THE STEAKS ARE HIGH: REDUCING MEAT CONSUMPTION BY CHANGING PHYSICAL AND ECONOMIC ENVIRONMENTS TO INCREASE VEGETARIAN SALES

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Dedication

This thesis is dedicated to my immediate family: Ned Garnett, Claire Garnett, Sarah Warren and Tom Williams.

Declaration

This thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared in the preface and specified in the text.

It is not substantially the same as any that I have submitted, or, is being concurrently submitted for a degree or diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text.

I further state that no substantial part of my dissertation has already been submitted, or, is being concurrently submitted for any such degree, diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text.

It does not exceed the prescribed word limit for the relevant Degree Committee (School of Biology).

Emma Elizabeth Garnett
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Summary

Livestock farming is responsible for ~15% of anthropogenic greenhouse gas emissions (GHGE) and is a leading cause of deforestation, biodiversity loss, water-use and pollution. To feed 10 billion people a healthy and sustainable diet, approximately 16kg of meat consumption per person per year has been recommended, compared with current mean consumption (including waste) of 81kg in the EU and UK. How might lower meat consumption be encouraged?

Research in other domains suggests altering the physical and economic environments in which people make decisions holds promise for achieving socially desirable behaviour change, but very little research has experimentally tested such approaches for reducing meat consumption. In this thesis I present the results of three different interventions (order, availability, price) in college cafeterias at the University of Cambridge and examine their effects on vegetarian meal sales. I collected data from 1142 mealtimes and 213,627 meal selections, obtaining individual-level purchase information for two out of three interventions.

It is widely assumed – but largely untested – that food encountered first in cafeterias is preferentially selected. I investigated the effects of order and found placing the vegetarian (rather than meat) option first increased vegetarian sales by 4.5 to 6 percentage points when there was a long distance (181cm) between options. However, order effects were inconsistent when the distance between options was shorter (<85cm).

In contrast, I found that increasing the proportion of vegetarian options available was consistently very effective. Doubling vegetarian availability from 25% to 50% (e.g. from 1 in 4 to 2 in 4 options) increased vegetarian meal sales by 14.5 to 14.9 percentage points in an observational study and by 7.8 percentage points in an experimental study. Individual-level data revealed that the largest relative effects were found in the quartile of diners with the lowest prior levels of vegetarian meal selection, but all quartiles of diners were more likely to select a vegetarian option when more were available.

Price is an important consideration for citizens when purchasing food. I experimentally decreased the vegetarian option price and increased the meat option price (each by 20p) halfway through a university term. Vegetarian sales increased overall by 3.2 percentage points, and by 13.7 percentage points in the most vegetarian quartile of diners. The other three

quartiles did not significantly change their meal selections. None of the three interventions tested substantially affected overall meal sales.

In the final data chapter I used individual-level data to examine the effects of gender on meal selection. I found that men were consistently less likely to select vegetarian meals than women, significantly more likely to select meat meals, and men and women were equally likely to select fish meals. Consequently on average men's meals had average GHG emissions 18% higher and land-use 28% higher than women's. Men and women were similarly responsive to the availability and price interventions.

These findings have important implications for catering policies, although these interventions should be tested in non-university populations and low and middle income countries. Placing vegetarian options first can increase their sales, but can also have no effect or even be counterproductive. A small change in price may only be enough to increase vegetarian selection for the most vegetarian quartile of diners. However, increasing the availability of vegetarian options appears to increase vegetarian selection by all quartiles of diners and is a relatively simple change to catering practices. My results provide robust evidence that – if implemented more broadly – increasing the proportion of vegetarian options available could make an important contribution to the global ambition for more sustainable diets.

Statement of Contributions

Chapters 2, 3 and 4. I designed these studies in collaboration with Andrew Balmford, Chris Sandbrook, Theresa Marteau and the relevant catering managers. I collected the data in collaboration with the catering managers and cafeteria staff. I carried out the analyses with expert advice and guidance from Mark Pilling. I wrote the manuscript with detailed input and editing from co-authors Andrew Balmford, Theresa Marteau, Chris Sandbrook and Mark Pilling.

Chapter 2. This is a reproduction of a paper published in *Nature Food,* link here: https://www.nature.com/articles/s43016-020-0132-8. At the request of the editor, after the first round of reviews we reformatted the manuscript from an Original Article (<6000 words) to a Brief Communication (<2000 words). The text here is the original full-length version, edited to address reviewers' comments. I have made some minor edits and changed the formatting. Data for the results in this paper can be found at https://doi.org/10.17863/CAM.41481 .

Chapter 3. This is a reproduction of a paper published in *PNAS* in 2019, link here: https://www.pnas.org/content/116/42/20923. I have edited the manuscript to avoid repetition in this thesis and changed the formatting. The aggregate data and summaries of the individual-level data can be found at https://doi.org/10.17863/CAM.41328.

Chapter 4. This is a reproduction of a paper under a second review at *Journal of Environmental Psychology.* I have edited the manuscript to avoid repetition in this thesis and changed the formatting.

Chapter 5. This chapter will be prepared later for publication. The data on the environmental footprint of cafeteria meals comes from a part II undergraduate project carried out by Anya Doherty and Matt Ewen, which I initially designed and subsequently supervised. Anya Doherty has continued to work on how cafeterias can best reduce their environmental footprint post-graduation and the manuscript will shortly be submitted to the *Journal of Cleaner Production*.

Appendices A, B and C. These are the Supplementary Information documents for Chapters 2, 3 and 4 respectively. As I have not yet prepared Chapter 5 for publication, this chapter does not have an associated Appendix. Due to different journal requirements and comments from reviewers, the Chapters and Appendices differ in some aspects of layout and structure.

For chapters 2, 3, 4 and 5, which are published or being prepared for publication, I use the first person plural “we” as is standard for multi-author publications. For chapters 1 and 6 (Introduction and Discussion), I use “I”.

Abbreviations and Glossary

AIC	Akaike information criterion to compare statistical models
CI	Confidence intervals
CO_2eq	Carbon dioxide equivalent, a measure for greenhouse gas emissions
DEFRA	Department for Environment, Food and Rural Affairs
FAO	Food and Agriculture Organisation of the United Nations
GHG	Greenhouse gas
GLM	Generalised linear model, fixed effects only
GLMM	Generalised linear mixed model, which includes fixed and random effects
Gt	Gigatonne, 1 billion tonnes or 1 trillion kilograms
IPCC	Intergovernmental Panel on Climate Change
Kg	Kilograms, 1000 grams
Km	Kilometre, 1000 metres
Km^2-years	Square kilometres of farmland occupied over one year, a measure for the land-use of food
Legumes	Plant in the family Fabaceae able to fix nitrogen through the root nodules. Legume crops include pulses (see below), crops grown for forage e.g. alfalfa and clover, crops grown for oil extraction e.g. soybeans and peanuts.
Livestock	Terrestrial farmed animals, and farmed fish and other seafood (aquaculture) unless otherwise specified
LM	Linear model
m^2-years	Square metres of farmland occupied over one year, a measure for the land-use of food
Mt	Megatonne, 1 million tonnes or 1 billion kilograms
Poultry	Domesticated birds kept for eggs and meat. Incudes chickens, turkeys, geese and ducks.
Pulses	Legume crops harvested for the dry seed, including peas, beans and lentils. Beans and peas which are harvested fresh (not dried), e.g. green peas are classified as a vegetable crop, not pulses.
Red meat	Meat from mammals, this includes ruminant meat and also pork
Ruminant meat	Meat from ruminants, this includes beef, lamb, goat and venison

SD	Standard deviation
SFP	Sustainable Food Policy
SOM	Supplementary Online Material
SO_2eq	Sulphur dioxide equivalent, a measure of air pollution and acidification
PO_4^{3}-eq	Phosphate equivalent, a measure of water pollution and eutrophication
t	Tonne, 1000 kg
UCS	University Catering Service (University of Cambridge)

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Chapter 1. Introduction

I've never seen a perfect world. I never will. But, I know that a world warmed by 2 degrees Celsius is far preferable to one warmed by 3 degrees, or 6. And that I'm willing to fight for it, with everything I have, because it is *everything I have. [..] This planet is the only home we'll ever have. There's no place like it. And home is always, always, always worth it.*

Mary Annaïse Heglar (2019) Medium

Eat food, not too much, mostly plants.

