion of sales revealed significant correlations for both vegan ($r = 0.868$, $p < 0.001$) and vegetarian ($r = 0.661$, $p < 0.001$) products, meaning that the proportion of vegan/vegetarian sales (out of total sales) varied in a similar pattern to the proportion of vegan/vegetarian products (out of all products) over the analysis period.

Additional information

The statistical significance of model parameters was conducted using a Z-test of coefficients, with a significance level of $\alpha = 0.05$.

For brevity, the results reported in Section 5 outline the primary models fitted to the time series for each outcome. Additional results are appended.

4. Results

4.1 Vegan sales

Summary of results

The analysis shows that the catering company’s 'Plant-Forward’ campaigns in 2020, 2021, and 2022 had positive effects for the proportion of vegan sales out of total sales.. The effects of the 2020 and 2021 campaign were estimated to be long-lasting, with positive impact around one third of the initial size still present one year after the campaign. In 2022 the decay in effect was more rapid. However, caution should be exercised when interpreting the decay function, given its p-value did not meet the threshold for statistical significance. No effects were found for the 2019 campaign.

Table 2 summarises the key results of the immediate effect of the campaign for vegan sales.

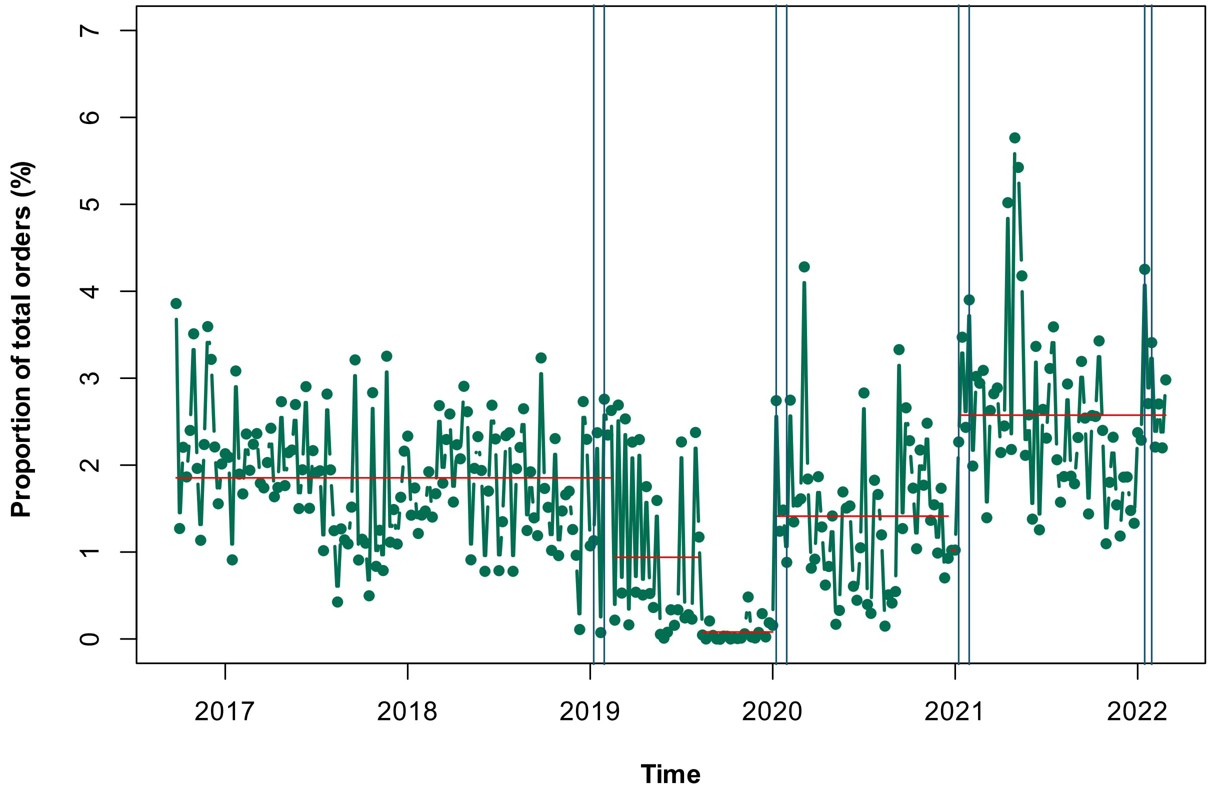
Table 2: Summary of the immediate campaign effect by year for vegan sales

Campaign year	Immediate effect: Increase in proportion of total sales accounted by vegan products, compared to counterfactual (weekly on average)	Estimated number of additional vegan products sold weekly during campaign period (weekly on average)
2019	Not significant	Not significant
2020	+1.6 percentage points ($p < 0.001$)	107
2021	+2.1 percentage points ($p < 0.001$)	190
2022	+2.1 percentage points ($p < 0.001$)	181

Figure 6 illustrates the proportion of total weekly sales for vegan products from 2017-2022. Vegan products accounted for approximately 0-6% of weekly sales, depending on the week and year. The average proportion of total weekly sales for vegan products was 1.86% (SD = 0.714%) for the period before the annual campaigns started (29/09/2016 to

30/12/2018); and 2.05% (SD = 0.770%) and 1.68% (SD = 0.422%) for January in 2017 and 2018.

Figure 6: Vegan sales (weekly), proportion of total sales



Note: The vertical lines mark the beginning and end of each campaign period.

Model fitting – Pre-intervention model

An ARIMA (3,1,1) $(0,0,0)_{52}$ model without drift provided the best fit for the unperturbed data (29/09/2016 to 30/12/2018), based on the AIC (AIC = -828.087).[6] An augmented Dickey-Fuller test confirmed the need for differencing (ADF = -3.351, p = 0.066).

Examination of the model residuals – including their ACF – indicated a satisfactory fit, an observation corroborated by the Ljung-Box Q statistic (Q = 13.825, p = 0.839). Model parameter estimates can be seen in Table 10 in the appendix.

[6] The fit of alternative models is appended.

Model fitting – Intervention analysis

Following the pre-intervention model, an ARIMA (3,1,0) $(0,0,0)_{52}$ was fitted to the data.[7] The model contained three transfer functions (for the 2020, 2021 and 2022 campaign periods) and three outliers (two innovative outliers and an additive outlier).

The three transfer functions took the form $\frac{\omega_1}{1-\delta B} P_t^{(T)}$, where ω_1 represents the immediate effect of the campaign and δ represents the subsequent decay in campaign effect over time (Cryer and Chan, 2008). Examination of the residuals again indicated a satisfactory fit, corroborated once more by the Ljung-Box test ($Q = 49.411$, $p = 0.301$).

The model's parameter estimates can be seen in Table 3.

[7] ARIMA (3,1,1) $(0,0,0)_{52}$ model was fitted to the full time series including four transfer functions; however, the MA parameter was not statistically significant, so it was removed from the model. Additionally, the intervention transfer functions were adjusted on the basis of statistical significance.

Table 3: Full time series ARIMA (3,1,0) $(0,0,0)_{52}$ model parameters, vegan

Parameter	Coefficient	Standard error	P-value
AR(1)	-0.777	0.051	$p < 0.001$
AR(2)	-0.588	0.060	$p < 0.001$
AR(3)	-0.480	0.051	$p < 0.001$
AOL, Week 180 (2020)	0.022	0.006	$p < 0.001$
IOL, Week 207 (2020)	0.031	0.007	$p < 0.001$
IOL, Week 240 (2021)	0.032	0.008	$p < 0.001$
ω_1 2020	0.016	0.005	$p < 0.01$
δ 2020	0.976	0.039	$p < 0.001$
ω_1 2021	0.021	0.005	$p < 0.001$
δ 2021	0.977	0.037	$p < 0.001$
ω_1 2022	0.021	0.006	$p < 0.001$
δ 2022	0.548	0.283	$p = 0.052$

Log likelihood = 983.4, AIC = -1942.8

Full results

The full time series of the ARIMA model for vegan sales is in Table 3. The absence of 2019 from the model outlined indicates that the initial Veganuary campaign did not have a statistically significant impact upon vegan product purchases in the observed period.[8] However, statistically significant campaign effects were observed for the 2020 (ω_1 2020 =

[8] The 2019 transfer function was omitted due to parameter estimates with p-values that did not reach the threshold required for statistical significance.

0.016, $p < 0.01$), 2021 (ω_1 2021 = 0.021, $p < 0.001$) and 2022 (ω_1 2022 = 0.021, $p < 0.001$) campaign periods.

Figure 7 provides an illustration of the estimated effect for the 2020 campaign activity. The effect was most pronounced throughout campaign activity in 2020 – peaking at a 1.6 percentage point increase in sales – with a gradual decay over time (δ 2020 = 0.976, $p < 0.001$). The model suggested an enduring effect, with a positive impact felt in 2021 (approximately 0.44 percentage points in January 2021), and a small positive impact still present in early 2022.

Figure 7 also contains an illustration of the estimated effect for the 2021 campaign activity. The effect had a similar shape to the effect in 2020: the decay was comparable ($\boldsymbol{\delta}$ 2021 = 0.977, $p < 0.001$); however, the peak was higher (an increase of 2.1 percentage points). Further, the effect was also persistent: the effects of the intervention were still observed in 2022 (approximately 0.63 percentage points in January 2022).

