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Classification

SOCIAL SCIENCES: Sustainability Science

Title

Impact of increasing vegetarian availability on meal selection and sales in cafeterias

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Data deposition

The aggregate data and summaries of the individual-level data can be found at https://doi.org/10.17863/CAM.41328 .

Abstract

Shifting people in higher-income countries towards more plant-based diets would protect the natural environment and improve population health. Research in other domains suggests altering the physical environments in which people make decisions ("nudging") holds promise for achieving socially desirable behaviour change. Here we examine the impact of attempting to nudge meal selection by increasing the proportion of vegetarian meals offered in a year-long large-scale series of observational and experimental field studies. Anonymised individual-level data from 94,644 meals purchased in 2017 were collected from three cafeterias at an English university. Doubling the proportion of vegetarian meals available from 25% to 50% - e.g. from 1 in 4 to 2 in 4 options - increased vegetarian meal sales (and decreased meat meal sales) by 14.9 and 14.5 percentage points in the observational study (two cafeterias) and by 7.8 percentage points in the experimental study (one cafeteria), equivalent to proportional increases in vegetarian meal sales of 61.8%, 78.8% and 40.8% respectively. Linking sales data to participants' previous meal purchases revealed that the largest effects were found in the quartile of diners with the lowest prior levels of vegetarian meal selection. Moreover serving more vegetarian options had little impact on overall sales and did not lead to detectable rebound effects: vegetarian sales were not lower at other mealtimes. These results provide novel and robust evidence to support the potential for simple changes to catering practices to make an important contribution to achieving more sustainable diets at the population level.

Significance statement

Reducing meat consumption in higher income countries is vital to protect the environment and improve public health. Few studies have tested the real-world performance of different strategies to increase plant-rich diets, and none has examined the impact of altering the availability of vegetarian meal options. In robust observational and experimental studies, we show that doubling the proportion of vegetarian meals offered increases vegetarian sales by between 41% and 79%. Our study is the first study to assess the impact of increasing the proportion of plant-based meal options on selection, and is based on over 90,000 meal choices. We suggest our findings have potential to make a significant contribution to the global ambition for more sustainable diets.

Introduction

High-income countries produce and consume animal-derived food – meat, fish, dairy, eggs – at levels that are incompatible with meeting greenhouse gas emissions (GHGE) reduction targets (1). Livestock and aquaculture are responsible for 56-58% of the global food system's GHGE and use 83% of farmland despite contributing just 18% of calories and 37% of our protein (2). In particular, meat from ruminants (cows, sheep, goats) has average GHGE per kg five times higher than pork, seven times higher than chicken and 43 times higher than legumes (3). Shifting towards a more plant-based diet is therefore one the most effective ways of reducing the environmental footprint of food (2, 4). For the UK it is estimated that switching from a high meat (>100g/day) to an entirely vegetarian diet would reduce the GHGE of a typical person's food by 47% (5).

Shifting diets to achieve sustainability outcomes is likely to require an array of strategies for changing human behaviour (6, 7). Education to bring about behaviour change is a popular and uncontroversial method but – while it can raise awareness – it appear to be largely ineffective at actually changing behaviour (8, 9). Models suggest that taxes on the most polluting foods would result in savings of 1Gt of GHGE worldwide (4) but these taxes can be regressive and are politically unpopular given their lack of public support (8). A third group of interventions – changing the physical, economic and social context (the so-called choice architecture) in which decisions are made – could potentially deliver improved environmental outcomes at a low cost and with little controversy, but so far has received relatively little empirical attention (10–13).

As one form of nudging, altering the relative availability of different food types has shown promise as a lever for changing dietary behaviour to improve population health. Reducing the availability of high calorie foods is estimated to be the third most effective strategy for combatting obesity after lowering portion size, and reformulation, although the evidence for subsequent behaviour change is rated as "limited" (14). A Cochrane review (15) found only five studies on altering availability that met the inclusion criteria (16–20), with a meta-analysis showing a non-significant decrease in consumption and a large significant decrease in selection. Other studies on availability, not included in the Cochrane review, have found increasing the relative availability of low- and moderate-fat entrées in a USA school cafeteria from 33% to 50% increased their selection by 108% and 63% respectively (21); and in four English workplace cafeterias, decreasing the number of high-calorie cooked meals offered to one option per lunchtime (while keeping the total number of options offered constant) reduced the mean energy per main meal sold by 26.1% (22).

Turning to reducing meat consumption, a recent review found no studies on the effects of changing the availability of plant-based meals (13). The likely patterns are hard to anticipate: at one extreme increasing relative availability might have a directly proportional impact on relative sales; conversely, if people have fixed preferences for meat or vegetarian meals, changing their relative availability might have no impact. It is important in such work that outcomes are assessed over sustained periods, because effects can wane over time (23, 24), and if possible that inter-individual variation is examined too: an online study altering menu configurations found different responses between those who frequently or infrequently ate vegetarian foods (25). However, we are aware of only one study (again focused on health rather than meat consumption) which presents long-term individual-level data on how availability affects food choices (26). There are two further considerations: for any intervention to be acceptable to caterers, it is important that total sales and revenue do not substantially drop as a result (24, 27); and to have a genuinely additional environmental effect it is important there are no sizeable rebound effects (28) whereby meat consumption increases on other occasions. However almost no studies address rebound effects or effects on total sales (24).

To tackle these research gaps, we conducted two studies – one observational and one experimental – in three college cafeterias in the University of Cambridge. These studies examined the effect on vegetarian sales of increasing the proportion of vegetarian options available (hereafter "availability"). We tested the hypothesis that meal selection is influenced by availability, such that increasing the availability of vegetarian options increases their selection. In these studies we take advantage of year-long and anonymised individual-level data to analyse whether increasing vegetarian availability had effects which differed with the prior levels of vegetarian meal consumption of individual diners, affected total sales, or resulted in rebound effects at other mealtimes when vegetarian availability was not altered.