Michael Pollan (2009) Food Rules: An Eater's Manual

1.1 Summary

The climate emergency is arguably the most urgent crisis facing global citizens. Reaching absolute zero emissions will require a fundamental transformation in the ways we live, travel, work and produce food. Agriculture has transformed the planet more than any other human activity and is the leading cause of natural habitat loss and species extinction. Livestock farming has particularly high impacts on the environment across a suite of environmental indicators including GHG emissions, land-use, and water and air pollution. Current consumption rates of meat, fish and dairy in high-income countries are incompatible with meeting climate targets and conserving biodiversity. Shifting to a more plant-based diet would bring both human health and environmental benefits. However, there are very few field studies assessing interventions to reduce meat and fish consumption. In this thesis I report field experiments on three interventions, altering the physical and economic environments in college cafeterias at the University of Cambridge, and examine their effects on vegetarian meal sales.

1.2 Agriculture, livestock and the environment

Producing food has a greater impact on patterns of land use, greenhouse gas (GHG) emissions and biodiversity than any other human activity (Tilman & Clark, 2014). Consequently sustainable food choices are one of the most powerful ways in which individuals and organisations can affect positive environmental change. Food production is the most common use of land accounting for 37% of ice- and desert-free land, with arable land and permanent pasture account for 11% and 26% respectively (Poore & Nemecek, 2018b). Farming is the leading driver of natural habitat loss, which is the greatest threat to threatened species (Vie, Hilton-Taylor, & Stuart, 2008). Food production is responsible for 26% of anthropogenic GHG emissions (13.7 Gt CO_2-eq per year), 32% of terrestrial acidification (92.4 Mt SO_2eq per year), 78% of freshwater and marine eutrophication (65.3 Mt PO_4^{3-}eq per year) and 70% of freshwater withdrawals (2200 km^3 per year) (FAO, 2017b; Poore & Nemecek, 2018b). Populations of wild fish have plummeted, with estimates that the biomass of large predatory fish such as tuna and swordfish are at only 10% of pre-industrial levels (Myers & Worm, 2003). Widely eaten seafood species, such as the Atlantic cod and European eel, are at risk of extinction according to the ICUN Red List (Jacoby & Gollock, 2014; Sobel, 1996). An estimated 34% of monitored fish stocks are already over-exploited, while another 60% are fully exploited and only 6% are under-exploited (FAO, 2020b). Furthermore, between one quarter and one third of food produced globally is wasted (FAO, 2011; Poore & Nemecek, 2018b). In high-income countries this amounts to 95 to 115 kg per person per year and mainly occurs at the end of the food supply chain (FAO, 2011).

Livestock farming has a particularly large environmental footprint and makes up a similar share of global GHG emissions as the direct emissions from transport (14.5% and 14.0% respectively, the livestock estimate does not include the opportunity cost of carbon sequestration foregone on grazing land) (Gerber et al., 2013). Broken down by GHG, 27% of livestock emissions (excluding aquaculture) are carbon dioxide (5% of anthropogenic CO_2 emissions), 29% are nitrous oxide from fertiliser application and manure decomposition (53% of anthropogenic N_2O emissions) and 44% are methane from ruminant enteric fermentation and manure decomposition (44% of anthropogenic CH_4 emissions) (Gerber et al., 2013). Livestock farming is also a leading cause of deforestation, biodiversity loss, species extinction and pollution (Machovina, Feeley, & Ripple, 2015). Even the lowest impact meat and dairy foods tend to cause more environmental damage than the highest impact plant-derived foods (Poore & Nemecek, 2018b). Livestock and aquaculture are responsible for 56-58% of the global food system's GHG emissions, water eutrophication and terrestrial acidification (7.8Gt CO_2eq, 36.9 Mt PO_4^{3-}eq and

50.7 Mt SO_2eq per year respectively) and use 83% of farmland (3428 million ha) despite contributing just 18% of calories and 37% of protein intake (Poore & Nemecek, 2018b). Ruminant animals have particularly high GHG emissions due to both their generation of methane (Dangal et al., 2017) and the disproportionately large area of land used per kg meat to meet current demand, much of which could potentially be restored to CO_2-sequestering woodland or wetland (Balmford et al., 2018; Committee on Climate Change, 2018; Searchinger, Wirsenius, Beringer, & Dumas, 2018). The average GHG emissions per kg for ruminant meat are five times higher than pork, seven times higher than chicken and 43 times higher than pulses (Clune, Crossin, & Verghese, 2017).

1.3 Comparing approaches to reduce the environmental footprint of diet

A combination of approaches is needed to keep the global food system within safe planetary boundaries, including shifting to a more plant-based diet, application and development of novel technologies, improving agricultural productivity, better management of fish stocks and reducing food waste (Searchinger et al. 2018a; Springmann et al. 2018). Reducing food waste is key to reducing the environmental footprint of food. Between one quarter and one third of food is wasted, and as such food waste is responsible for ~6% of global GHG emissions (FAO, 2011; Poore & Nemecek, 2018b). However, models for Sweden suggest that large reductions in ruminant consumption are more critical to meeting climate targets than halving food waste (Bryngelsson, Wirsenius, Hedenus, & Sonesson, 2016). Reducing food waste also saves households money which can be spent on goods and services with their own environmental footprints, and this rebound effect reduces the estimated GHG savings from food waste prevention by 60% (Salemdeeb, Font, Al-tabbaa, & zu Ermgassen, 2016). Globally, shifting to a more plant-based diet is not predicted to affect overall food waste; switching from meat to pulses as a primary protein source reduces food waste, but this is offset by higher levels of food waste from higher levels of vegetable and fruit consumption (Poore & Nemecek, 2018b).

Reducing overall travel and its associated emissions are key components of climate strategies, with direct or “tail-pipe” transport emissions responsible for 14% of global climate change (Gerber et al., 2013). However, transporting food from farms to citizens makes up only 6% of the food system’s GHG emissions (Poore & Nemecek, 2018b) and estimates from the USA indicate that for the average family giving up meat for one day a week would lead to greater GHG savings than sourcing all of their food locally . Nevertheless, it is possible to decarbonise road and rail transport with current technologies, but not freight shipping or aviation (Allwood et al., 2019). Shipping and aviation make up 58.97% and 0.16% of food miles respectively (measured in tonne-kilometres, the transport of one tonne of food over one km), road and rail transport make up 30.97% and 9.90% respectively (Poore & Nemecek, 2018b). Estimates of shifting from the average global diet to lower meat and vegan diets do not predict a reduction in food miles or a change in the proportion of transport methods (Poore & Nemecek, 2018b). Reaching absolute zero emissions will require a transformation in how we source, trade and transport our food.

Organic food is generally perceived as better for the environment. Organic food tends to have lower environmental impacts per hectare of land but per kg food non-organic (or conventional) farming often out-performs organic methods (Tuomisto, Hodge, Riordan, & Macdonald, 2012). One review found no significant differences in GHG emissions between the two farming practices, however this overlooks the carbon sequestration potential of reverting farmland to natural habitat (Clark & Tilman, 2017). Due to lower yields organic farming consistently has higher land-use than non-organic farming and therefore higher carbon sequestration opportunity costs. Organic farming also tends to lead to higher eutrophication and acidifications emissions but has lower energy use (Clark & Tilman, 2017).