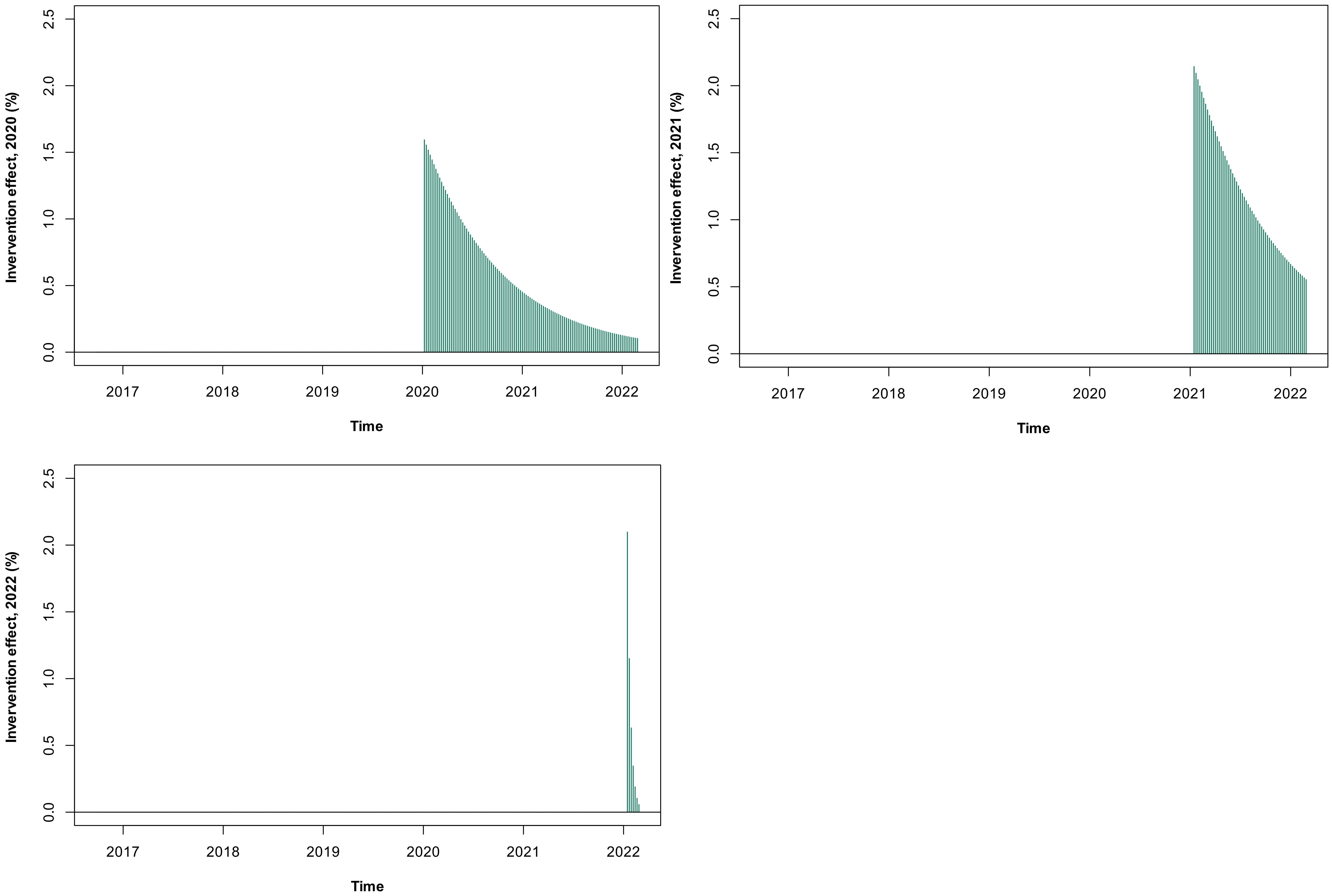
The 2022 campaign period had a spike with a similar magnitude to 2021 (2.1 percentage points), but in contrast to previous years, the decay in effect was more rapid (δ 2022 = 0.548, $p = 0.052$). However, caution should be exercised when interpreting the decay function, given its p-value did not meet the threshold for statistical significance ($p = 0.052$).

Using the average number of total meals sold per week in each campaign period, we estimate the initial effects of 2020, 2021 and 2022 campaigns translated into107, 190, and 181 of the meals sold these respective weeks being vegan meals.[9]

Additional outputs of this model – as well as the results of analysis of secondary outcomes – are appended

[9] As we are translating an effect size proportion, this assumes that the campaign did not impact on the total number of sales for those weeks.

Figure 7: Estimated absolute treatment effects (vegan), 2020/2021/2022 campaigns



4.2 Vegetarian sales

Summary of results

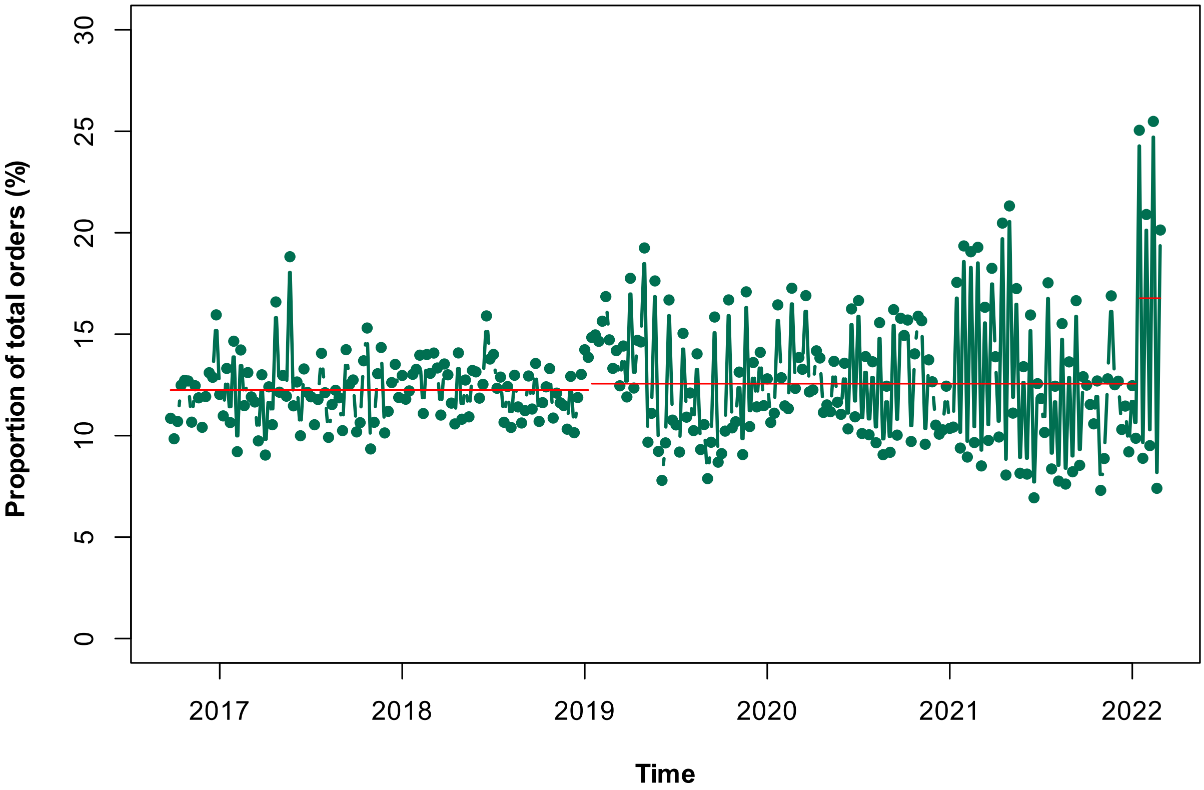
Our analysis shows that the catering company's internal 'Plant-Forward' campaigns in 2019, 2021, and 2022 had positive effects on the proportion of vegetarian sales out of total sales.. The effects of the 2019 and 2021 campaign were enduring, with a small positive impact present after one year for the 2019 campaign and until the end of the year for 2021 campaign. No effects were found for the 2020 campaign. Table 4 summarises the key results of the immediate effect of the campaign for vegetarian sales.

Table 4: Summary of the immediate campaign effect by year for vegetarian sales

Campaign year	Immediate effect: Increase in proportion of total sales accounted by vegetarian products (weekly on average)	Estimated number of additional vegetarian products sold weekly during campaign period (weekly on average)
2019	+3.2 percentage points ($p<0.01$)	232
2020	Not significant	Not significant
2021	+2.8 percentage points ($p<0.01$)	253
2022	+9.7 percentage points ($p<0.001$)	835

Figure 8 illustrates the proportion of total weekly sales for vegetarian products from 2017-2022. Relative to vegan products, vegetarian products were more popular: they accounted for approximately 7-26% of weekly sales, depending on the week and year. The average proportion of total weekly sales for vegetarian products was 12.22% (SD = 1.57%) for the period before the annual campaigns started (29/09/2016 to 30/12/2018); and 11.74% (SD = 1.04%) and 12.50% (SD = 0.518%) for January in 2017 and 2018.

Figure 8: Vegetarian sales (weekly), proportion of total sales



Model fitting – Pre-intervention model

An ARIMA (4,0,0) $(0,0,0)_{52}$ model with an intercept and no drift provided the best fit for the unperturbed data (29/09/2016 to 30/12/2018), based on the AIC (AIC = -654.13).[10] An augmented Dickey-Fuller test confirmed that no differencing was needed (ADF = -4.022, p = 0.011). Model residuals indicated a satisfactory fit, confirmed by the Ljung-Box Q statistic (Q = 21.126, p = 0.323).

Model parameter estimates can be seen in Table 13 in the appendix.

Model fitting – Intervention analysis

Following the pre-intervention model, an ARIMA (4,0,0) $(0,0,0)_{52}$ model with an intercept was fitted to the data.[11] The model contained three transfer functions (for the 2019, 2021 and 2022 campaign periods) and 10 outliers (seven innovative outliers and three additive outliers). As for the vegan analysis, the transfer functions took the form $\frac{\omega_1}{1-\delta B} P_t^{(T)}$. Examination of the residuals indicated an acceptable fit, corroborated once more by the Ljung-Box Q statistic (Q = 47.832, p = 0.090).

The model's parameter estimates can be seen in Table 5.

[10] The fit of alternative models is appended.

[11] ARIMA (4,0,0) $(0,0,0)_{52}$ model was fitted to the full time series including four transfer functions; the intervention transfer functions were adjusted on the basis of statistical significance.

Table 5: Full time series ARIMA (4,0,0) $(0,0,0)_{52}$ model parameters, vegetarian

Parameter	Coefficient	Standard error	P-value
AR(1)	-0.157	0.053	$p < 0.01$
AR(2)	0.118	0.053	$p < 0.05$
AR(3)	-0.122	0.053	$p < 0.05$
AR(4)	0.407	0.054	$p < 0.001$
Intercept	0.121	0.002	$p < 0.001$
AOL, Week 14 (2016)	0.052	0.018	$p < 0.01$
AOL, Week 35 (2017)	0.043	0.018	$p < 0.05$
AOL, Week 240 (2021)	0.064	0.019	$p < 0.01$
IOL, Week 140 (2019)	-0.052	0.019	$p < 0.01$
IOL, Week 236 (2021)	0.048	0.019	$p < 0.05$
IOL, Week 237 (2021)	-0.050	0.019	$p < 0.05$
IOL, Week 238 (2021)	0.089	0.019	$p < 0.001$
IOL, Week 239 (2021)	-0.052	0.020	$p < 0.01$
IOL, Week 251 (2021)	0.072	0.019	$p < 0.001$
IOL, Week 278 (2022)	-0.091	0.023	$p < 0.001$
ω_1 2019	0.032	0.010	$p < 0.01$
δ 2019	0.935	0.032	$p < 0.001$
ω_1 2021	0.028	0.010	$p < 0.01$
δ 2021	0.890	0.046	$p < 0.001$
ω_1 2022	0.097	0.016	$p < 0.001$
δ 2022	0.818	0.053	$p < 0.001$

Log likelihood = 720.56, AIC = -1399.11

Full results

The full time series results of the ARIMA model for vegetarian sales is in Table 5. In contrast to the vegan sales model, the vegetarian model indicated that the 2020 campaign did not have a statistically significant impact upon vegetarian product sales.[12] However, statistically significant campaign effects were observed for the 2019 (ω_1 2019 = 0.032, $p < 0.01$), 2021 (ω_1 2021 = 0.028, $p < 0.01$) and 2022 (ω_1 2022 = 0.097, $p < 0.001$) campaign periods.