Research setting

We collected data from three University of Cambridge college cafeterias during weekday term-time lunches and dinners (the University's colleges are broadly equivalent to halls of residence). All colleges already varied the number of total meal options and vegetarian options served at lunch and dinner. Vegetarian options contained no meat or fish, but may have included eggs and dairy products; vegan options were entirely plant-based, and therefore contained no eggs or dairy products. Approximately 30% of the vegetarian options on offer were vegan. Hereafter vegetarian and vegan options are both referred to as "vegetarian". Study 1 comprised non-experimental data of 86,932 hot main meals (hereafter referred to simply as "meals"; salads and sandwiches were not included) from Colleges A and B, across lunch and dinner during spring, summer and autumn terms in the 2017 calendar year (Figure 1). Study 2 consisted of experimental data of 7712 meals from College C lunches during autumn term 2017, when we experimentally altered the number of vegetarian options on offer at lunchtimes (Figure 1).

We summarised the sales transaction data into a) aggregate data, summarising the total vegetarian and meat/fish (hereafter simply "meat") sales at each lunch and dinner and b) individual-level data on whether each diner at a meal selected a vegetarian or meat meal. Purchases made with university cards enabled anonymised individual diner-level purchases to be tracked; this is useful in evaluating how diners with different pre-study levels of purchasing vegetarian meals responded to increasing vegetarian availability (Methods). We used the total number of vegetarian and meat meals sold at a mealtime to analyse total sales. Measuring rebound effects, i.e. increased meat purchases at another time, is not possible for Study 1 as vegetarian availability varied across lunches and dinners. For Study 2 – although we cannot completely capture rebound effects as we do not have information on what diners ate outside the cafeteria – as a proxy we measured vegetarian sales at College C during dinner times, which were not included in the experimental intervention. We had originally intended dinners to be included, but this posed too much of an operational burden for the cafeteria (Methods). This created the opportunity to conduct a *post-hoc* analysis of rebound effects that was not part of the original study design.

We estimated the effect of vegetarian availability on vegetarian meal sales and total meal sales, adjusting for other pre-determined variables including day of the week, ambient temperature, average price difference between vegetarian and meat options (Methods) using Linear Models (LMs) and binomial Generalised Linear Models (GLMs) for aggregate data. Binomial Generalised Linear Mixed Models (GLMMs) were used for the individual-level data, with individual diner fitted as a random effect, which allows each diner to have a different likelihood of selecting a vegetarian meal (29). A 95% confidence level was used to calculate confidence intervals (CIs). Models were evaluated using the Akaike Information Criterion (AIC), interpretability and model diagnostics (30).

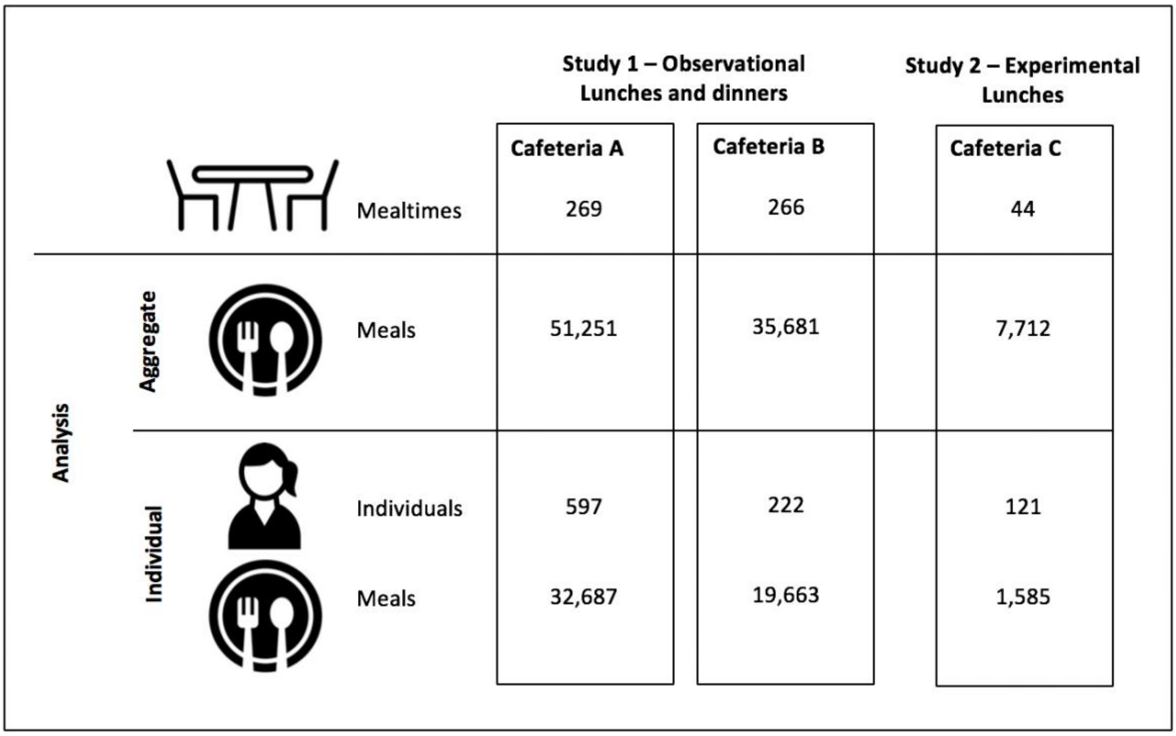

Figure 1: Overview of data and levels of analyses in Study 1 and Study 2. Credit: icons from thenounproject.com.

Study 1: observational

Aims and design

For Study 1 we did not experimentally alter the menu (Supporting Information (SI) Appendix, Tables S1 and S2) but observed the number of vegetarian and meat options available from the sales data. We analysed long-term data from 269 mealtimes at College A and 266 mealtimes at College B. Excluding the few mealtimes where no vegetarian options were served (SI Appendix Tables S3 and S4), vegetarian availability ranged from 16.7% to 75% in College A and 12.5% to 66.7% in College B.