Generally, the least damaging animal-derived food has higher environmental impacts than the highest impact plant-derived food (Poore & Nemecek, 2018b). However, there are some exceptions and there are still important variations in the environmental impacts of plant-derived foods. Coastal bivalve aquaculture has the potential to reduce water pollution and produce protein-rich food with zero land and freshwater use, although the GHG emissions are still higher than many plant-based proteins (Willer & Aldridge, 2020). Fruit and vegetables grown in heated greenhouses have twice the GHG emissions of produce from passive greenhouses and four times the emissions of field-grown fruit and vegetables (median kg CO_2eq per kg produce: field-grown vegetables, 0.37; field-grown fruits 0.42; passive greenhouse fruit and vegetables, 1.10; heated greenhouse fruit and vegetables, 2.13) (Clune et al., 2017). Farming rice in flooded paddies produces methane, consequently rice has the highest GHG emissions of field-grown crops (2.55 kg CO_2eq per kg) and slightly higher emissions than fruit and vegetables from heated greenhouses (Clune et al., 2017). Switching from fragile produce, which is likely to spoil, to robust field-grown produce can also reduce environmental impacts by lowering food waste (T. Garnett, 2011). Arable farming on peatland leads to high land-use change emissions as the peat oxidises into carbon dioxide. In Cambridgeshire, farming only makes up 7% of the county's GHG footprint if peatland emissions are excluded. However, when land-use change emissions from farmed peatland are included (4.0-5.5 Mt CO_2eq per year), the county's GHG emissions jump by 65-90% (Weber et al., 2019).

Reducing the consumption of animal products, particularly those from ruminants, is probably the single most effective route to lowering the GHG, land and water footprint of diets in high-income countries. It is likely to generate greater environmental benefits than reducing food waste, reducing food miles or eating organic food.

1.4 Livestock, human health and animal welfare

Alongside the impact that meat production has on the natural world, farming animals at current levels compromises both animal welfare and human health. Livestock farming is a leading cause of novel diseases and pandemics in people (Dhingra et al., 2018; Jones et al., 2013) and its widespread use of antibiotics is contributing to antimicrobial resistance (Van Boeckel et al., 2015). Diets high in red meat and processed meat can increase the risk of cardiovascular disease and cancer (Aston, Smith, & Powles, 2012; De Oliveira Mota, Boué, Guillou, Pierre, & Membré, 2019; Schwingshackl et al., 2019; Zhang et al., 2019).

Most farmed animals are kept on industrial farms in cramped conditions which do not fulfil their social and psychological needs, and they are generally killed after a fraction of their natural lifespan (Harari, 2011). Global livestock populations (number of animals alive at any single time-point) have increased substantially between 1961 and 2014 (FAO, 2020a; Ritchie, 2017). Chicken numbers have jumped from 3.9 billion to 21.4 billion, pigs from 0.4 billion to 1.0 billion and cows from 0.9 billion to 1.5 billion (FAO, 2020a; Ritchie, 2017). The increase in the number of livestock killed for meat per year is more pronounced than the increase in livestock populations; due to artificial selection for faster growing breeds, animals today have a shorter average lifespan before slaughter. Between 1961 and 2014 the number of chickens killed increased tenfold from 6.6 billion to 68.8 billion, the number of pigs killed almost quadrupled from 0.4 billion to 1.5 billion, and cows killed increased from 0.2 billion to 0.3 billion (FAO, 2020a; Ritchie, 2017).

1.5 Reducing animal product consumption for healthy and sustainable diets

There is substantial overlap between healthy and sustainable diets: diets low in saturated fat, red and processed meat, and high in vegetables, wholegrains and pulses (Springmann, Godfray, Rayner, & Scarborough, 2016). An analysis of 15 foods found that those with lowest climate and water impacts tended to also reduce mortality risk: pulses, wholegrains, nuts, fruits and vegetables. Conversely, red and processed meats have both high environmental impacts and increase mortality risk (Clark, Springmann, Hill, & Tilman, 2019). There are some important exceptions: eating fish can be beneficial to health, but the production of fish has higher GHG emissions than producing plant-based proteins and current levels of fishing are contributing to the collapse in populations of wild fish and other marine species (FAO, 2020b). Sugar sweetened beverages have low environmental impacts but do not provide any nutritional value besides calories. If citizens in high-income countries followed each nation's national dietary guidelines – compared to the average diet – GHG emissions, land-use and eutrophication would reduce by an average of 13%, 6% and 10% due to the change in dietary composition (fewer animal products). These values increase to 25%, 18% and 21% respectively if reductions in calories are also included (Behrens et al., 2017). However, many national recommended diets (including those of the USA, Australia, China and Canada) have high GHG emissions which are incompatible with limiting global heating to 1.5 degrees (Ritchie, Reay, & Higgins, 2018; Springmann et al., 2020).

Reducing meat production and consumption in high-income countries such as the UK is almost universally advocated as a necessary strategy to reach net and absolute zero GHG emissions (Allwood et al., 2019; Committee on Climate Change, 2020; Energy Systems Catapult, 2019; Shukla et al., 2019). The National Farmers' Union (UK) net zero report does not include reducing meat consumption to reduce GHG emissions (National Farmers' Union, 2019a). For the UK it is estimated that switching from a high meat (>100g/day) to a medium meat (50-100g/day), low meat (<50g/day), vegetarian or vegan diet would reduce the GHG emissions from food by 22%, 35%, 47% and 60% respectively (Scarborough et al., 2014). To feed 10 billion people a healthy and sustainable diet within planetary boundaries (the "Planetary Health" diet), approximately 16kg of meat and 10kg of seafood consumption per person per year is recommended (Willett et al., 2019). However, mean global consumption (including consumer-level food waste) is currently 43kg and 19kg per person per year respectively, and averages 81kg and 23kg in the EU and UK combined (FAO, 2017a; Ritchie, 2017).

1.6 Behaviour change and reducing meat consumption

It is vital that conservationists consider behavioural sciences, and not just environmental sciences, to achieve sustainable outcomes (Pechey, Cartwright, et al., 2019; Reddy et al., 2016). Numerous studies have established the environmental harms of meat and the benefits of a more plant-based diet (Aston et al., 2012; Poore & Nemecek, 2018b; Springmann et al., 2016) but there are few field studies that test which approaches can work to encourage lower meat consumption (Bianchi, Dorsel, Garnett, Aveyard, & Jebb, 2018; Bianchi, Garnett, Dorsel, Aveyard, & Jebb, 2018; Kurz, 2018).

Shifting diets to reduce the environmental footprint of food will require an array of strategies (Lehner, Mont, & Heiskanen, 2016; Marteau, 2017). Education to bring about behaviour change is a popular and uncontroversial method but – while it can raise awareness – it appears to be largely ineffective at actually changing behaviour (Bianchi, Dorsel, et al., 2018; Diepeveen, Ling, Suhrcke, Roland, & Marteau, 2013). For example, an experiment in a USA college found students were no more likely to select a vegetarian meal when provided with an information label on the environmental benefits of lowering meat consumption (Campbell-Arvai, Arvai, & Kalof, 2014). Models suggest that taxes on the most polluting foods would result in savings of 1Gt of GHG emissions worldwide (9% decrease in food-related GHG emissions) (Springmann et al., 2017) but livestock farming is widely subsidised in the EU and other countries (Greenpeace, 2019; Wasley, Heal, & Snaith, 2018) and no specific meat taxes have yet been introduced. A third group of interventions – changing the physical and social contexts (the so-called choice architecture) in which decisions are made – could potentially deliver improved environmental outcomes. Nudges are defined as:
"Any aspect of the choice architecture that alters people's behaviour in a predictable way without forbidding any options or significantly changing their economic incentives. To count as a mere nudge, the intervention must be easy and cheap to avoid. Nudges are not mandates. Putting fruit at eye level counts as a nudge. Banning junk food does not" (Thaler & Sunstein, 2009).

Choice architecture interventions have the potential to shift diets at a low cost and with little controversy, but so far have received relatively little empirical attention (Bianchi, Garnett, et al., 2018; Bucher et al., 2016; Cadario & Chandon, 2017; Campbell-Arvai et al., 2014). In the absence of nation-wide taxes, businesses and other institutions have the power to introduce economic interventions by pricing their products to encourage shifts to more sustainable diets. Financial incentives have been shown to be effective at promoting healthy behaviour change (Giles, Robalino, McColl, Sniehotta, & Adams, 2014). Choice architecture and economic incentives are two distinctive groups of interventions but do share an important characteristic. Both groups of interventions are low agency, i.e. individuals do not need to exert high levels of personal resources to benefit or be affected by the changes (Adams, Mytton, White, & Monsivais, 2016). Low agency interventions are more likely to be effective and equitable than high agency interventions such as information provision, which requires individuals to obtain, read, understand and act on information (Adams et al., 2016).