Figure 9 provides an illustration of the estimated effect of the 2019 campaign activity. The campaign effect peaked at a 3.2 percentage point increase in vegetarian product sales with a gradual decay over time (δ 2019 = 0.935, $p < 0.001$). The model suggested that the effect persisted over a period of more than one year, with a small positive impact still present in early 2020 (approximately 0.10 percentage points in January 2020).

Figure 9 also contains an illustration of the estimated effect of the 2021 campaign activity. The treatment effect had a similar shape to the effect in 2019; however, the peak was lower (an increase of 2.8 percentage points), and the decay was faster ($\boldsymbol{\delta}$ 2021 = 0.890, $p < 0.001$). Due to this faster decay, the effect had receded to a negligible value – near zero – in the last quarter of 2021.

The 2022 campaign period had a much larger initial effect compared to previous years – peaking at a 9.7 percentage point increase in vegetarian product sales. However, the decay was also faster than in previous years (δ 2022 = 0.818, $p < 0.001$).

Using the average number of total meals sold per week in each campaign period, it was estimated that the initial effects of 2019, 2021 and 2022 campaigns translated into 232, 253 and 835 of the meals sold in these respective weeks being vegetarian meals.

Additional outputs for this model – and additional detail on the analysis of secondary outcomes - can be seen in the Appendix.

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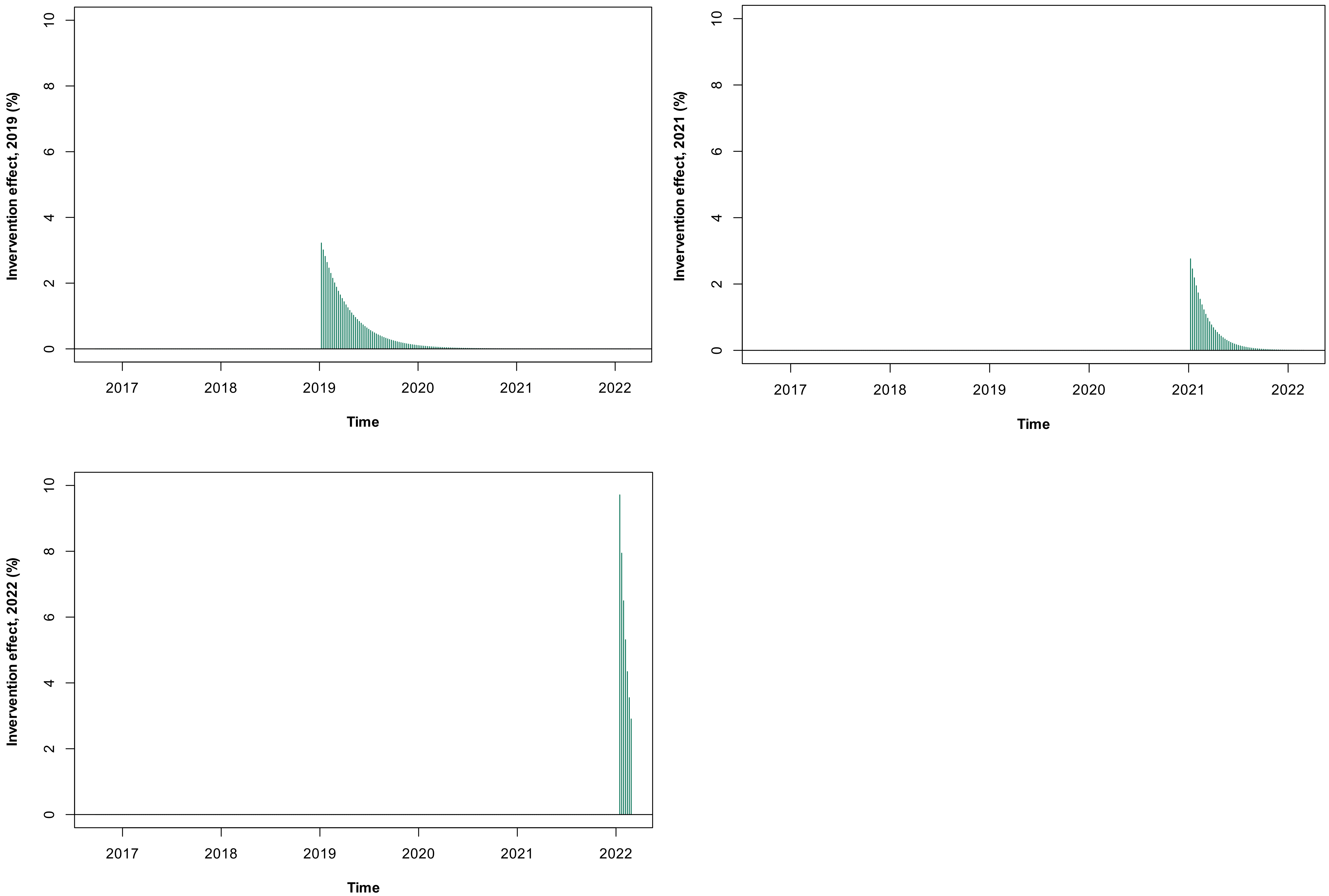
[12] The 2020 transfer function was omitted due to parameter estimates with p-values that did not reach the threshold required for statistical significance.

Figure 9: Estimated absolute treatment effects (vegetarian), 2019/2021/2022 campaigns



4.3 Consistency of observed treatment effects

To investigate the consistency of the treatment effects noted in Sections 0 and 0, we randomly selected a single cafeteria using the *randomizr* package in R and modelled the impact of the promotional periods at that location.

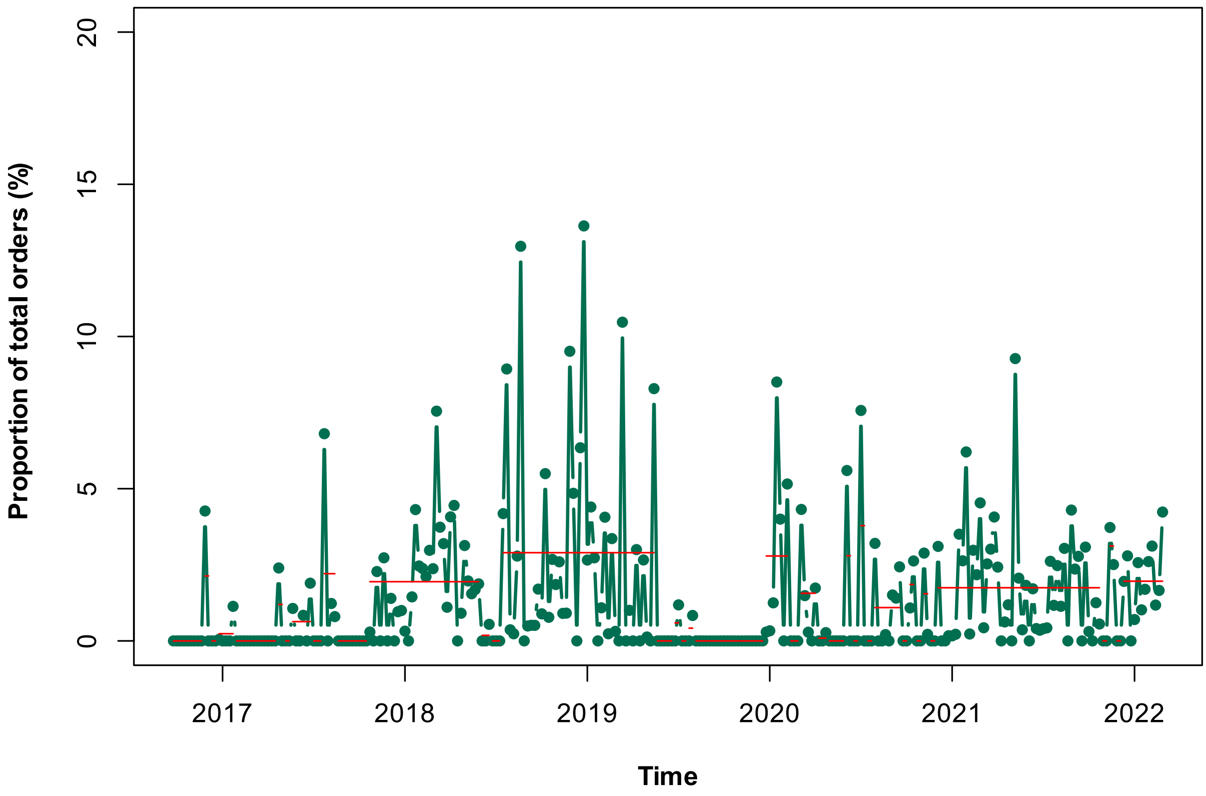
The randomly selected branch was relatively large compared to other branches in this study, with average sales of 439.771 products per week, compared to a total average (221.379 products per week).

We found that, in contrast to the findings from the aggregate data across 36 branches, looking at the data of one randomly selected branch no campaign effects were found for the proportion of vegan sales. Effects were only found for the 2019 campaign for the proportion of vegetarian sales, suggesting that the campaign effects differed across branches.

Vegan sales

The proportion of total weekly sales accounted for by vegan products in the selected branch is depicted in Figure 10. There was more variability in the selected cafeteria's vegan sales relative to the aggregate; vegan sales accounted for approximately 0-14% of total product sales depending on the week and year. In contrast to the aggregate analysis, changes in the mean and variance of vegan sales did not clearly coincide with campaign periods, aside from in 2020.