Vegetarian sales: aggregate data

Vegetarian availability alone explained 20.9% and 31.9% of variation in vegetarian sales at College A and College B respectively (Binomial GLMs, McFadden's pseudo R^2). When controlling for other variables the best GLMs for College A and B explained 26.1% and 39.3% respectively of the variability in vegetarian sales (SI Appendix Tables S5 and S6), with vegetarian availability remaining a highly significant predictor of vegetarian sales for both colleges (College A, n= 51,251 meals, $p<0.001$; College B, n= 35,681 meals, $p<0.001$). Specifically, the models estimated that doubling vegetarian availability from 25% to 50% increased vegetarian sales by 61.8% in College A (from 24.1% (CI= 22.5%, 25.7%) to 39.0% (CI= 36.7%, 41.3%) of total sales) and by 78.8% in College B (from 18.4% (CI= 16.8%, 20.1%) to 32.9% (CI= 30.6%, 35.4%), Figure 2a and SI Appendix Tables S5 and S6).

Other variables also correlated with vegetarian sales but often had different effects in the two colleges. For example, as the vegetarian option became relatively cheaper compared to the meat options, vegetarian sales increased in College A but decreased in College B; higher ambient temperatures were associated with higher vegetarian sales in College A but lower vegetarian sales in College B. However, increasing vegetarian availability increased vegetarian sales consistently in a similar way across colleges, indicating a strong and potentially generalizable effect.

Vegetarian sales: individual-level data

1394 identifiable individual diners at College A and 746 at College B used the cafeteria during the study period; this excludes guests and cash-only diners. Of these, 597 and 222 diners, respectively, purchased ≥10 meals in autumn 2016 (prior to our main study) and were divided into quartiles within each college, based on their level of vegetarian meal consumption during this period (Figure 1, Methods and SI Appendix Tables S7 and S8). In both colleges every quartile from the Most Vegetarian to the Least Vegetarian bought more vegetarian meals as vegetarian availability increased (Figure 2b&c). For both Colleges A and B, the Least Vegetarian quartile had the strongest response to increasing vegetarian availability (GLMM, College A, n= 32,687 meals, interaction effect size = 1.012 (CI= 1.004, 1.020), p=0.004; College B, n= 19,663 meals, interaction effect size= 1.024 (CI= 1.014, 1.034), p<0.001, SI Appendix Tables S9 and S10).

Total sales

College A sold an average of 191 main meals at a mealtime, and College B, 134. When adjusted for other variables, increasing vegetarian availability had no significant effect on total sales in College A and a small negative effect in College B where the mean total meals sold decreased from 138 (CI= 129, 147) to 128 (CI= 118, 137) as vegetarian availability increased from 25% to 50% (LM for main meals sold at a mealtime: College A, n=51,251 meals, availability effect size= 1.001 (CI= 0.997, 1.003), p=0.707; College B, n=35,681 meals, availability effect size= 0.998 (CI= 0.997, 0.999), p<0.001)(Figure 2d and SI Appendix Tables S11 and S12). The different quartiles of diners in College A did not respond differently, in terms of number of meals bought at a mealtime, as vegetarian availability increased (LM, n=33,180 meals, interaction terms p>0.05). In College B those in the Least Vegetarian quartile responded more negatively to increasing vegetarian availability than those in other quartiles, in terms of total number of meals purchased (LM, n=19,950 meals, interaction effect size= 0.995 (CI= 0.992, 0.998), p<0.001). This was, however, still a small drop from a mean of 27.4 (CI= 26.2%, 28.6%) meals to 24.7 (CI= 23.2%, 25.9%) as vegetarian availability increased from 25% to 50%.