From the literature there is some evidence that choice architecture interventions can be successful in promoting healthier eating, such as selecting less calorie-dense food.
A recent Cochrane review found four studies testing the effect of the order of physical presentation of food (Hollands et al., 2019). While all reported that items nearer the start of a line were more likely to be selected, one study found this was not the case for all food products (Kongsbak et al., 2016), three introduced additional confounding interventions such as more prominent labelling (Cohen et al., 2015; Greene, Gabrielyan, Just, & Wansink, 2017; Kongsbak et al., 2016), and two were based on only a single mealtime on one day (Kongsbak et al., 2016; Wansink & Hanks, 2013). 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” (Dobbs et al., 2014). However, there are very few studies testing choice architecture interventions on reducing meat consumption (Bianchi, Garnett, et al., 2018). We cannot assume that the effects of interventions for e.g. foods of different calorie densities, is necessarily the same for vegetarian and non-vegetarian meals.

1.7 Thesis aims and structure

This thesis describes a series of novel field experiments conducted within University of Cambridge college cafeterias which aim to investigate the effectiveness of different choice architecture and economic interventions at increasing vegetarian sales. A key conceptual advance of this thesis is my use of individual-level information across months of data collection to dissect how different population segments responded to interventions delivered at a group level. I circumvent a typical trade-off between lab and field experiments in psychology: lab experiments with actively recruited participants can track individual-level responses but are generally conducted at one time interval and may not accurately reflect real-world behaviours (List & Levitt, 2005; Mitchell, 2012). It is often possible to conduct field experiments over longer time periods and therefore obtain larger sample sizes, but it is rare to be able to track repeated decisions by the same individuals.

A proposed typology on choice architecture, TIPPME (typology of interventions in proximal physical micro-environments), classifies interventions into two main types: placement (availability and position) and properties (functionality, presentation, size, information) of products (Hollands et al., 2017). The choice architecture interventions in this thesis involved changing the placement (availability and position) of meat and vegetarian meals; I did not alter the properties (e.g. taste, portion size) of the meals themselves. University cafeterias are examples of physical micro-environments: settings that people use for specific purposes where they interact directly with objects in those environments (Hollands et al., 2017). In contrast, macro-environments are higher-level systems and infrastructure needed for the operation of a society or organisation, and these influence the characteristics of micro-environments.

All studies were approved by the University of Cambridge Psychology Research Ethics Committee and consent forms were signed by the participating catering managers at each college. Diners were not informed about the studies, which is in keeping with research governance for interventions that target environments and not individuals directly. University of Cambridge colleges are broadly equivalent to halls of residence. To preserve college anonymity, all colleges were assigned cryptonyms A, B C and D. One college appears in three different chapters with two different cryptonyms to maintain internal consistency within each chapter (College 1, Table 1.1). Due to the different college set ups and the different research questions in each chapter, the terms "vegetarian" and "meat" are used slightly differently in different chapters (Table 1.1).

In Chapter 2 I investigate the effects of meal position and order on meal sales in two college cafeterias. Meal options were alternated week by week between "VegFirst" – positioning the vegetarian option first – and "MeatFirst", in two studies involving 105,143 meal selections.

In Chapter 3 I examine the effects of increasing the proportion of vegetarian options available on vegetarian sales in three colleges and two studies compromising 94,644 meal selections. I use individual-level data to assign diners into quartiles based on their prior likelihood of selecting a vegetarian meal, and investigate how the different quartiles respond to changing vegetarian availability. By some definitions this counts as a "nudge", however it could be argued that this counts as choice editing. Although meat options were not banned or removed, the number of options did change.

In Chapter 4 I introduce a small change to the price of vegetarian meals (decreased by 20p from £2.05 to £1.85) and meat meals (increased by 20p from £2.52 to £2.72) in one college cafeteria. This study consists of 13,840 meal selections. Diners were also assigned to quartiles based on prior vegetarian selection.

In Chapter 5 I use the individual-level data from chapters 3 and 4 to examine the effects of gender on vegetarian, fish, poultry, pork and ruminant meat selection, and I investigate if the response to the price and availability interventions differed by gender.

In Chapter 6 I summarise my findings and their broader implications.

Table 1.1: Cryptonyms A, B, C and D assigned to each college (1 to 5) in the different chapters.

	Chapter 2. Order	Chapter 3. Availability	Chapter 4. Price	Chapter 5. Gender
College 1	A	C	NA	C
College 2	B	NA	NA	NA
College 3	NA	A	NA	A
College 4	NA	B	NA	B
College 5	NA	NA	Single college study, no cryptonym used.	D
Vegetarian definition	The vegetarian option which moved position	All vegetarian and vegan meals	Vegetarian only, excluding vegan meals	All vegetarian and vegan meals
Meat definition	Meat and fish	Meat and fish	Meat, excluding fish	Meat, excluding fish

Chapter 2. Not going the distance: effects of order on student cafeteria vegetarian sales

Were the walls of our meat industry to become transparent, literally or even figuratively, we would not long continue to raise, kill, and eat animals the way we do.

Michael Pollan (2006) The Omnivore's Dilemma

Human nature is above all things – lazy. [..] Even I would not write this article were not the publication-day hard on my heels.

Harriet Beecher Stowe (1864) Household Papers and Stories

2.1 Summary

Reducing meat consumption could help mitigate climate change. It is widely assumed – but largely untested – that food encountered first in cafeterias is preferentially selected. We investigated this by changing meal order in a British university's cafeterias between "VegFirst" – positioning the vegetarian option first – and "MeatFirst", in two studies involving 105,143 meal selections. In Study 1, meal order had no impact in Cafeteria A, but in Cafeteria B VegFirst increased vegetarian sales by 25.2% (4.6 percentage points) when options were alternated weekly and 39.6% (6.2 percentage points) when alternated monthly. We hypothesised that the difference observed was due to the longer distance between vegetarian and meat options in Cafeteria B (181cm) than A (85cm). In Study 2 we reduced this distance in B to 67cm. This eliminated increased vegetarian sales under VegFirst – and in some contexts vegetarian sales were lower – suggesting order effects depend on the distance between options. These findings have important implications for sustainable food policies.

2.2 Introduction

Shifting to more plant-based diets is a commonly proposed strategy to mitigate climate change and protect the natural environment (Poore & Nemecek, 2018b), particularly in high-income countries with high levels of animal product (meat, dairy, eggs, fish) consumption (Bryngelsson et al., 2016). Traditional approaches to shifting diets across populations include information provision and taxation (Bloomberg et al., 2019; Diepeveen et al., 2013; Wood & Neal, 2016). A third set of interventions – targeting non-conscious processes and the contexts in which behaviours occur ("choice architecture" or "nudging") – hold promise (Lehner et al., 2016) but are largely untested. One such nudge – rearranging the order in which foods are presented (e.g. in cafeteria lines) – is widely advocated to achieve dietary change (Thaler & Sunstein, 2009). If effective, placing vegetarian options first might be a simple and acceptable approach to reducing meat consumption, but the evidence for this intervention is limited in both quantity and quality (Bianchi, Garnett, et al., 2018; Hollands et al., 2019). A recent Cochrane review found only four studies testing the effect of the order of physical presentation of food (Hollands et al., 2019). While all reported that items nearer the start of a line were more likely to be selected, one study found this was not the case for all food products (Kongsbak et al., 2016), three introduced additional confounding interventions such as more prominent labelling (Cohen et al., 2015; Greene et al., 2017; Kongsbak et al., 2016), and two were based on only a single mealtime on one day (Kongsbak et al., 2016; Wansink & Hanks, 2013). Furthermore, none of the studies were focused on lowering meat consumption, and we cannot assume that the effects of changing the order of e.g. foods of different calorie densities, is necessarily the same for vegetarian and non-vegetarian meals.