Figure 10: Vegan sales (weekly), proportion of total sales (selected branch)



Model fitting – Intervention analysis

For the intervention analysis, an ARIMA (4,0,0) $(0,0,0)_{52}$ model with an intercept was fitted. An augmented Dickey-Fuller test confirmed differencing was not needed (ADF = -4.322, p = 0.01). The model residuals indicated an acceptable fit, subsequently confirmed by the Ljung-Box test (Q = 53.437, p = 0.111).

Table 6: Full time series ARIMA (4,0,0) $(0,0,0)_{52}$ model parameters, vegan (selected branch)

Parameter	Coefficient	Standard error	P-value
AR(1)	0.103	0.046	$p < 0.05$
AR(2)	0.054	0.046	$p = 0.240$
AR(3)	0.105	0.047	$p < 0.05$
AR(4)	0.283	0.047	$p < 0.001$
Intercept	0.012	0.002	$p < 0.001$
AOL, Week 138 (2019)	0.090	0.016	$p < 0.001$
AOL, Week 173 (2020)	0.079	0.016	$p < 0.001$
AOL, Week 197 (2020)	0.056	0.017	$p < 0.001$
IOL, Week 96 (2018)	0.072	0.016	$p < 0.001$
IOL, Week 114 (2018)	0.082	0.017	$p < 0.001$
IOL, Week 129 (2019)	0.095	0.016	$p < 0.001$
IOL, Week 241 (2021)	0.082	0.016	$p < 0.001$
ω_1 2020	-0.001	0.016	$p = 0.953$
ω_1 2021	-0.007	0.016	$p = 0.649$
ω_1 2022	-0.007	0.016	$p = 0.653$

Log likelihood = 760.08, AIC = -1490.17

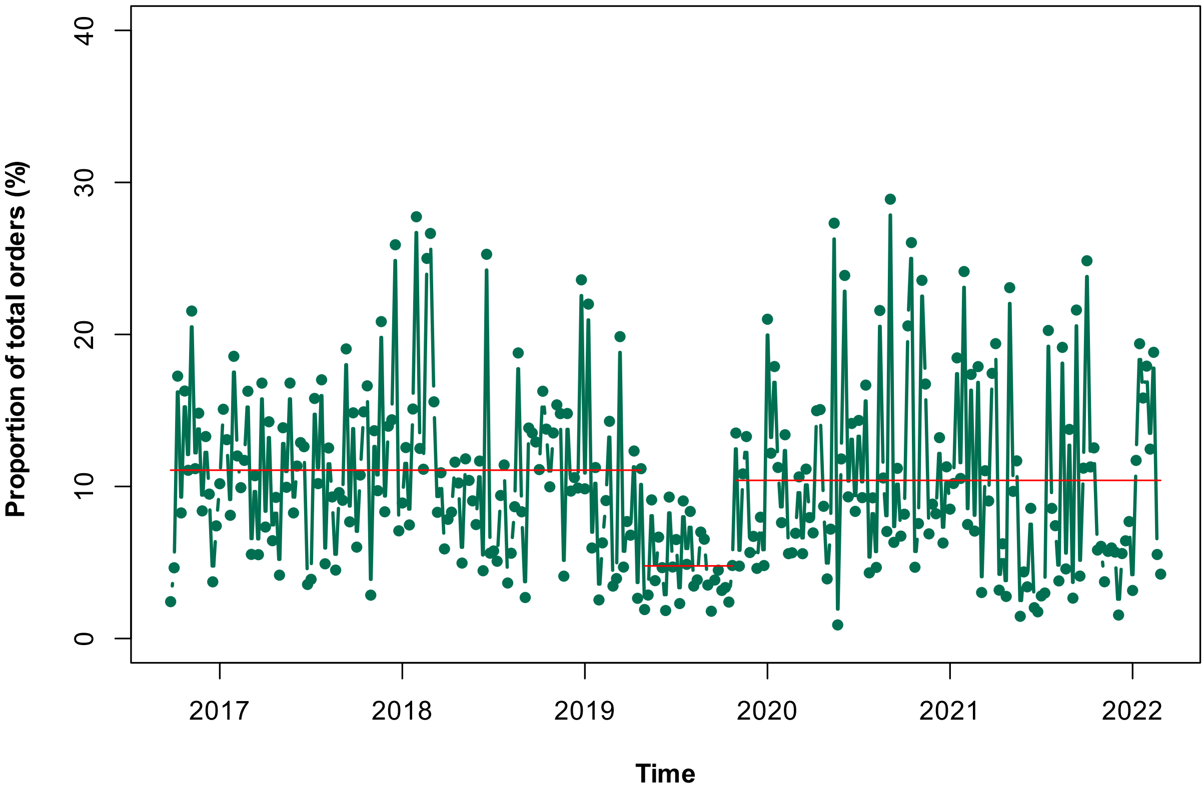
Intervention analysis model

As Table 6 shows, the vegan product sales treatment effects observed for the aggregate were not observed in the randomly selected branch. Specifically, none of the transfer functions for the 2020 (ω_1 2020 = -0.001), 2021 (ω_1 2021 = -0.007) and 2022 (ω_1 2022 = -0.007) campaigns were statistically significant and were near zero in value, suggesting a negligible campaign impact.

Vegetarian sales

In comparison to the branch's vegan sales, vegetarian sales were more consistent across the time series (see Figure 11). Aside from a significant decrease in the latter half of 2019 – which coincided with a reduction in the availability of vegan products across the aggregate dataset – vegetarian sales accounted for approximately 10% of the branch's sales, on average.

Figure 11: Vegetarian sales (weekly), proportion of total sales (selected branch)



Model fitting – Intervention analysis

In intervention analysis, an ARIMA (0,0,4) $(0,0,0)_{52}$ model with an intercept was fitted. An augmented Dickey-Fuller test confirmed differencing was not needed (ADF = -4.914, p = 0.01). Model residuals suggested the model was acceptable, confirmed by the Ljung-Box test (Q = 51.305, p = 0.345).

Table 7: Full time series ARIMA (0,0,4) $(0,0,0)_{52}$ model parameters, vegetarian (selected branch)

Parameter	Coefficient	Standard error	P-value
MA(1)	0.021	0.057	$p = 0.718$
MA(2)	0.114	0.057	$p < 0.05$
MA(3)	0.057	0.057	$p = 0.316$
MA(4)	0.278	0.057	$p < 0.001$
Intercept	0.100	0.005	$p < 0.001$
IOL, Week 206 (2019)	0.195	0.056	$p < 0.001$
ω_1 2019	0.119	0.053	$p < 0.05$
ω_1 2021	-0.013	0.053	$p = 0.805$
ω_1 2022	0.070	0.053	$p = 0.189$

Log likelihood = 419.12, AIC = -820.23

Intervention analysis model

As Table 7 indicates, only one of the treatment effects for vegetarian products observed for the aggregate was also observed in the chosen branch. While there was a relatively large 11.9 percentage point increase in the purchase of vegetarian products in the 2019 campaign period (ω_1 2019 = 0.119, $p < 0.05$), there were no statistically significant changes in sales in 2021 and 2022.

5.Discussion

Results in the context of the literature

This study sought to investigate the impact of an annually recurring campaign that promotes plant-based products in 36 workplace cafeterias serviced by a large UK catering company. The results of this study indicate that the campaign has had a consistent positive impact on the sales of both vegan and vegetarian products across branches, although its success has differed according to year. When observed, the positive effects of the campaign typically persisted beyond the immediate campaign period.

In terms of vegan options, statistically significant increases in the proportion of vegan products purchased were noted for the 2020, 2021 and 2022 campaign periods, with the largest uplifts noted for the latter two periods.

In isolation, the absolute increases appear small – a 1.6 percentage point increase in 2020, a 2.1 percentage point increase in 2021 and a 2.1 percentage point increase in 2022. However, considering that vegan sales only account for a small proportion of total small percentage point increases convert to large increases in relative terms.

Additionally, increases persisted over time, apart from in 2022, the 2020 and 2021 campaign effects' decays were gradual, meaning small increases in consumption appeared to be present in subsequent years. However, similar treatment effects were not observed in a randomly selected branch, suggesting differences of campaign effects across branches.

Vegetarian sales also significantly rose in three of the four years in which the campaign ran: 2019 (a 3.2 percentage point increase), 2021 (a 2.8 percentage point increase) and 2022 (a 9.7 percentage point increase). However, these increases do not indicate such a high relative increase as vegan products as vegetarian purchases were higher than vegan (for example, 11.74% of total sales were vegetarian meals in January 2017 and 12.50% in January 2018).)

As for vegan products, the impact of the campaigns in the former two years was relatively persistent: for 2019, positive effects appeared to be present in 2020; and for 2021, the effects appeared to be present until the end of that year. When examining data for a randomly selected branch, effects were only observed in 2019, suggesting heterogeneity across branches again.

The effect sizes observed in this study are broadly comparable with those observed in the literature. Garnett et al. (2019) in their cafeteria study observed that increasing the number of plant-based products on cafeteria menus led to a proportional increase in the consumption of vegetarian meals of 41% to 79%, depending on site. Similarly, the study found the campaign in this study resulted in an initial increase of 23% - 79% in the proportion of total weekly sales for vegetarian products relative to the baseline level, depending on the year. Further, the effects for vegan products relative to the baseline level were larger – 86% to 113% – due to the low absolute level of vegan sales before the introduction of the campaigns. However, of note, in the aforementioned paper and in the current literature, the longevity of changes in sustainable sales over subsequent years was not measured. Therefore, the current study contributes new evidence regarding the potential endurance of similar interventions.

There are several factors that are likely to have contributed to the overall success of the yearly campaigns. First, in a result congruent with the findings of Garnett et al. (2019), Pechey et al. (2019), and Public Health England (2018), altering the availability of vegan and vegetarian products appeared to positively influence consumption. Specifically, the years in which plant-based products accounted for a higher proportion of products were the years in which significant increases in sales were observed. Further, statistically significant associations between vegan/vegetarian product availability and sales were noted. These results suggest that, when used in collaboration with promotional material that increases salience, increasing the availability of vegan and vegetarian items in cafeteria menus can have an ongoing positive impact on sales.

While the availability of products likely had a pronounced positive impact in this study, it is unlikely to be wholly responsible for the observed campaign effects. In 2022, the peak impact in vegetarian sales vastly surpassed that of previous years; however, the number of plant-based options was similar to 2021. Further analysis suggested that this increase was, in part, caused by the introduction of a new vegetarian meal (Spinach and Ricotta Cannelloni) that was one of the five highest selling vegetarian meals that year.