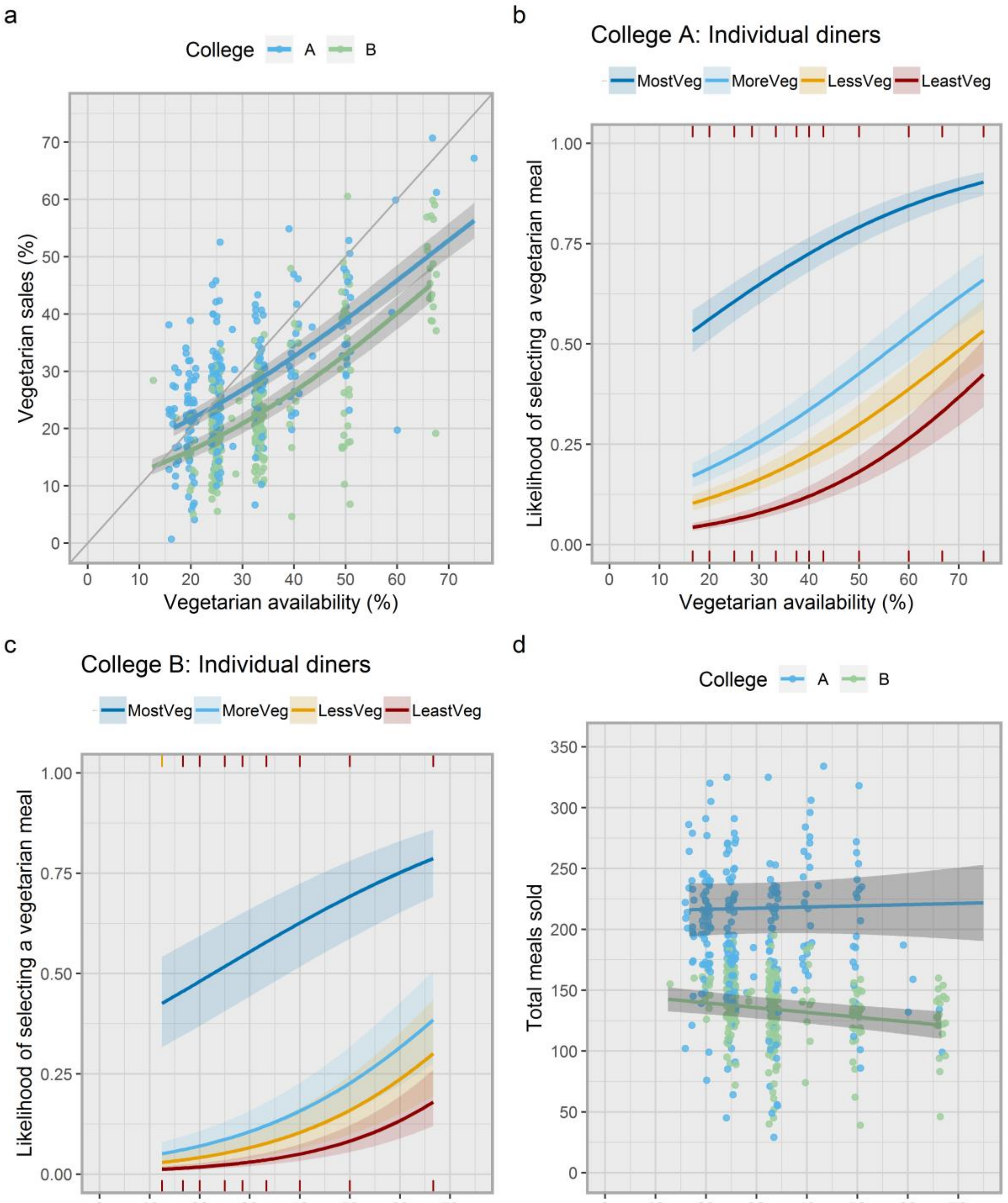

Figure 2: Effects of vegetarian availability on vegetarian and total sales for Study 1. a) Raw values (jittered) of vegetarian sales against vegetarian availability; b and c): Modelled likelihood of selecting a vegetarian meal for individual diners at Colleges A and B, with individual diners divided into Least Vegetarian to Most Vegetarian quartiles; d) Raw values (jittered) of total sales against vegetarian availability. Lines of best fit and confidence intervals generated from the models using conditional regression and the visreg package in R (Methods).

Study 2: experimental

Aims and design

We tested the causality of the association between vegetarian availability and vegetarian sales by running an experiment at College C in autumn term 2017 based on fortnightly alternation between one (control) and two (experiment) vegetarian options at lunchtimes (Methods, SI Appendix Tables S13 and S14 and Figure S1). We analysed data from 44 lunchtimes. Vegetarian availability ranged from 16.7% to 50%, (impacted by differences in the total number of options served, as well as our manipulation, SI Appendix Table S15).

Vegetarian sales: aggregate data

Vegetarian availability alone explained only 3.9% of the variation in vegetarian sales (Binomial GLM, n=7712 meals, McFadden's pseudo R^2=0.039, p<0.001) in a univariate analysis. When controlling for other variables (Methods) 31.8% of the variation was explained (day of the week, week of term and the price differential of vegetarian and meat meals were the predictors which explained most of the variation in vegetarian sales), and availability remained a highly significant predictor of vegetarian sales (p<0.001, Figure 3a and SI Appendix, SI Appendix Table S16). The model estimated that doubling vegetarian availability from 25% to 50% increases vegetarian sales by 40.8% (from 19.1% (CI= 15.1%, 23.9%) to 26.9% (CI= 21.5%, 33.1%) of total sales, SI Appendix Table S16).

Vegetarian sales: individual-level data

121 of the 491 individual diners who bought a main meal during our experiment could be assigned a quartile based on their level of vegetarian meal consumption in the previous term, summer 2017 (Figure 1, SI Appendix Tables S17 and S18). When other variables were controlled for, diners in every quartile (except Most Vegetarian) bought more vegetarian meals in response to increasing vegetarian availability (SI Appendix Table S19). Similarly to Study 1, for College C the Least Vegetarian quartile of diners had a significantly stronger response to increasing vegetarian availability than the other quartiles (GLMM, n=1585 meals, interaction term effect size= 1.053 (CI= 1.002, 1.106), p=0.041, Figure 3b and SI Appendix Table S19).

Total sales and possible rebound effects

College C sold an average of 175 meals per lunchtime and increasing vegetarian availability had no effect on total sales (LM for main meals sold at lunchtime: n=7712 meals, availability effect size= 1.000 (CI= 0.993, 1.004), p=0.942; Figure 3c and SI Appendix Table S20). Moreover the different quartiles of diners responded similarly to each other in terms of numbers of meals bought at a mealtime as vegetarian availability increased (LM, n=3201 meals, interaction terms p>0.1). In College C, unlike in Study 1, vegetarian sales at dinnertimes could be used to explore possible rebound effects. We analysed dinner sales for the 71% of autumn term lunchtime diners who also ate at dinner. When adjusted for other variables, they bought similar numbers of vegetarian meals during the experimental weeks (when there were two vegetarian options at lunchtimes) as in the control weeks (with one vegetarian option)(GLM, control v experimental weeks, n=5287 meals, experimental weeks effect size= 0.953 (CI= 0.795, 1.141), p=0.601, Figure 3d and SI Appendix Table S21). Hence we found no evidence for a rebound effect involving a drop in vegetarian sales at dinnertimes during weeks when there were higher vegetarian sales at lunchtimes.