To our knowledge the experiments presented here are the first to address this research gap by testing the effect of order on vegetarian meal sales. The studies were conducted in two college cafeterias in the University of Cambridge. We tested the hypothesis that the first main-meal option encountered by customers is preferentially selected and therefore has higher sales (Study 1). We tested the generality of this hypothesis by working in two different college cafeterias, collecting data on 54,745 meal selections. Based on our initial findings, we conducted a second study to better understand the results seen in Study 1, focusing on the distance between choice options and the likelihood of their selection, collecting data on 50,398 meal selections (Study 2). In both studies we assessed the persistence of any effects detected.

2.3 Study 1: Impact of order on vegetarian meal selection

2.3.1 Aims and design

This study involved two multiple treatment reversal design experiments, swapping the order in which customers were presented with vegetarian and meat main-meal options. Experiments were run on week-day lunch and dinner times across the university term in two University of Cambridge (UK) college cafeterias. The intervention involved alternating each week between a vegetarian option ("VegFirst") and a meat option ("MeatFirst") being placed first in line, i.e. nearest the cafeteria entrance (Figure 2.1 and Appendix A Figure A1-A3). This took place at College A during spring term 2017 (9 weeks) and at College B during summer term (10 weeks). To test whether altering the order of meals had longer-term effects on vegetarian sales these experiments were followed by a monthly alternation of VegFirst (four weeks) and then MeatFirst (five weeks) at College B during autumn term 2017.

The primary outcome was the number of vegetarian main-meals (hereafter "meals") sold at each mealtime, expressed as a percentage of the total meal sales; salads, sandwiches and side dishes were not included. College A provided four options at lunch and five at dinner; sometimes a second vegetarian or vegan option was provided but this did not count towards the sales of the focal vegetarian option (Appendix A Table A1). College B had a third main option, placed towards the back of the cafeteria; in summer term 2017 this third option was always meat at lunch and dinner (Appendix A Table A2), but starting from autumn term 2017 at lunchtimes a vegan option was provided (Appendix A Table A3). Similarly, the vegan sales did not contribute to the vegetarian sales considered in our analysis. Here we present results from binomial generalised linear models (GLMs) when order was the only predictor variable (univariate models) and when controlling for other predetermined independent variables (multivariate models, see Methods), following the recommendation of Simmons et al. (2011). We report p-values, odds ratios (OR), 95% confidence intervals (CI), McFadden's pseudo R^2 (hereafter simply "R^2") and model-predicted vegetarian sales (%).

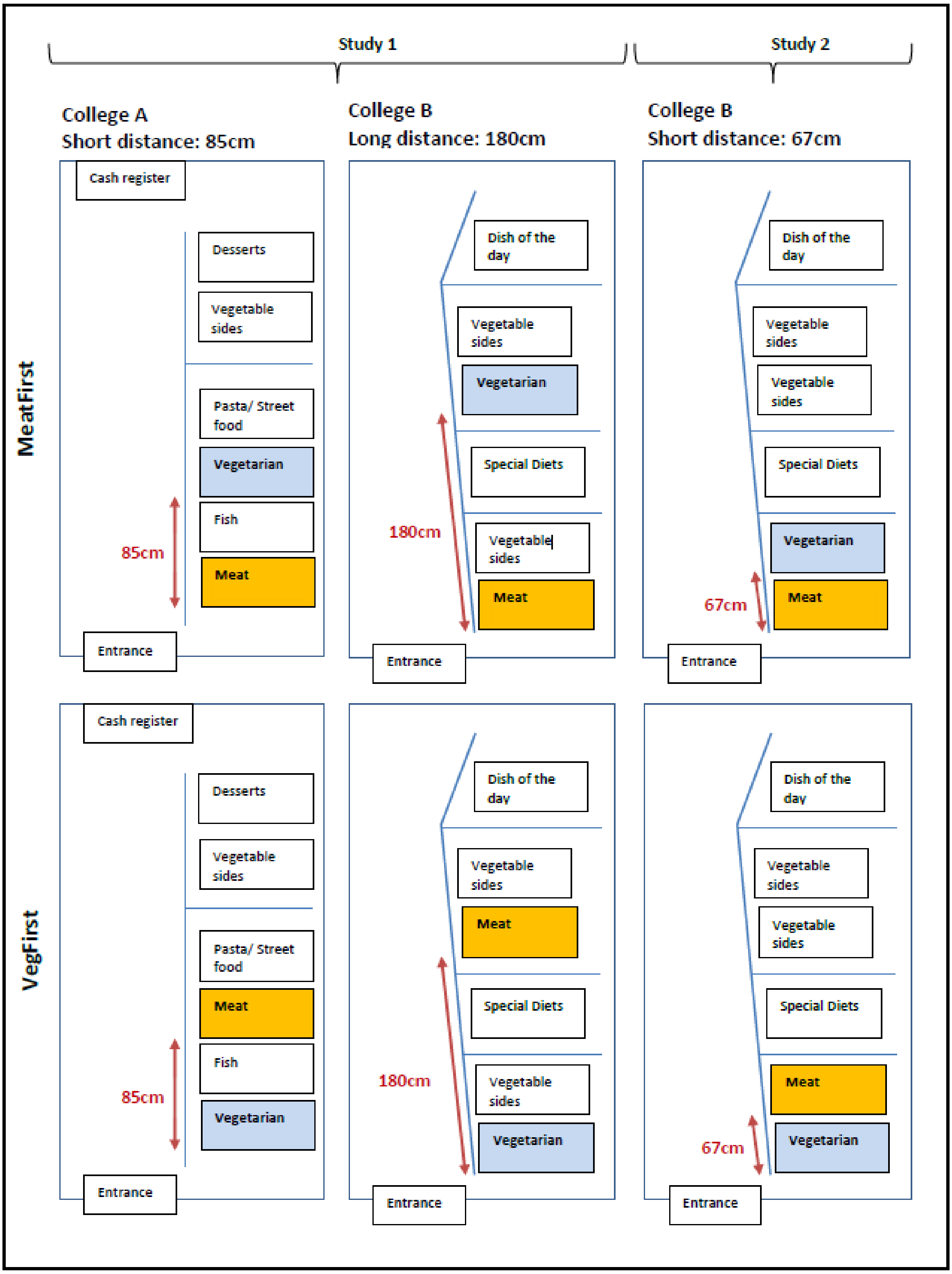

Figure 2.1: Stylised representation of MeatFirst (top) and VegFirst (bottom) cafeteria configurations in Study 1 for College A, short distance (left) and College B, long distance (middle); and in Study 2 for College B, short distance (right). In College A, diners have to walk past all options to reach the cash register. However in College B, the entire cafeteria is square rather than rectangular (with an island in the middle with salad components) and diners do not need to walk past all the options to reach the cash registers on the left hand side of cafeteria. For the exact layout of each location and a photo of College A cafeteria, see Appendix A Figures A1 to A3.

2.3.2 Results

Data were analysed from weekly alternations of meal order from 92 mealtimes involving 11,683 meals sold at College A (mean of 127 meals per mealtime), and from 96 mealtimes involving 20,544 meals sold at College B (mean of 214 meals per mealtime).

In College A, changing the order of meal options had no significant effect on vegetarian sales in either univariate (GLM, R^2= 0.000, VegFirst OR= 0.99 (CI= 0.90, 1.09), p= 0.876) or multivariate models (GLM, R^2=0.084, VegFirst OR=0.879 (CI= 0.768, 1.004), p=0.0579; Figure 2.2a, Table 2.1 and Appendix A Table A4). The models estimated that the mean percentage of vegetarian meals sold was 17.5% under MeatFirst and 15.7% under VegFirst (Figure 2.2a).

In College B, placing the vegetarian option first increased vegetarian sales by 25.2% (4.6 percentage points, from 18.2% to 22.8% of all meal sales, Figure 2.2b, Table 2.1 and Appendix A Table A5). Meal order alone explained 5.5% of the variation in vegetarian sales in the univariate GLM (R^2=0.055, VegFirst OR= 1.32 (CI= 1.24, 1.42), p<0.001) and remained a highly significant predictor in the multivariate model (R^2=0.070, VegFirst OR= 1.33 (CI= 1.24, 1.42), p<0.001).