Finally, the rapidly increasing consumption of plant-based options may have played some unmeasurable role in the observed larger effects in recent years. Over the past decade, there have been considerable increases in both the proportion of the population who identify as vegan and the number of consumers who have tried plant-based options. A study analysing food consumption data from the National Diet and Nutrition Survey found that consumption of plant-based foods increased from 6.7% in 2008–2011, to 13.1% in 2017–2019 ($p < 0.01$) (Alae-Carew et al., 2022).

Previous research has observed that once actions become embedded in a culture or society, wide-spread behaviour change often follows (Gelfand and Jackson, 2016); in this case, the “mainstreaming” of veganism and plant-based consumption may have had an impact on consumption. Specifically, each year, more consumers chose plant-based options; as such, the choices of fellow consumers were increasingly likely to have been affected via normative social influence (Einhorn, 2020). If present, one might expect the effect of normative influence to be augmented by the increased product availability noted above.

Strengths, limitations and considerations for future research

The strengths of this study should be noted. First, this study involved the application of a robust analytical technique to interrogate an expansive, dynamic dataset encompassing 2,255,404 meals and 1,838 products. Second, the dataset included workplace cafeterias from five client companies that a large contract catering company served, with geographically dispersed branches spanning much of the United Kingdom. It provided a unique opportunity to examine the effects of an annual campaign focusing on promoting plant-based meal options which was of a relatively large scale.

However, this study also has several limitations that must be acknowledged and considered alongside its strengths. First, the exclusion procedure could have led to selection bias in the set of branches included in the final dataset. The analysis excluded branches with more than 5% missing data or that had missing data for two consecutive weeks, in order to ensure quality of data after imputation. However, exclusion of these branches could have led to sample bias. For example, if the amount of missing data was correlated with level of sales, then we could have ended up selecting relatively larger cafeterias. Also, as relatively longer periods of shutdown during the COVID-19 pandemic would have led to a substantial amount of missing data, the exclusion procedure should have also resulted in selection of branches that were open consistently during the COVID-19 lockdown periods. The study did not have data on the characteristics of the cafeterias to examine the potential selection bias, but one should bear such issues in mind when interpreting and generalising the findings. In addition, a substantial amount of imputation was required to populate missing values in the dataset. While this is not a problem in and of itself, the variability in data across days, weeks and years lowered the accuracy of imputation for vegan sales, in particular. Nonetheless, the study dataset only included branches in which missing data accounted for less than 5% of the total time series; therefore, we maintain that the overall impact of this imputation is likely to be minimal.

The second limitation of this study is that the campaign was only implemented in a limited number of cafeterias in the United Kingdom, which belonged to a selected set of client companies served by the large catering company. While the number of cafeterias in this study's dataset was large compared to many in the literature, the extent to which the results may be generalised – that is, whether similar interventions could be implemented at scale (including internationally) – remains unclear. Indeed, in this study's sensitivity analysis, the annual campaign effects observed at an aggregate level were not consistently observed for a randomly selected branch. Similarly, Pechey et al. (2019) found that effects only existed in two out of the six worksite cafeterias they studied, suggesting that a degree of heterogeneity of effect might be a general feature of such interventions and should be investigated in future research.

The third limitation of this study is that limited information was available about the details of the annual campaign activities and the fidelity of the implementation of the campaign activities across the cafeterias. Differential levels of fidelity could contribute to the inconsistency of effects between the aggregate level and the individual branch level; lower fidelity was also likely to be a problem during the COVID-19 period when supply chain issues were serious.[13] Lack of data on intervention implementation restricts our ability to conduct more detailed and in-depth examination of the mechanisms that drove the intervention effects and the heterogeneity across years and branches.

Future studies should also seek to examine the extent to which the efficacy of similar

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[13] In addition to the problems of missing data/exclusion of branches and implementation fidelity, total footfall and sales may have been lower during the COVID-19 period as well. We did not have information on the operation of the workplace cafeterias, but we did observe a drop of total sales in the second quarter of 2020 using the final dataset; however, the level bounced back in the second half of 2020 and was higher in 2021 than the pre-COVID-19 level. We expected the ARIMA model to capture these trends in the time series data; in addition, if there was any significant shock that resulted in a large temporary change in the outcome variables, it would have been captured by the outliers detected in the modelling procedure (see the methods section for more details on outlier detection). More importantly, we used proportions of vegan/vegetarian sales out of total sales, rather than the absolute vegan/vegetarian sales as our primary outcome variables; unlike the absolute sales level, the data of the two primary outcomes did not exhibit significant changes during the COVID-19 period.

interventions – which manipulate the choice architecture in cafeterias and similar outlets – may be enhanced by other interventions. Research has indicated that traditional economic interventions, such as small discounts, can increase the sales of sustainable foods (Garnett et al., 2019); however, the extent to which such interventions can work in concert should be explored.

Conclusion

In spite of these limitations, this study provides unique evidence regarding the potential efficacy – and longevity – of the effects of internal promotions on plant-based products - which increased the availability and salience of plant-based meal options. Additionally, the intervention investigated in this study is relatively low cost – particularly as plant-based options are reducing in cost (Proveg, 2022) – and relatively straightforward to implement compared to other interventions such as customer education and individual lifestyle counselling. Therefore, similar approaches may play an important role in helping to increase the adoption of a more plant-based foods.

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Appendix

Additional data on product availability and price

Table 8: Availability of vegan and vegetarian products for different periods

Period	Number of all products (per week on average)	Number of Vegan products per week (per week on average)	Number of vegetarian products (per week on average)	Proportion of vegan products (per week on average)	Proportion of vegetarian products (per week on average)
Baseline period	955	25	188	2.63%	19.79%
January 2017	1049	26	183	2.45%	17.49%
January 2018	886	19	185	2.12%	20.82%
Campaign period 2019	**810**	**28**	**201**	**3.31%**	**24.58%**
Non-campaign period 2019	911	11	178	1.16%	19.56%
1st Quarter 2019	867	29	205	3.24%	23.73%
2nd-4th Quarter 2019	914	7	172	0.74%	18.80%
Campaign period 2020	**901**	**27**	**190**	**2.97%**	**21.08%**
Non-campaign period 2020	843	23	179	2.64%	21.13%
1st Quarter 2020	885	30	191	3.33%	21.62%
2nd-4th Quarter 2020	836	21	177	2.46%	20.97%
Campaign period 2021	**896**	**61**	**216**	**6.77%**	**24.08%**

Period	Number of all products (per week on average)	Number of Vegan products per week (per week on average)	Number of vegetarian products (per week on average)	Proportion of vegan products (per week on average)	Proportion of vegetarian products (per week on average)
Non-campaign period 2021	801	47	172	5.69%	21.08%
1st Quarter 2021	878	54	203	6.10%	23.00%
2nd-4th Quarter 2021	788	46	167	5.67%	20.81%
Campaign period 2022	**759**	**40**	**182**	**5.24%**	**23.87%**

Table 9: Prices of vegan, vegetarian and non-vegetarian products for each year

Year	Average amount paid for a vegetarian meal (£)	Average amount paid for a vegan meal (£)	Average amount paid for a non-vegetarian meal (£)	Ratio of vegetarian to non-vegetarian meal	Ratio of vegan to non-vegetarian meal
2017	2.36	2.65	2.75	85.8%	96.3%
2018	2.32	2.17	2.62	88.4%	82.9%
2019	2.39	2.23	2.81	85.0%	79.4%
2020	2.36	2.87	2.78	84.7%	103.2%
2021	2.53	2.64	2.81	90.3%	94.2%
2022	2.70	2.75	2.71	99.4%	101.4%

Intervention analysis model additional outputs, vegan data

Table 10: Pre-campaign ARIMA (3,1,1) $(0,0,0)_{52}$ model parameters, vegan

Parameter	Coefficient	Standard error	P-value
AR(1)	-0.331	0.119	p < 0.01
AR(2)	-0.390	0.110	p < 0.001
AR(3)	-0.315	0.110	p < 0.01
MA(1)	-0.717	0.097	p < 0.001

Log likelihood = 419.04, AIC=-828.09

Table 11: Alternative ARIMA models for the pre-campaign period, including AIC values, vegan

Model	With drift?	AIC
ARIMA(2,1,2)	With drift	-823.492
ARIMA(0,1,0)	With drift	-744.793
ARIMA(1,1,0)	With drift	-768.809
ARIMA(0,1,1)	With drift	-819.829
ARIMA(0,1,0)	-	-746.772
ARIMA(2,1,1)	With drift	-821.979
ARIMA(3,1,2)	With drift	-824.978
ARIMA(3,1,1)	With drift	-826.925
ARIMA(3,1,0)	With drift	-810.487
ARIMA(4,1,1)	With drift	-824.989
ARIMA(2,1,0)	With drift	-782.973
ARIMA(4,1,0)	With drift	-818.235

Model	With drift?	AIC
ARIMA(3,1,1)	-	-828.087
ARIMA(2,1,1)	-	-822.809
ARIMA(3,1,0)	-	-812.401
ARIMA(4,1,1)	-	-826.112
ARIMA(3,1,2)	-	-826.109
ARIMA(2,1,0)	-	-784.946
ARIMA(2,1,2)	-	-824.704
ARIMA(4,1,0)	-	-820.066
ARIMA(4,1,2)	-	-824.65
ARIMA(2,1,2)(0,1,0)[52]	-	-403.2494
ARIMA(0,1,0)(0,1,0)[52]	-	-364.5596
ARIMA(1,1,0)(0,1,0)[52]	-	-380.213
ARIMA(0,1,1)(0,1,0)[52]	-	-405.5357
ARIMA(1,1,1)(0,1,0)[52]	-	-404.6834
ARIMA(0,1,2)(0,1,0)[52]	-	-405.3587
ARIMA(1,1,2)(0,1,0)[52]	-	-404.5259

Intervention analysis - outliers

Aside from the campaign periods, highly significant innovative and additive outliers[14] were detected. Innovative outliers were observed in Weeks 207 and 240 (weeks 37 and 17 of 2020 and 2021, respectively), and an additive outlier was observed in Week 180 (week 10 of 2000).

The lack of periodicity between these outliers suggests that these are not related to seasonal consumption patterns.

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[14] Innovative outliers refer to outliers which have an effect on subsequent observations, while additive outliers refer to those which do not. See Chang, I.H., Tiao, G.C. and C. Chen (1988). Estimation of Time Series Parameters in the Presence of Outliers. *Technometrics*, 30, 193-204.