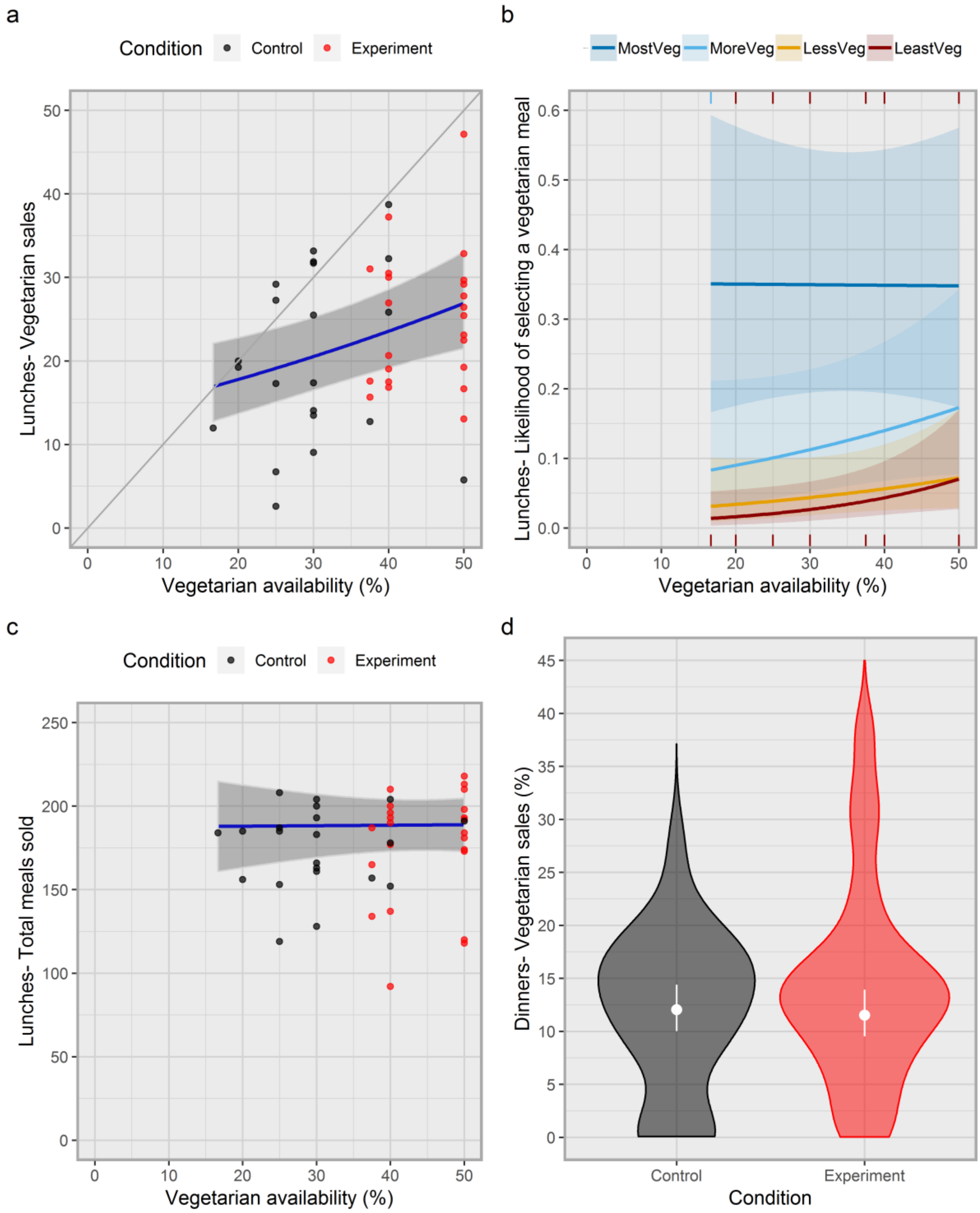

Figure 3: Effects of vegetarian availability on vegetarian and total sales for College C, Study 2. a) Raw values of vegetarian sales against vegetarian availability; b) Modelled likelihood of selecting a vegetarian meal for individual diners, divided into Least Vegetarian to Most Vegetarian quartiles; c) Raw values of total sales against vegetarian availability; d) Raw values of vegetarian sales at dinner during the control and experimental weeks, with model mean estimates and confidence intervals in white. Lines of best fit and confidence intervals in a) and c) and model mean estimate with confidence intervals in d) generated from the models using conditional regression and the visreg package in R (Methods).

Discussion

In all three participating colleges across Study 1 and Study 2 increasing the proportion of vegetarian meals offered increased vegetarian sales, with a large effect size which was greatest amongst those who prior to the study were less likely to select vegetarian meals. To our knowledge this is the first year-long study on how altering availability affects sustainable food choices. From 94,644 meals selected we found that doubling vegetarian availability from 25% to 50% increased vegetarian sales (and decreased meat sales) by 7.8, 14.9 and 14.5 percentage points, equivalent to 40.8%, 61.8% and 78.8% increases. Increasing vegetarian availability had little effect on total sales or vegetarian sales at other mealtimes not involved in experiments, indicating rebound effects were probably small or non-existent. In two out of three cafeterias increasing vegetarian availability did not to lead different responses, in terms of number of meals bought, by diners with different prior levels of vegetarian meal selection. In the third college there was a modest difference (with those previously eating meat responding slightly negatively to increasing vegetarian meal availability) but together these results suggest that increasing vegetarian availability did not substantially put off meat eaters.

Although it might seem intuitive that providing proportionally more vegetarian options would increase vegetarian sales, to our knowledge, this is untested. If meal preferences were fixed, changing the availability of vegetarian options would have no effect. If meal selections were random, this would lead to sales tracking the proportion of each meal option available. Our results indicate that meal selection is neither fixed nor random but rather is partially determined by availability. These results suggest that increasing the proportion of vegetarian options may have a larger effect than many other choice architecture interventions included in a recent systematic review on meat selection and consumption (13): in previous studies neither restructuring food menus with different meal descriptions nor positioning meat in less prominent positions reduced meat uptake. Providing US and UK participants with meat substitutes, recipes and educational materials led to large reductions in meat consumption (13): a 40% reduction in red and processed (31), a 54% reduction in spending on meat (32), and a 70% reduction in meat consumed (33). These results are impressive but, unlike increasing vegetarian availability, are time- and resource-intensive – so may not be scalable – and their effects can diminish over time (24, 31): one paper found that at the end of the intervention meat consumption was 60% lower than at the baseline but after two months the effect had decreased to 40% (31). Reducing the serving size of meat portions reduced meat consumption by 13-14% (34, 35); hence increasing vegetarian availability combined with smaller meat portions could be a powerful combined strategy to reduce the mass of meat served by cafeterias.

Our studies have several strengths. While many recent papers have stressed the importance of reducing meat consumption (1–3, 36) very few studies have tested which interventions might work. For example, a recent systematic review found only 18 studies with 11,290 observations that tested how changing some aspect of choice architecture could reduce meat consumption (13). Our studies have 94,644 observations from months of robust, individual-level data. We collected both observational and experimental data and included analyses on total meal sales. We have shown that increasing vegetarian availability can substantially reduce meat consumption, even for those with low prior levels of vegetarian meal consumption – the most important demographic group to shift to reduce the GHGE of the food system (5).