In College B we also conducted month-long alternations of meal order from 86 mealtimes involving 22,518 meals sold (mean of 262 meals per mealtime). Vegetarian sales were 39.6% higher – an increase of 6.2 percentage points – under VegFirst, increasing from 15.6% to 21.8% of meal sales (multivariate GLM, VegFirst OR= 1.51 (CI= 1.30, 1.75), p<0.001; Figure 2.2c, Table 2.1 and Appendix A Table A6). The odds ratio of meal order was not significantly different between the weekly and the monthly alternations in the multivariate models (Weekly VegFirst OR CI= 1.24, 1.42; Monthly VegFirst OR CI= 1.30, 1.75): the confidence intervals overlapped, suggesting that the effect size of order persisted and diners did not become habituated to order for at least one month after meal order was changed.

In the multi-variate analyses, we found consistent correlations between some co-variates and vegetarian sales, but some co-variates which correlated with vegetarian sales had different effects in the different experiments. (Tables A4-A6). In two out of three experiments, dinnertimes had significantly lower vegetarian sales than lunchtimes, and in the third there was no significant difference (College A dinnertimes, OR=0.79 (CI= 0.70, 0.88), p<0.001; College B weekly dinnertimes OR= 0.83 (CI= 0.78, 0.89), p<0.001). In College A, spring term 2017 vegetarian sales were higher on warmer days (OR= 1.03, (CI= 1.00, 1.06), p=0.033); but in

College B autumn term 2017 vegetarian sales were lower on warmer days (OR= 0.97 (CI= 0.96, 0.99), p<0.001). There was not a consistent pattern in vegetarian sales across days of the week. In College A, menu rotation D had significantly higher vegetarian sales (OR= 1.20 (CI= 1.04, 1.40), p=0.015) than the others; vegetarian sales (of the focal vegetarian option) were lower when an additional vegetarian option (which did not change position) was present (OR= 0.64 (CI= 0.54, 0.76), p<0.001). In College A vegetarian sales significantly increased when the meat options were relatively more expensive than the vegetarian options (OR= 2.42 (CI= 1.21, 4.87), p=0.013).

2.3.3 Study 1 Interpretation

To summarise, we found no effects of altering meal order on vegetarian sales at College A, but strong and persistent effects at College B. There are several possible explanations for the different effects of order in Colleges A and B. These include the characteristics of the cafeterias, the customers, the different term times in which the studies were conducted, a mixture of all three, or indeed something else. We postulated that the first of these offered the most plausible explanation, and hypothesised that altering meal order had an effect in College B but not College A due to the different distances between the vegetarian and meat options: 85cm in College A and 181cm in College B. Previous studies have found that foods placed further away from participants are selected less frequently (Hollands et al., 2019), although to our knowledge no studies have tested interactions between distance and order. In College A, the options are adjacent to each other and so simultaneously within arm's reach of the diners; whereas in College B when the first option is reachable, the second is out of reach. This difference may have contributed to the different results in the two colleges. We devised Study 2 to test this hypothesis directly.

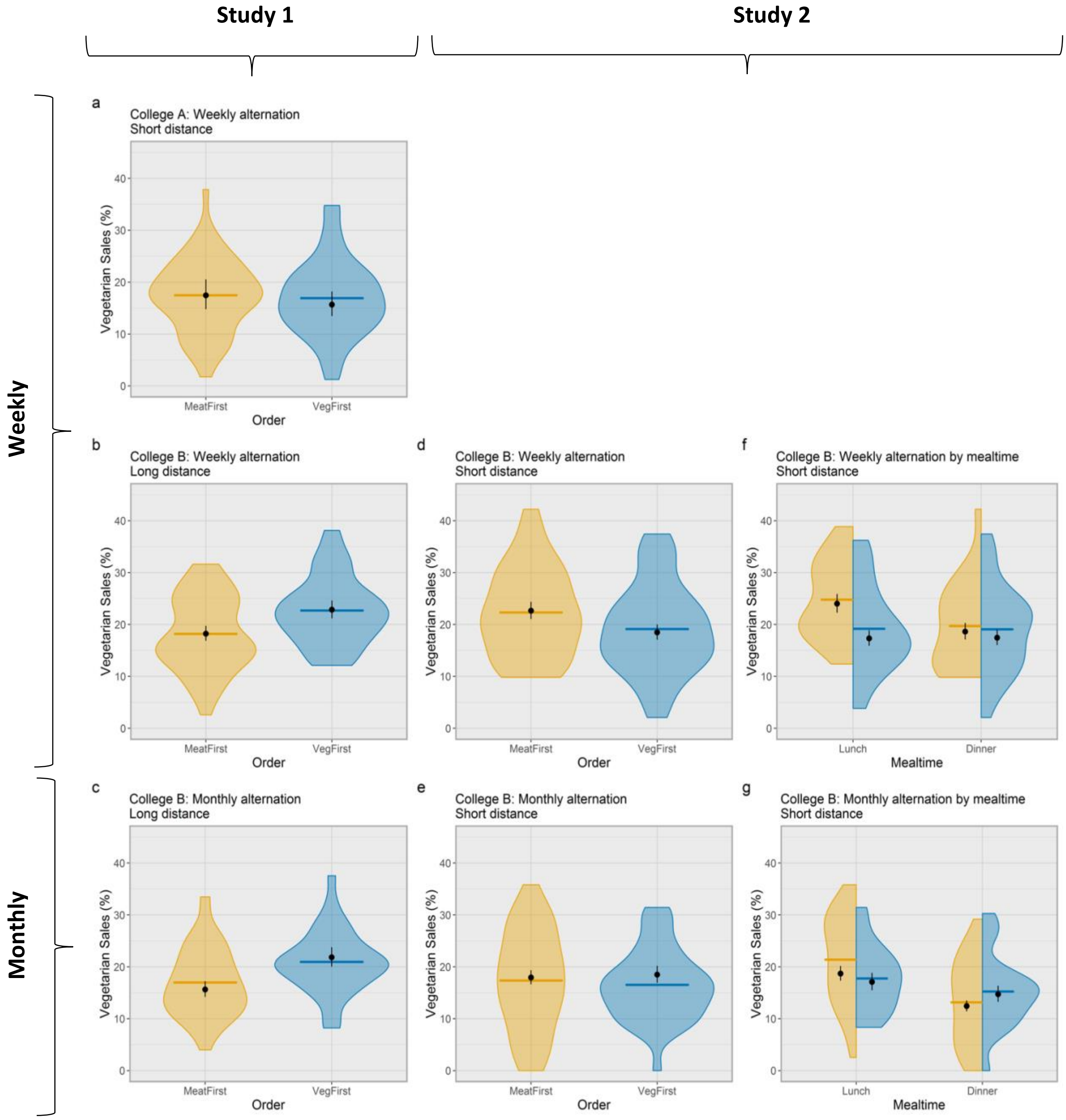

Figure 2.2: Effects of order on vegetarian sales in Study 1 (a-c) and effects of order and distance on vegetarian sales in Study 2 (d-g). Plots f) and g) present the same data as d) and e) respectively with the interaction between mealtime and order shown. Horizontal lines show the means of the raw data; black circles and vertical lines show the model predictions and confidence intervals from conditional regression, using the visreg package in R (Breheny & Burchett, 2016). *Conditions were selected so vegetarian sales predictions closely matched the raw means.*

Table 2.1: Summary of experiments and multivariate model estimates for order in Studies 1 and 2. 95% confidence intervals (CIs) reported.
[a]McFadden's pseudo R^2 for the multivariate model; [b]Model estimates for vegetarian sales (% of total sales) under MeatFirst; [c]Model estimates for vegetarian sales (% of total sales) under VegFirst; [d]Effect size of VegFirst compared to MeatFirst (the reference category) in the multivariate model; [e] Meal order variable p-value in multivariate model. [f] Model estimates for vegetarian sales at mealtimes from the multivariate model with an interaction between order and mealtime; the same model was run twice, once with Lunch-MeatFirst and once with Dinner-MeatFirst as the reference categories in order to generate odds ratios for both.
Independent variables included in multivariate models: mealtime, ambient temperature (centigrade), days since the start of the experiment, day of the week. Variables in College A only (as invariant in College B): vegetarian price differential, menu rotation, presence of an additional vegetarian option (Table 2.2).