Figure 12: Distribution of standardised residuals and ACF, pre-campaign ARIMA (3,1,1) (0,0,0)$_{52}$ model (vegan)

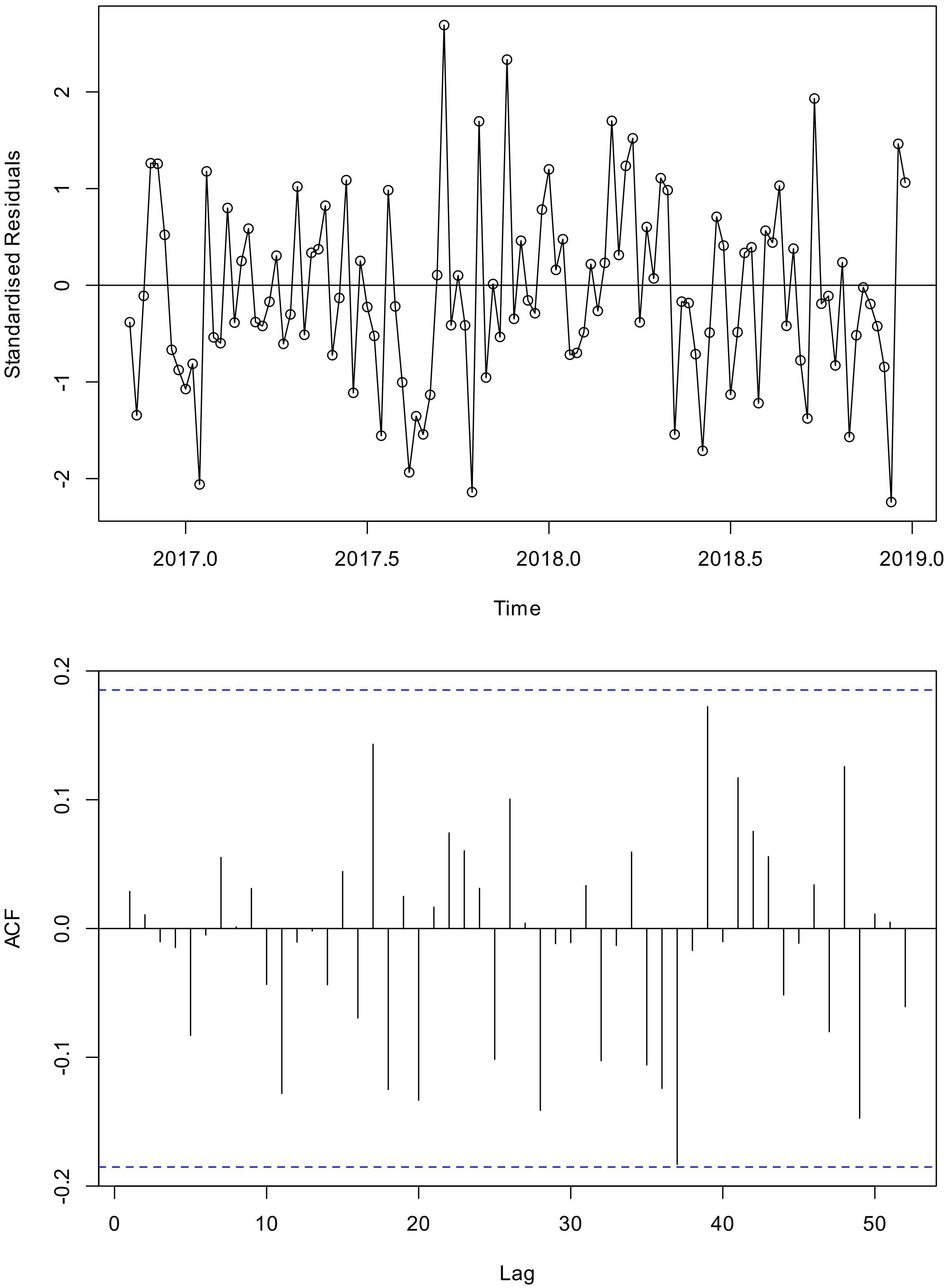
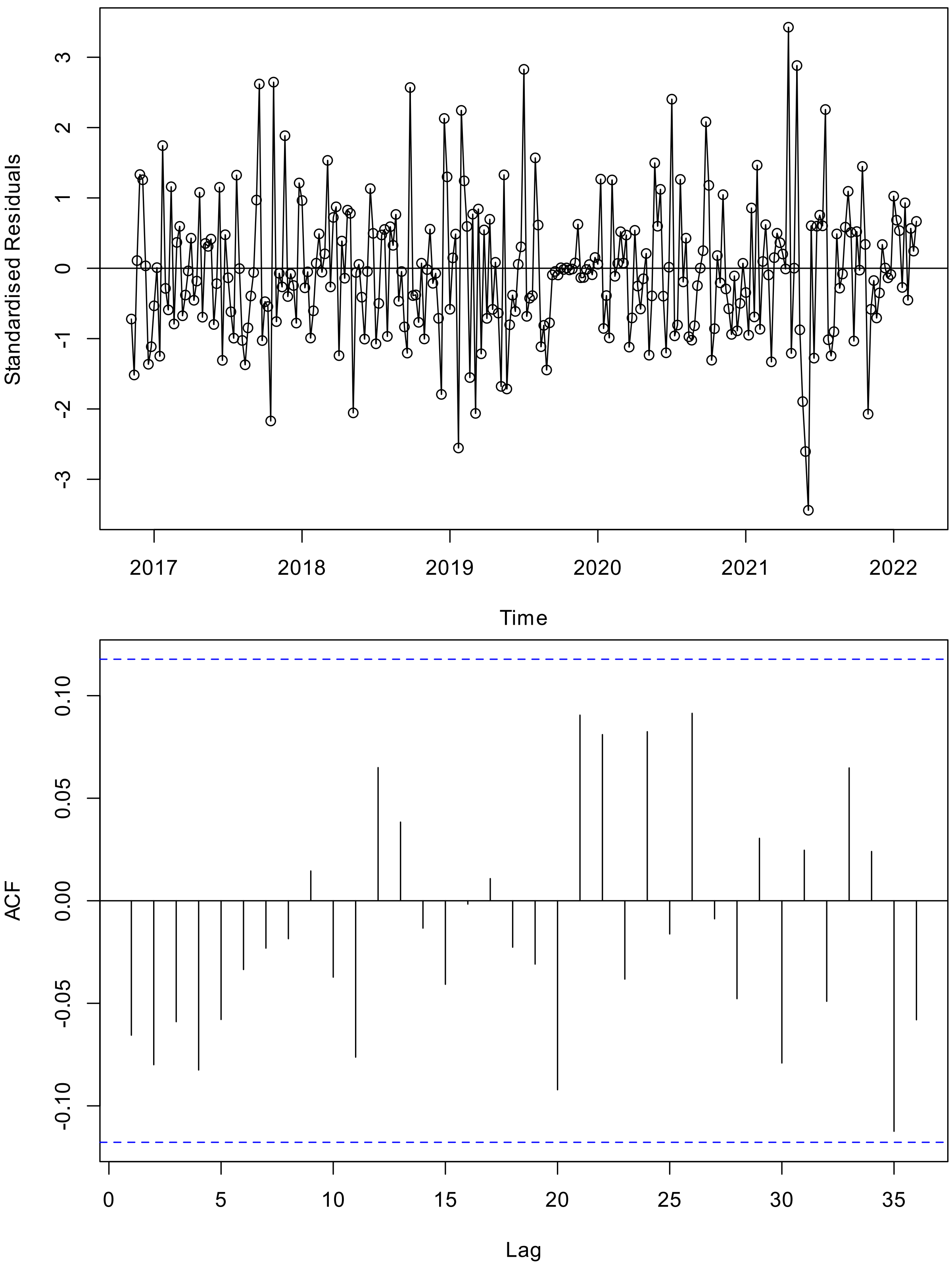


Figure 13: Distribution of standardised residuals and ACF, full time series ARIMA (3,1,0) $(0,0,0)_{52}$ model (vegan)



Secondary outcomes, total sales (vegan)

A different model was fitted to these data: an ARIMA (0,1,1) $(0,0,0)_{52}$. Examination of model residuals indicated an acceptable fit, corroborated by the Ljung-Box Q-statistic (Q = 54.20, $p = 0.139$). The results of this model suggested a similar pattern of results to the primary analysis: significant effects were observed for the 2020, 2021 and 2022 campaign periods, with the smallest peak magnitude observed for 2020 (ω_1 2020 = 135.249, $p < 0.01$), and broadly similar peak magnitudes observed for 2021 (ω_1 2021 = 156.950, $p < 0.05$) and 2022 (ω_1 2022 = 166.558, $p < 0.01$).

Table 12: Secondary analysis (absolute vegan weekly sales), ARIMA (0,1,1) $(0,0,0)_{52}$ model parameters

Parameter	Coefficient	Standard error	P-value
MA(1)	-0.819	0.034	$p < 0.001$
AOL, Week 10 (2016)	244.690	60.447	$p < 0.001$
AOL, Week 180 (2020)	197.091	59.585	$p < 0.001$
IOL, Week 11 (2016)	188.390	63.493	$p < 0.01$
IOL, Week 207 (2020)	150.534	62.328	$p < 0.05$
IOL, Week 224 (2021)	109.466	62.325	$p = 0.079$
IOL, Week 238 (2021)	240.949	62.331	$p < 0.001$
ω_1 2020	135.249	59.725	$p < 0.05$
δ 2020	0.095	0.036	$p < 0.01$
ω_1 2021*	156.950	60.934	$p < 0.05$
δ 2021	0.130	0.015	$p < 0.001$
ω_1 2022	166.558	63.036	$p < 0.01$
δ 2022	0.263	0.090	$p < 0.01$

Log likelihood = -1565.86, AIC = 3157.72

* 2021's impact was lagged a week in this model

Intervention analysis model additional outputs, vegetarian data

Table 13: Pre-campaign ARIMA (4,0,0) $(0,0,0)_{52}$ model parameters, vegetarian

Parameter	Coefficient	Standard error	P-value
AR(1)	-0.057	0.087	p = 0.507
AR(2)	0.030	0.086	p = 0.728
AR(3)	-0.127	0.088	p = 0.146
AR(4)	0.337	0.088	p < 0.001