However, our studies also have several limitations. First, due to the design of the studies, we did not collect data on the nutrition of the cafeteria meals or their palatability to students, which are important considerations for catering managers (12, 37). Second, in keeping with other similar field studies (22), some data were misclassified. Miscoding of a small number of vegetarian meals as meat meals in College C led to a slight underestimate in Study 2 of the effect of vegetarian availability on vegetarian sales (Methods), however this is highly unlikely to change the results in a significant direction.

The current studies suggest opportunities for future research. First, they were conducted in a university setting with students and staff. While this is a good context in which to generate proof-of-concept evidence for the intervention, studies are now needed in other types of food outlets, serving other populations including those in middle and low income countries to estimate the generalisability of the current findings. Second, we were informed by catering managers that ingredients costs were considerably cheaper for vegetarian meals, but that labour costs might be higher. Future research could investigate the effects of increasing sales of vegetarian meals on profits. Third, to achieve tangible environmental benefits, any reduction in demand for meat needs to lead to reduced livestock farming, and not simply redirecting livestock products to other countries (38). Shifting both diets and agricultural production towards less meat will require the support of governments and farmers as well as pressure from citizens (38, 39).

Nevertheless, our results demonstrate the potential of choice architecture for making progress towards improved sustainability. Increasing the availability of vegetarian options in cafeterias is a relatively cheap and easily-implemented strategy which generally goes unnoticed: it does not require restructuring the canteen layout, or running meat-free days that can prove unpopular (40), and it can save money on ingredients (24). Increasing the availability of plant-based meals will require diversification of vegetarian provision by cafeterias and restaurants which may in turn necessitate changes in the training offered to chefs (37). Interest in reducing meat consumption and in "flexitarianism" is on the rise (41) and our results show that caterers serving more plant-based options are not just responding to but also re-shaping customer demand. Further long-term studies – intervening on availability in addition to other aspects of choice environments, and conducted in a wider range of settings – might usefully test behavioural interventions that are scalable and offer the potential to significantly mitigate climate change and biodiversity loss.

Methods

This research was approved by the University of Cambridge Psychology Research Ethics Committee (PRE.2016.100). In keeping with research governance for interventions that target environments and not individuals directly, consent was obtained from those who have authority over these environments, i.e. the managers of the college cafeterias. Signed consent forms, approved by the Research Ethics Committee, were obtained from each of the catering managers of the three participating colleges.

Study setting

Colleges A and B have both undergraduate and postgraduate members. College A has over 1100 members, and College B over 500. College C is a graduate college with over 600 members. All three colleges admit students of any gender identity. Students pay for meals by swiping their university cards, meals are not included in the tuition or accommodation fees. In Colleges A and B, students top up their card with credit throughout the academic year, in College C students pay the bill at the end of each term. Meals typically cost between £2.30 [€2.51, $2.45] and £3.70 [€4.04, $4.50]. Although many students eat in the college cafeteria, others cook their own meals or eat elsewhere. In the cafeterias vegetarian and meat meals are available throughout the mealtime, if meat or vegetarian options run out they are quickly replaced by an option in the same category.

Study design

Study 1

Colleges A and B in their normal operations varied both the total number of options and the number of vegetarian options available. We did not experimentally alter the menus from these colleges but observed how the availability of vegetarian meals related to their relative sales. We used data from lunch and dinner on weekdays (Monday to Friday) during spring (16^{th} January to 17^{th} March), summer (24^{th} April to 30^{th} June) and autumn terms (2^{nd} October to 1^{st} December) 2017.

Study 2

College C experimentally altered the number of vegetarian meals on their menus. The original experimental design specified that that both lunch and dinner would alternate between one and two vegetarian options week by week. However, this was too much for the cafeteria to implement within the timeframe of the study. Therefore, only lunchtimes alternated between the experimental condition of one and two vegetarian options, every two weeks. The number of vegetarian options still sometimes varied from experimental allocation due to cafeteria constraints (SI Appendix Table S15). Some misclassifications at the checkout occurred, resulting in some vegetarian meals being recorded as meat sales. This meant that vegetarian sales may have been up to 21.5% greater than recorded (EG, pers. obs.). No meat meals were misclassified as vegetarian. Though unfortunate, this error is conservative and suggests that the true effect of availability at College C could be substantially greater than that reported, and closer to that estimated from the observational work at Colleges A and B.

We collected and analysed the experimental data from weekday lunchtimes from College C to test the effect of vegetarian availability, and also compared this with weekday dinner sales to investigate if increasing vegetarian availability at lunch affected vegetarian sales at dinner. Data were collected across autumn term and the first two weeks of the Christmas holidays 2017 (2nd October to 15th December). Unlike College A and B, College C is a graduate college and meals were served to staff and students outside of normal university term-times, so to increase the sample size we included the first two weeks of the Christmas holidays. These two weeks did have slightly lower total sales than term time weeks (SI Appendix Table S19) but did not have significantly different vegetarian sales (SI Appendix Table S15).

Data collection

Sales data were downloaded from the online catering platforms Uniware (42) and Accurate Solutions (43) and identifiable data were stored on a secure online server. All three colleges had online menus; however the options served sometimes varied from this. At Colleges A and B the number of vegetarian options and total number of options could be inferred from how the sales data are coded. At College C it was not possible to infer the number of vegetarian options and total options from the sales data, therefore visits were made at lunchtimes to directly observe the options available. When the lunch offer included a pasta bar this commonly had two sauces, often one vegetarian and one meat; we counted each sauce+pasta as half an option.

Data preparation

We summarised the sales data into a) aggregate data, summarising the total vegetarian and meat sales at each lunch and dinner and b) individual-level data on whether each individual diner at a meal selected a vegetarian or meat meal. Eight mealtimes at College A and three at College B served no vegetarian main meals, and therefore vegetarian availability and vegetarian sales were zero. These data were excluded from the analysis to avoid overestimating the effect of availability (SI Appendix Table S3). In College B one mealtime only served one main meal in total and this was also excluded from the analysis. Only lunchtimes when direct observations were made of the vegetarian and total options available were included in the analysis for College C.