Study characteristics							Multivariate model				
Study	Term	College	Distance between options (cm)	Order alternation	Number of mealtimes	Number of meals	[a] R^2	[b] MeatFirst: Veg sales % [CIs]	[c] VegFirst: Veg sales % [CIs]	[d] Meal order odds ratio [CIs]	[e] Meal order p-value
1	Spring 2017	A	Short (85)	Weekly	92	11,683	0.084	17.5 [14.8, 20.5]	15.7 [13.5, 18.2]	0.88 [0.77, 1.00]	0.058
1	Summer 2017	B	Long (181)	Weekly	96	20,544	0.070	18.2 [16.8, 19.7]	22.8 [21.2, 24.6]	1.33 [1.24, 1.42]	<0.001
1	Autumn 2017	B	Long (181)	Monthly	86	22,518	0.111	15.6 [14.2, 17.2]	21.8 [20.0, 23.8]	1.51 [1.30, 1.75]	<0.001
2	Spring 2018	B	Short (67)	Weekly	87	20,224	0.099	22.7 [21.0, 24.4]	18.5 [17.1, 20.0]	0.77 [0.72, 0.83]	<0.001
"	*"*	*"*	*[f] Lunchtimes*		*45*	*10,236*	*0.115*	*24.0 [22.3, 25.9]*	*17.3 [15.9, 18.8]*	*0.66 [0.60, 0.73]*	*<0.001*
"	*"*	*"*	*Dinnertimes*		*42*	*9,988*	*"*	*18.6 [17.1, 20.3]*	*17.5 [16.0, 19.0]*	*0.92 [0.83, 1.02]*	*0.126*
2	Summer 2018	B	Short (67)	Monthly	88	28,688	0.180	17.9 [16.6, 19.3]	18.5 [16.9, 20.2]	1.04 [0.92, 1.18]	0.560
"	*"*	*"*	*Lunchtimes*		*45*	*14,177*	*0.189*	*18.7 [17.3, 20.2]*	*17.1 [15.5, 18.8]*	*0.89 [0.78, 1.03]*	*0.132*
"	*"*	*"*	*Dinnertimes*		*43*	*14,511*	*"*	*12.4 [11.4, 13.5]*	*14.7 [13.3, 16.4]*	*1.22 [1.06, 1.40]*	*0.007*

2.4 Study 2: Impact of distance on order effects

2.4.1 Aims and Design

To test if the different effects in College A and B were indeed due to the different distances separating meal options, the College B cafeteria was re-arranged during spring and summer terms 2018, reducing the distance between the focal meal options to 67cm (cf 181cm in Study 1; Figure 2.1, right-hand panel). The same protocols as in Study 1 were then implemented, with a weekly alternation between VegFirst and MeatFirst in spring term 2018. To test for longer-term effects, this was followed by four weeks of VegFirst then five weeks of MeatFirst in summer term 2018. Unfortunately performing the opposite distance manipulation in College B, increasing the separation of meal options and then examining order effects, was not physically possible because of the design of the servery.

2.4.2 Results

Data were analysed from 20,224 meals sold at 87 mealtimes (mean of 232 meals per mealtime) when meal order was alternated weekly and 28,688 meals sold at 88 mealtimes (mean of 326 meals per mealtime) when alternated monthly.

Under the short-distance condition with weekly alternation of meal order, vegetarian sales were unexpectedly and significantly lower under VegFirst in both a univariate (GLM, R^2=0.019, VegFirst OR= 0.83 (0.78, 0.89), p<0.001) and multivariate model (GLM, R^2=0.099, VegFirst OR= 0.77 (CI= 0.72, 0.83), p<0.001; Table 2.1 and Appendix A Table A7). The multivariate model estimated that under VegFirst, compared to MeatFirst, vegetarian sales decreased by 18.5% (4.2 percentage points, from 22.7% to 18.5%, Figure 2.2d). Further investigation of this result showed an interaction between mealtime and meal order (GLM, interaction term p<0.001): at lunchtimes vegetarian sales were 27.9% lower under VegFirst compared with MeatFirst (6.7 percentage points, MeatFirst= 24.0% (CI= 22.3, 25.9); VegFirst= 17.3% (CI= 15.9, 18.8)), but meal order had no significant effect on vegetarian sales at dinnertimes (MeatFirst= 18.6% (CI=17.1, 20.3); VegFirst= 17.5% (CI= 16.0, 19.0), Figure 2.2f).

With monthly alternation of order in the short-distance condition there was no significant difference in vegetarian sales between VegFirst and MeatFirst in the univariate analysis (univariate GLM, VegFirst OR= 0.98 (CI= 0.91, 1.04), p=0.477) nor multivariate analysis (multivariate GLM, VegFirst OR = 1.04 (CI= 0.92, 1.18), p=0.560; Figure 2.2e and Appendix A Table A8). However, a significant interaction was again found between mealtime and meal order (GLM, interaction term, p< 0.001): there was no significant change in vegetarian sales with meal order at lunchtimes (MeatFirst= 18.7% (CI= 17.3, 20.2), VegFirst= 17.1% (CI= 15.5, 18.8) but at dinner times vegetarian sales were significantly higher, by 18.7%, under VegFirst (2.3 percentage points, MeatFirst= 12.4% (CI= 11.4, 13.5), VegFirst= 14.7% (CI= 13.3, 16.4); Figure 2.2g).

For the co-variates, we found again that vegetarian sales were significantly lower at dinnertimes than lunchtimes for both the weekly (OR= 0.86 (CI= 0.80, 0.92), p<0.001; Table A7) and monthly alternation (OR = 0.68 (CI= 0.64, 0.72), p<0.001; Table A8). Again, temperature had significant effects in different directions in the two experiments. In the weekly alternation in spring term, vegetarian sales were lower on warmer days (OR= 0.95 (CI= 0.94, 0.96), p<0.001) but in the monthly alternation in summer term were higher on warmer days (OR= 1.02 (CI= 1.00, 1.03), p=0.008).

To summarise, under short distance conditions at College B for weekly alternation of meal order vegetarian sales were 27.91% lower at lunchtimes under VegFirst, but there was no difference at dinnertimes. However, monthly alternation of meal order had no effect at lunchtimes but vegetarian sales were 18.60% higher under VegFirst at dinnertimes. The effect size of meal order was significantly different between the weekly and monthly alternation under a short distance at College B: the confidence intervals for the multivariate models (without interaction) do not overlap. This suggests that the effects of order under short distance do not persist in College B and are perhaps influenced by other aspects of the choice environment.

2.5 Discussion

Placing vegetarian meal options first can increase their sales and hence offers some potential for helping tackle climate change by achieving more sustainable diets. However, the effect of meal order appears to be modified by the distance between the meat and vegetarian options. Placing the vegetarian option first (instead of a meat option) increased vegetarian sales when the distance between options was longer (181cm: Study 1 College B) rather than shorter (<85cm:

Study 1 College A and Study 2 College B). The effects of a long distance between meal options persisted when order was alternated monthly instead of weekly. Contrary to expectations, however, under short distance conditions, vegetarian sales did not consistently increase under VegFirst, and in some contexts vegetarian sales were lower, higher or unchanged when vegetarian meals were placed first. These findings have important implications for catering policies: a nudge which we predicted would increase vegetarian sales can work, but can also have no effect or even be counterproductive.

Our studies have several strengths. First, they provide the most robust estimate to date of the impact on selection of the order in which meals are presented. They are based on 105,143 meal selections across two years. This compares with a recent systematic review which found a combined total of only 11,290 observations across all 18 studies testing other forms of choice architecture interventions aimed at lowering meat consumption (Bianchi, Garnett, et al., 2018). Unlike previous studies, the current studies tested one intervention only, thus avoiding the confounding effects present in many other similar studies (Cohen et al., 2015; Greene et al., 2017; Kongsbak et al., 2016). By alternating the order of meals both weekly and monthly, the current studies were able to show that effects of order persisted under the long distance condition – which is key to designing interventions capable of delivering long-term shifts towards more sustainable diets. Follow-up studies tested the inconsistent effects of order and established that the distance between options influences the effects of order on vegetarian sales. Finally, fidelity to protocol was high, estimated from 76 observations to be over 95% at both colleges.