Log likelihood = 333.07, AIC=-654.13

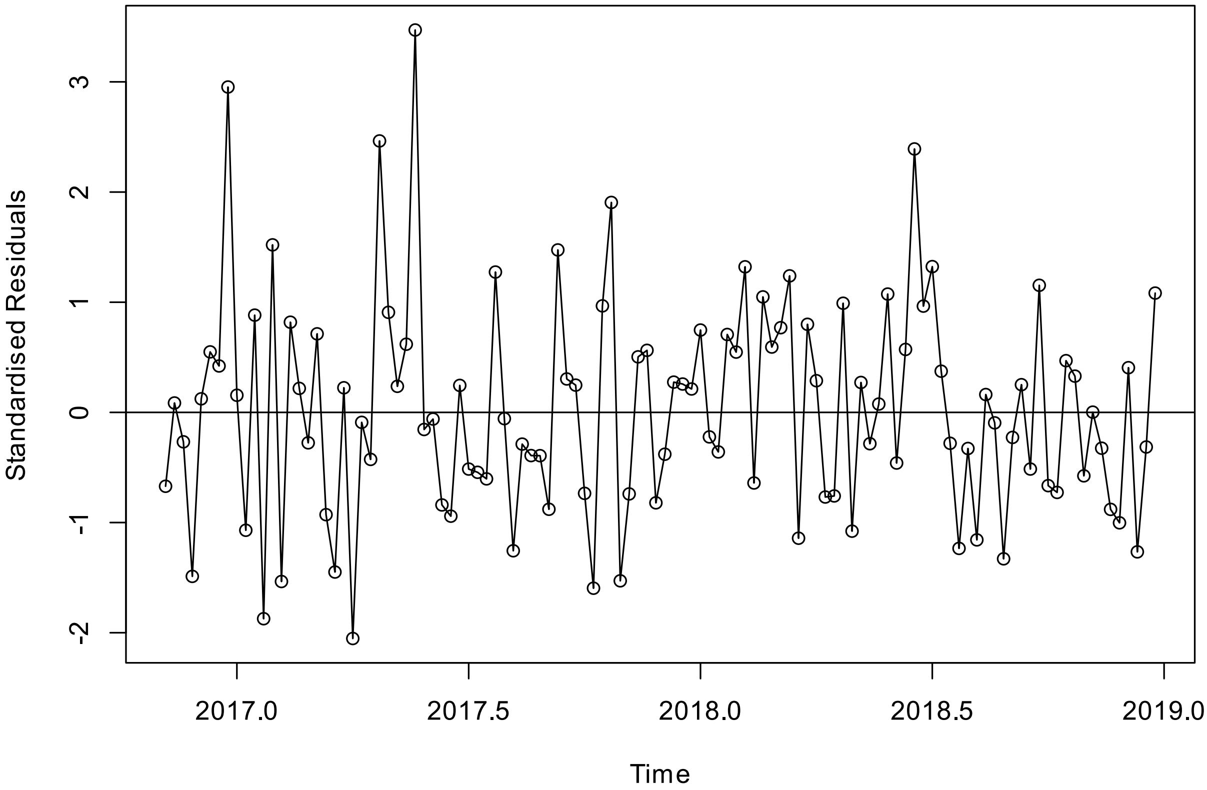
Table 14: Alternative ARIMA models for the pre-campaign period, including AIC values, vegetarian

Model	Mean	AIC
ARIMA(0,0,0)	With zero mean	-157.3592
ARIMA(0,0,0)	With non-zero mean	-641.7266
ARIMA(0,0,1)	With zero mean	-264.234
ARIMA(0,0,1)	With non-zero mean	-641.7996
ARIMA(0,0,2)	With zero mean	-363.4315
ARIMA(0,0,2)	With non-zero mean	-640.0633
ARIMA(0,0,3)	With zero mean	-396.9117
ARIMA(0,0,3)	With non-zero mean	-640.8059
ARIMA(0,0,4)	With zero mean	-425.0282
ARIMA(0,0,4)	With non-zero mean	-648.698
ARIMA(0,0,5)	With zero mean	-454.3674
ARIMA(0,0,5)	With non-zero mean	-647.0897
ARIMA(1,0,0)	With zero mean	-541.756
ARIMA(1,0,0)	With non-zero mean	-642.0666
ARIMA(1,0,2)	With non-zero mean	-638.22
ARIMA(1,0,3)	With non-zero mean	-649.6786
ARIMA(1,0,4)	With non-zero mean	-646.9031
ARIMA(2,0,0)	With non-zero mean	-640.6975
ARIMA(2,0,1)	With non-zero mean	-638.3395
ARIMA(3,0,0)	With non-zero mean	-642.2764
ARIMA(3,0,1)	With non-zero mean	-650.281
ARIMA(3,0,2)	With non-zero mean	-648.5888
ARIMA(4,0,0)	With non-zero mean	**-654.1311**
ARIMA(4,0,1)	With non-zero mean	-652.2098
ARIMA(5,0,0)	With non-zero mean	-652.2488

Outliers

Aside from the campaign periods, highly significant innovative and additive outliers were detected. Innovative outliers were observed in Week 140 (week 22 of 2019), Week 236-239 (week 13-16 of 2021), Week 251 (week 28 of 2021), and Week 278 (week 3 of 2022). Additive outliers were observed in Week 14 (week 52 of 2016), Week 35 (week 21 of 2017), and Week 240 (week 17 of 2021).

Figure 14: Distribution of standardised residuals and ACF, pre-campaign ARIMA (4,0,0) $(0,0,0)_{52}$ model (vegetarian)



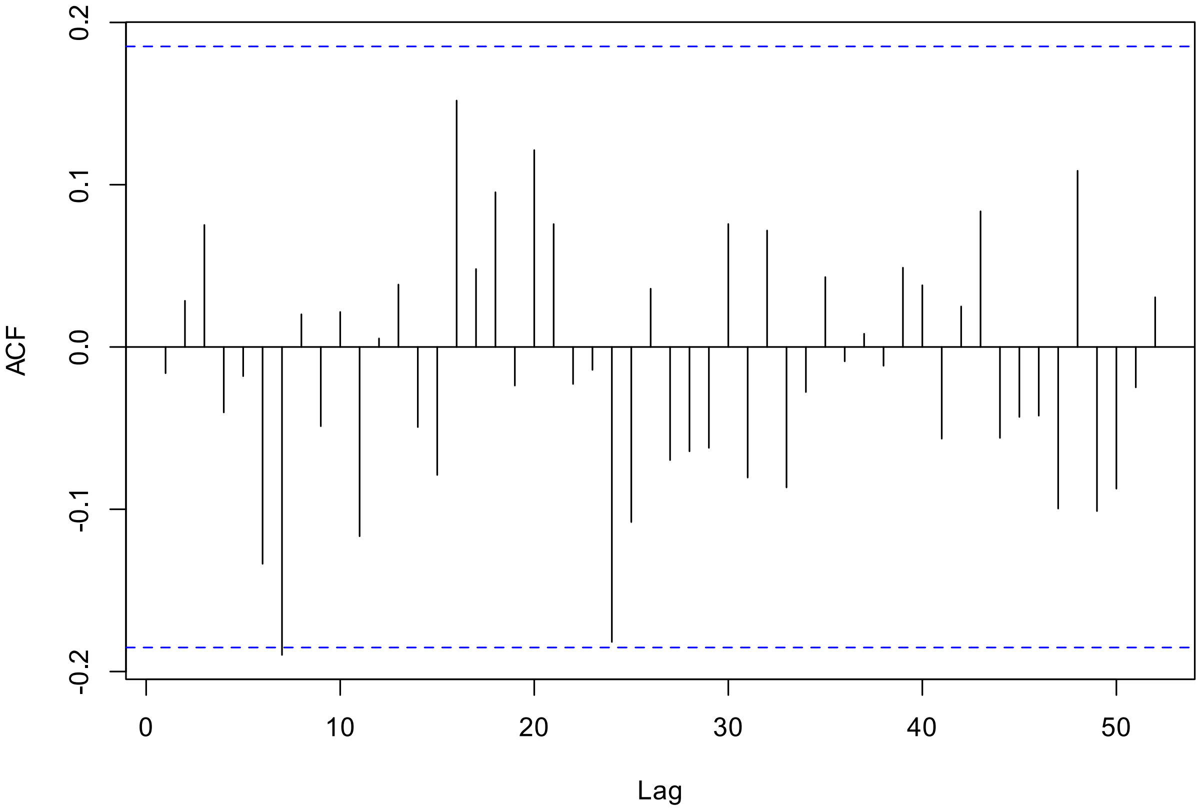
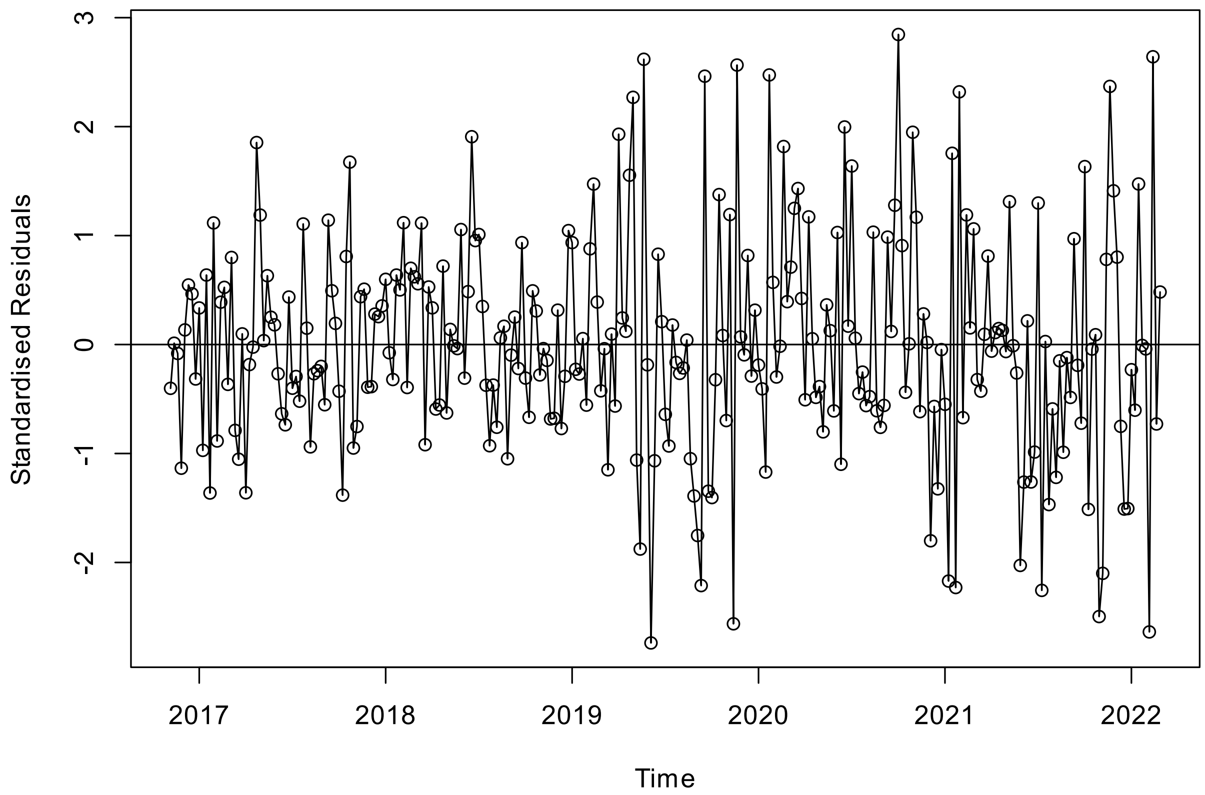
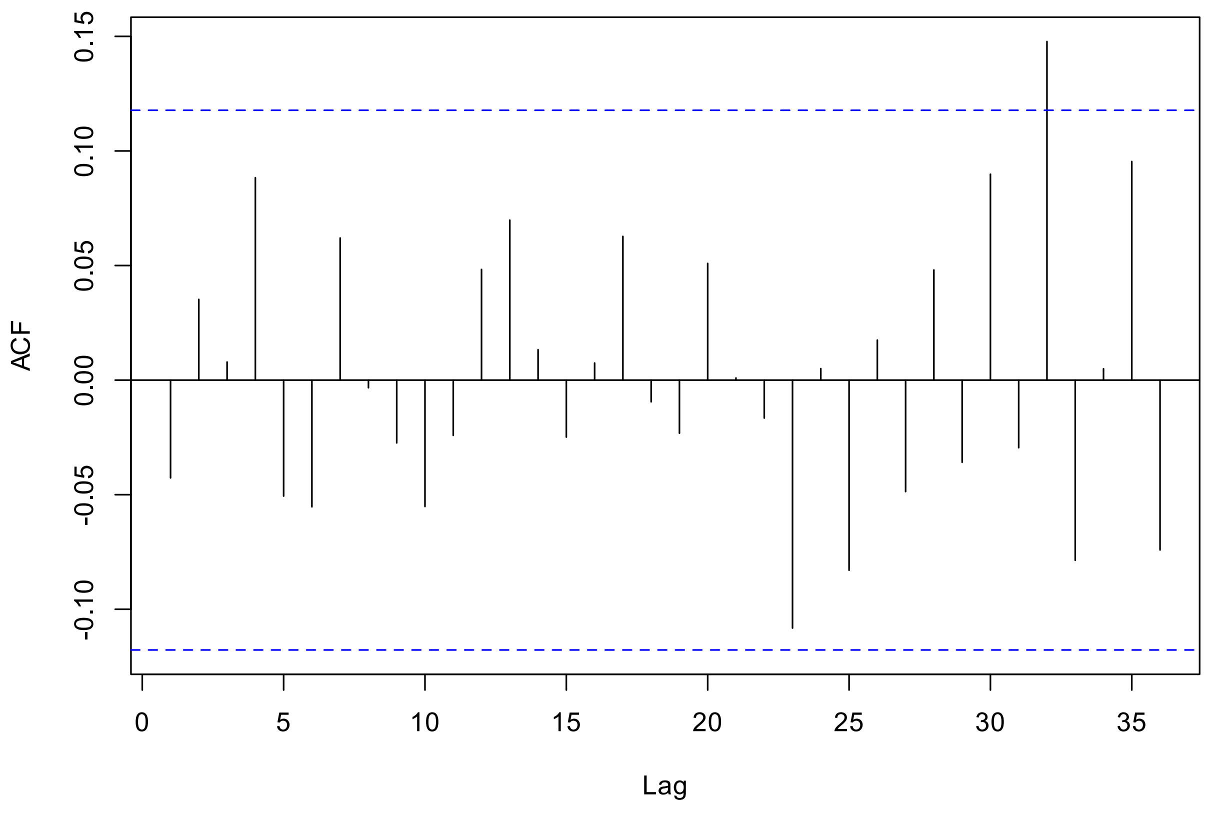