Aggregate data included main meals bought by both college members and guests. Individual-level data only included meals bought by college members on their university cards, as only these meals could be associated with individual diners. An individual diner who bought one or more vegetarian meals at a mealtime was coded as 1; an individual diner who bought one or more meat meals was coded as 0. Any individual diners who bought both vegetarian and meat meals at one meal time were coded as NA and we excluded those meal choices from the analysis; this removed 1.6% of the individual-level data at College A (699/43,751), 1.5% at College B (468/31,956) and 4.5% at College C (207/4,565).

We wanted to test if the response to increasing vegetarian availability varied with background levels of meat consumption. To calculate this, for individuals who bought ≥10 main meals during the preceding term (autumn 2016 for Colleges A and B, summer term 2017 for College C), we calculated the proportion of main meals bought that were vegetarian, and these values were used to divide the individual diners into within-college quartiles: Least, Less, More and Most Vegetarian.

Statistical approaches

We carried out analyses in R 3.5 (44), using the lme4 (45) packages. We used Binomial Generalised Linear Models for the aggregate data, and Binomial Generalised Linear Mixed Models for the individual-level data with each individual diner included as a random effect. Models were evaluated using AIC values and interpretability. We follow the recommendations of Simmons et al (46), which includes citing the effect of vegetarian availability, with and without covariates. Initial analyses showed that relative vegetarian availability (number of vegetarian options/ number of total options) was a better predictor of vegetarian sales than number of vegetarian or meat options and therefore we used this as the predictor variable for vegetarian availability. We estimated the effect of vegetarian availability on vegetarian sales and total sales, adjusting for other pre-determined variables (Table 1). After model selection, we used the predict function to generate the predicted values and plotted out lines of best fit, using conditional regressions with 95% confidence intervals using the effects (47) and visreg packages (48).

Table 1: Variables considered for statistical models.

Model	**Variable**	**Description**
All models	Vegetarian availability	Number of vegetarian options/ total options available
	Total options available	Number of different meal options offered at a mealtime
	Total main meals sold	Number of main meals sold at a mealtime
	Vegetarian price differential (£)	The difference between the mean cost of the meat options and the vegetarian options
	Ambient temperature (centigrade)	Mean temperature over 24 hours each day in Cambridge(49)
	Day	Monday, Tuesday, Wednesday, Thursday, Friday
	Week of term	1-11
For Study 1 only (no variation in Study 2)	Meal	Lunch or dinner
	Term	Spring, summer, autumn
For individual-level models only	Individual diner as a random effect	
For individual-level models and models of total sales considering diner background	Prior level of vegetarian meal consumption	Individual diners at each college were divided into Least, Less, More and Most Vegetarian quartiles and we tested for any interaction effects with vegetarian availability
For Study 2 rebound model	Week condition	Control or experimental week

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Author contributions

E.G., A.B., C.S. and T.M. designed research; E.G. performed research; E.G. and M.P. analysed data; E.G., A.B., C.S. and T.M. wrote the paper.

Conflict of interest

The authors declare no conflict of interest.

References

1. Bryngelsson D, Wirsenius S, Hedenus F, Sonesson U (2016) How can the EU climate targets be met? A combined analysis of technological and demand-side changes in food and agriculture. *Food Policy* 59:152–164.

2. Poore J, Nemecek T (2018) Reducing food's environmental impacts through producers and consumers. *Science (80-)* 992(6392):987–992.

3. Clune S, Crossin E, Verghese K (2017) Systematic review of greenhouse gas emissions for different fresh food categories. *J Clean Prod* 140:766–783.

4. Springmann M, et al. (2017) Mitigation potential and global health impacts from emissions pricing of food commodities. *Nat Clim Chang* (7):69–74.

5. Scarborough P, et al. (2014) Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK. *Clim Change* 125(2):179–192.

6. Reddy SMW, et al. (2016) Advancing Conservation by Understanding and Influencing Human Behavior. *Conserv Lett* 00(May):1–9.

7. Marteau TM (2017) Towards environmentally sustainable human behaviour: targeting non-conscious and conscious processes for effective and acceptable policies. *Philos Trans R Soc A Math Phys Eng Sci* 375(i). doi:10.1098/rsta.2016.0371.

8. Diepeveen S, Ling T, Suhrcke M, Roland M, Marteau TM (2013) Public acceptability of government intervention to change health-related behaviours: a systematic review and narrative synthesis. *BMC Public Health* 13(1):756.

9. Bianchi F, Dorsel C, Garnett E, Aveyard P, Jebb SA (2018) Interventions targeting conscious determinants of human behaviour to reduce the demand for meat: A systematic review with qualitative comparative analysis. *Int J Behav Nutr Phys Act* 15(102):1–25.

10. Bucher T, et al. (2016) Nudging consumers towards healthier choices: a systematic review of positional influences on food choice. *Br J Nutr* (9):1–12.

11. Cadario R, Chandon P (2017) *Which Healthy Eating Nudges Work Best? A Meta-Analysis of Behavioral Interventions in Field Experiments*.

12. Campbell-Arvai V, Arvai J, Kalof L (2014) Motivating sustainable food choices: The role of nudges, value orientation, and information provision. *Environ Behav* 46(4):453–475.

13. Bianchi F, Garnett E, Dorsel C, Aveyard P, Jebb SA (2018) Restructuring physical micro-environments to reduce the demand for meat: A systematic review with qualitative comparative analysis. *Lancet Planet Heal* 2(9):e384–e397.

14. McKinsey Global Institute (2014) *Overcoming obesity: An initial economic analysis*.

15. Hollands GJ, et al. Altering the availability or proximity of food, alcohol and tobacco products to change their selection and consumption. *Cochrane database Syst Rev* (3). doi:10.1002/14651858.CD011672.READS.

16. Fiske A, Cullen KW (2004) Effects of promotional materials on vending sales of low-fat items in teachers' lounges. *J Am Diet Assoc* 104(1):90–93.