Figure 15: Distribution of standardised residuals and ACF, full time series ARIMA (4,0,0) $(0,0,0)_{52}$ model (vegetarian)





Secondary outcomes, total sales (vegetarian)

A different model was fitted to these data: an ARIMA (15,0,0) $(1,0,0)_{52}$ with three transfer functions taking the same form as the primary analysis. Examination of model residuals indicated an acceptable fit, corroborated by the Ljung-Box Q-statistic (Q = 34.89, p = 0.378).

The coefficients denoting the campaign period for the 2019 (ω_1 2019 = 183.943, p = 0.270), 2021 (ω_1 2021 = 227.618, p = 0.190) and 2022 (ω_1 2022 = 319.043, p = 0.101) were not statistically significant, likely due to challenges modelling the outcome due to additional variability in the outcome variable. Nonetheless, they had a broadly similar pattern to those from the primary analysis: the highest parameter coefficient was observed for 2022.

Table 15: Secondary analysis (absolute vegetarian weekly sales), ARIMA (15,0,0) $(1,0,0)_{52}$ model parameters

Parameter	Coefficient	Standard error	P-value
AR(1)	0.028	0.060	p = 0.640
AR(2)	0.394	0.059	p < 0.001
AR(3)	-0.004	0.066	p = 0.953
AR(4)	0.304	0.064	p < 0.001
AR(5)	-0.092	0.066	p = 0.163
AR(6)	-0.115	0.066	p = 0.082
AR(7)	0.105	0.067	p = 0.118
AR(8)	0.158	0.066	p < 0.05
AR(9)	0.084	0.066	p = 0.208
AR(10)	-0.072	0.067	p = 0.281
AR(11)	0.070	0.068	p = 0.301

Parameter	Coefficient	Standard error	P-value
AR(12)	-0.086	0.064	p = 0.184
AR(13)	0.163	0.066	p < 0.05
AR(14)	-0.028	0.062	p = 0.652
AR(15)	-0.227	0.062	p < 0.001
SAR(1)	0.325	0.074	p < 0.001
Intercept	988.803	51.632	p < 0.001
IOL, Week 225 (2021)	950.170	207.314	p < 0.001
ω_1 2019	183.943	166.773	p = 0.270
δ 2019	0.000	0.014	p = 0.990
ω_1 2021	227.618	173.531	p = 0.190
δ 2021	0.000	0.023	p = 0.983
ω_1 2022	319.043	194.408	p = 0.101
δ 2022	0.004	0.070	p = 0.950

Log likelihood = -1907.25, AIC = 3862.5

Secondary outcomes, total sales (all products)

A different model was fitted to these data: an ARIMA (3,1,0) $(0,1,1)_{52}$ with four transfer functions taking the simple form $\omega_1 P_t^{(T)}$, where ω_1 represented the immediate effect of the intervention. Examination of model residuals indicated an acceptable fit, corroborated by the Ljung-Box Q-statistic (Q = 57.69, p = 0.097).

The results of this model suggested a significant increase in total sales in the 2021 campaign period, and no significant changes of total sales in the 2019, 2020 and 2022 campaign periods.

Table 16: Secondary analysis (absolute total weekly sales), ARIMA (3,1,0) $(0,1,1)_{52}$ model parameters

Parameter	Coefficient	Standard error	P-value
AR(1)	-0.636	0.079	$p < 0.001$
AR(2)	-0.228	0.092	$p < 0.05$
AR(3)	-0.285	0.075	$p < 0.001$
SMA(1)	-0.380	0.081	$p < 0.001$
AOL, Week 54 (2017)	-884.482	565.176	$p = 0.118$
AOL, Week 55 (2017)	-512.342	542.635	$p = 0.345$
AOL, Week 222 (2020)	872.831	554.933	$p = 0.116$
AOL, Week 283 (2022)	-4110.166	717.997	$p < 0.001$
ω_1 2019	446.066	571.986	$p = 0.435$
ω_1 2020	435.884	595.587	$p = 0.464$
ω_1 2021	2243.308	599.502	$p < 0.001$
ω_1 2022	-1024.164	652.039	$p = 0.116$

Log likelihood = -1840.95, AIC = 3705.9

Sensitivity analysis – Individual branch

Model fitting – Pre-intervention model, vegan

An ARIMA (3,1,0) $(0,0,0)_{52}$ model without drift was the best fit for the unperturbed data, based on AIC (AIC = -547.39). An augmented Dickey-Fuller test confirmed differencing was needed (ADF = -2.875, $p = 0.213$). The model residuals indicated a satisfactory fit, confirmed by the Ljung-Box Q statistic (Q = 19.107, $p = 0.839$).

Model parameters can be seen below in Table 17.

Table 17: Pre-campaign ARIMA (3,1,0) $(0,0,0)_{52}$ model parameters (selected branch), vegan

Parameter	Coefficient	Standard error	P-value
AR(1)	-0.730	0.085	p < 0.001
AR(2)	-0.710	0.092	p < 0.001
AR(3)	-0.515	0.086	p < 0.001

Log likelihood = 283.22, AIC= -547.39

Model fitting – Pre-intervention model, vegetarian

An ARIMA (0,0,5) $(0,0,0)_{52}$ model with an intercept was the best fit for the unperturbed data, based on AIC (AIC = -356.67). An augmented Dickey-Fuller test confirmed that data were stationary (ADF = -4.0127, $p < 0.05$). The model residuals indicated an acceptable fit, confirmed by the Ljung-Box Q statistic (Q = 10.859, $p = 0.900$).

Model parameters can be seen below in Table 18.

Table 18: Pre-campaign ARIMA (0,0,5) $(0,0,0)_{52}$ model parameters (selected branch), vegetarian

Parameter	Coefficient	Standard error	P-value
MA(1)	0.033	0.097	p = 0.736
MA(2)	0.050	0.087	p = 0.557
MA(3)	-0.037	0.096	p = 0.699
MA(4)	0.349	0.094	p < 0.001
MA(5)	-0.154	0.094	p = 0.102
Intercept	0.113	0.006	p < 0.001

Log likelihood = 283.22, AIC= -547.39

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