17. Foster GD, et al. (2014) Placement and promotion strategies to increase sales of healthier products in supermarkets in low-income, ethnically diverse neighborhoods: A randomized controlled trial. *Am J Clin Nutr* 99(6):1359–1368.

18. Roe LS, Meengs JS, Birch LL, Rolls BJ (2013) Serving a variety of vegetables and fruit as a snack increased intake in preschool children. *Am J Clin Nutr* 98(3):693–699.

19. Stubbs RJ, Johnstone AM, Mazlan N, Mbaiwa SE, Ferris S (2001) Effect of altering the variety of sensorially distinct foods, of the same macronutrient content, on food intake and body weight in men. *Eur J Clin Nutr* 55(1):19–28.

20. Kocken PL, et al. (2012) Promoting the Purchase of Low-Calorie Foods From School Vending Machines: A Cluster-Randomized Controlled Study. *J Sch Health* 82(3):115–122.

21. Bartholomew JB, Jowers EM (2006) Increasing frequency of lower-fat entrees offered at school lunch: An environmental change strategy to increase healthful selections. *J Am Diet Assoc* 106(2):248–252.

22. Pechey R, et al. (2019) Impact of increasing the proportion of healthier foods available on energy purchased in worksite cafeterias: A stepped wedge randomized controlled pilot trial. *Appetite* 133(October 2018):286–296.

23. Clark M (2017) Chronic effects of replacing red and processed meat with non/reduced meat alternatives. Dissertation (University of Cambridge).

24. Gravert C, Kurz V (2017) *Nudging À La Carte – A Field Experiment on Food Choice* doi:10.2139/ssrn.2909700.

25. Bacon L, Krpan D (2018) (Not) Eating for the environment: The impact of restaurant menu design on vegetarian food choice. *Appetite* 125:190–200.

26. Whitaker RC, Wright JA, Finch AJ, Psaty BM (1993) An environmental intervention to reduce dietary fat in school lunches. *Pediatrics* 91(6):1107–1111.

27. Grech A, Allman-Farinelli M (2015) A systematic literature review of nutrition interventions in vending machines that encourage consumers to make healthier choices. *Obes Rev* 16(12):1030–1041.

28. O'Reilly GA, et al. (2017) Sugar Restriction Leads to Increased Ad Libitum Sugar Intake by Overweight Adolescents in an Experimental Test Meal Setting. *J Acad Nutr Diet* 117(7):1041–1048.

29. McCulloch CE, Searle SR, Neuhaus JM (2008) *Generalized, Linear, and Mixed Models* (Wiley-Blackwell). Second Edi.

30. Hosmer DW, Lemeshow S, Sturdivant RX (2013) Applied Logistic Regression. *Applied Logistic Regression* (Wiley), pp 89–152. Third Edit.

31. Ali M, Simpson EJ, Clark M, Razak A, Salter A (2017) The impact of dietary meat intake reduction on haematological parameters in healthy adults. *Proc Nutr Soc* 76(OCE3):E70.

32. Flynn MM, Reinert S, Schiff AR (2013) A Six-Week Cooking Program of Plant-Based Recipes Improves Food Security, Body Weight, and Food Purchases for Food Pantry Clients. *J Hunger Environ Nutr* 8(1):73–84.

33. Holloway T, Salter AM, Mccullough FS (2012) Chapter 4: Dietary intervention to reduce meat intake by 50 % in University students –a pilot study. *Proc Nutr Soc* 71(OCE2):119–151.

34. Reinders MJ, Huitink M, Dijkstra SC, Maaskant AJ, Heijnen J (2017) Menu-engineering in restaurants - adapting portion sizes on plates to enhance vegetable consumption: a real-life experiment. *Int J Behav Nutr Phys Act* 14(1):41.

35. Rolls BJ, Roe LS, Meengs JS (2010) Portion size can be used strategically to increase vegetable consumption in adults. *Am J Clin Nutr* 91(4):913–922.

36. Godfray HCJ, et al. (2018) Meat consumption, health, and the environment. *Science (80-)* 243(July). doi:10.1126/science.aam5324.

37. Volkhardt I, et al. (2016) Checklist for a vegan lunch menu in public catering. *Ernaehrungs Umschau* 63(09):176–184.

38. Buckwell A, Nadeu E (2018) *What is the Safe Operating Space for EU livestock?* (Brussels) Available at: www.risefoundation.eu/publications.

39. Committee on Climate Change (2018) *Land use: Reducing emissions and preparing for climate change*.

40. Lombardini C, Lankoski L (2013) Forced Choice Restriction in Promoting Sustainable Food Consumption: Intended and Unintended Effects of the Mandatory Vegetarian Day in Helsinki Schools. *J Consum Policy* 36(2):159–178.

41. Eating Better (2017) *The future of eating is flexitarian: Companies leading the way*.

42. Uniware Available at: http://www.uniware.co.uk/ [Accessed January 8, 2019].

43. Accurate Solutions Available at: http://www.accurate-solutions.co.uk/ [Accessed January 8, 2019].

44. R Core Team (2018) R: A language and environment for statistical computing. Available at: https://www.r-project.org/.

45. Bates D, Bolker BM, Maechler M, Walker SC (2015) Fitting Linear Mixed Effects Models using lme4. *J Stat Softw* 67(1):251–264.

46. Simmons JP, Nelson LD, Simonsohn U (2011) False-Positive Psychology: Undisclosed Flexibility in Data Collection and Analysis Allows Presenting Anything as Significant. *Psychol Sci* 22(11):1359–1366.

47. Fox J, Weisberg S (2018) Visualizing Fit and Lack of Fit in Complex Regression Models with Predictor Effect Plots and Partial Residuals. *J Stat Softw* 87(9):1–27.

48. Breheny P, Burchett W (2016) Visualization of Regression Models Using visreg. *R J* 9(December):56–71.

49. Cambridge Daily Weather Graphs (2018) Available at: http://www.cl.cam.ac.uk/research/dtg/weather/index-daily-graph.html.