These studies also have some limitations. First, individual-level data on cafeteria visitors were not available to the researchers. This is common in field studies on food sales (Hollands et al., 2018) and means that there is some uncertainty in the p-value estimates. Second, the studies were conducted in British university cafeterias, a convenient but unrepresentative study setting. Cambridge has the second lowest intake of state school pupils in the Russel Group (63%) and is therefore also unrepresentative of British universities more generally (Montacute & Cullinane, 2018). Studies in different populations and other settings and countries will be needed to test the generalisability of the results. Further studies are also needed to understand better why order effects vary with distance and mealtimes. In Study 2 (College B, short distance) under weekly alternation of meal order, putting the vegetarian option first significantly reduced vegetarian meal sales at lunchtimes but not dinnertimes. These findings were not replicated under the monthly alternation, where meal order had no effect at lunch but placing vegetation meals first boosted their sales at dinner. These detailed differences were unexpected and are hard to interpret: the cafeteria characteristics mean we cannot elicit if these differences are due to a combination of term time, mealtime and the different third option (vegan at lunchtimes and meat at dinnertimes, Appendix A Tables A9 and A10), or some other factors. We speculate that under short-distance conditions meal order can sometimes influence vegetarian sales but that this effect can be modified by other elements of the choice environment. Further studies are needed to explicitly test why order effects might have varied with both distance and mealtimes in Study 2.

The effort to obtain a meal and the visibility or salience of the meal options are possible mechanisms which might explain why vegetarian sales were higher under VegFirst when there was a longer (> 1.5 metre) distance between the vegetarian and meat options, but generally not when the distance was shorter (<1 metre). All other things being equal, food options that require less effort to obtain are preferentially chosen (Hollands et al., 2019; Meiselman, Hedderley, Staddon, Pierson, & Symonds, 1994) and the distance between the meat and vegetarian options could be a proxy for effort. We are not aware of any tests examining how effort might interact with order. However, some studies have tested interventions which increase the effort to obtain a meat option. Two have removed meat options from a menu, one instead listing the meat options on a board 3.5 metres away (Campbell-Arvai et al., 2014), and the second requiring customers to request a specially prepared meat dish (Gravert & Kurz, 2017). In both studies the selection of vegetarian meals increased. A complementary hypothesis is that with increased distance the second option becomes less visible and salient than the first. Similarly, we are not aware of any studies which have tested interactions between salience and food presentation order, though some have tried increasing the salience of vegetarian options. One found that placing a vegetarian (instead of a meat) meal on the counter, so that it was visible to restaurant customers at the point of meal selection, increased vegetarian sales (Kurz, 2018). However, studies altering menus have found vegetarian meal selection did not significantly increase if vegetarian options were promoted using "Chef's recommendation" (Bacon & Krpan, 2018) or "Dish of the day" (dos Santos et al., 2020; Zhou et al., 2018) descriptors. This perhaps suggests that altering menu properties is less effective than altering the positions of the meals themselves, or that effort might be more influential than salience.

Our results indicate that although meal presentation order could have a role in reducing meat consumption in cafeterias, the effects are context-dependent. Placing the vegetarian option first when the meat option is not within reach (Pechey, Hollands, & Marteau, 2019) appears to increase sales, but when both meat and vegetarian options are within reach, placing the vegetarian option first does not have a consistent impact on meal selection and, in some contexts, vegetarian sales may even decrease. For caterers interested in shifting customers to a more plant-based diet, changing order – at least without pilot-testing its impacts – may be a less effective strategy than alternative approaches such as reducing the serving sizes of meat (Bianchi, Garnett, et al., 2018). Contrary to widespread assumptions, meal order does not have a consistent effect on selection of vegetarian meals, and seems instead to vary with the distance between options. More studies are needed to specify more precisely the conditions under which placing vegetarian meals first increases the likelihood of their selection.

2.6 Methods

2.6.1 Study setting

College A is a graduate college with over 600 students. College B has over 900 students, both undergraduate and graduate. Both colleges admit students of any gender identity. Meals are not included in the tuition or accommodation fees: students can choose to eat in the college cafeteria, cook their own meals or eat at another establishment. Students pay for meals by swiping their university cards. The cafeterias are approximately self-service: students take a tray, view the different meal options available, and ask the serving staff for their preferred meal and/or side dishes. Students serve themselves salads, desserts and other cold items.

2.6.2 Power analyses

Power analyses were conducted on simulated data to estimate what effect size of VegFirst our experiments might detect 90% of the time (Power =0.9) at $p<0.05$. In Study 1 College A sold ~11,000 meals over a term, and in Study 1 and 2 College B sold >20,000 meals each term. Based on these sample sizes, for baseline (MeatFirst) vegetarian sales between 16 and 20%, the simple power analysis estimated that a >=2.5 percentage point increase could be detected 90% of the time for the experiment in College A, and a >=2.0 percentage point increase for experiments in College B. Although these power analyses do not take into account other independent variables and assume that these can be properly controlled for in the model, they indicate that our experiments were likely to be sufficiently powerful to detect quite small effects.

2.6.3 Data collection and analyses

Sales data were downloaded from the online catering platform Uniware ("Uniware," n.d.). We carried out analyses in R 3.5 (R Core Team, 2020) using binomial Generalised Linear Models (GLMs) to examine the effect of order. Many individuals visit the college cafeterias more than once over a term and make repeated meal selections. In the absence of individual-level data, each meal selection was treated as independent. While this approach has been used in numerous other studies (Cohen et al., 2015; Greene et al., 2017; Pechey, Cartwright, et al., 2019) it adds uncertainty to p-value estimates. We therefore focused primarily on the effect size of our intervention, presenting the odds ratio, 95% confidence intervals and McFadden's pseudo R^2. The effect size (i.e. the odds ratio) was calculated by taking the exponential of the model estimate. Model diagnostics were used to check that the models did not violate any regression assumptions.

In the multivariate analyses we included co-variates that could influence vegetarian sales (Table 2.2). Previous studies have used day of the week, ambient temperature, number of days since the start of the study as co-variates in analyses on food and drink selections (Pechey, Cartwright, et al., 2019; Pechey et al., 2016). Students may be more likely to select a meat meal at lunchtimes or dinnertimes depending on which mealtime students perceive as the main meal of the day. In college A, we anticipated that the presence of an extra vegetarian option could reduce sales from the focal vegetarian option, and we included menu rotation to control for the variation in meal offerings which could affect choices. The relative difference in price between meat and vegetarian options varied in College A, we included this as a co-variate as price is an important influence on food choices (DEFRA, 2016).

2.6.4 Sensitivity analyses

In our studies we present results from both binomial GLMs when order was the only predictor variable (univariate models) and when controlling for other predetermined independent variables (multivariate models, see Table 2.2).

The presence or absence of a VegFirst effect and its direction (i.e. increasing or decreasing vegetarian sales) did not change between univariate models, multivariate models, and multivariate models with an interaction between mealtime and order, for all but one analysis.

This indicates our results are consistent with respect to different statistical models and the inclusion of independent variables, and that our conclusions and interpretation are robust. However for the final experiment in Study 2 (College B, monthly alternation, short distance) meal order had no effect on vegetarian sales in the univariate and multivariate models, but in the multivariate model with an interaction, dinnertimes had significantly higher vegetarian sales under VegFirst. This result should therefore be interpreted more cautiously than the results and conclusions from our other experiments.

Table 2.2: Independent variables included in the binomial Generalised Linear Models

Model	**Variable**	**Description and notes**
Both College A and B	Order	Option placed nearest the entrance (VegFirst vs MeatFirst)
	Mealtime	Lunch or dinner
	Ambient temperature (centigrade)	Mean outside temperature on that date ("Cambridge Daily Weather Graphs," 2018)
	Days Since	Days since the start of the experiment
	Day	Monday, Tuesday, Wednesday, Thursday, Friday
College A only (as invariant in College B)	Vegetarian price differential (£)	Difference between the mean cost of the meat options and the vegetarian options Constant at College B
	Menu rotation	Different menus are offered each week, College A had a 4-week cycle; College B had an 8-week cycle. As the menu cycle was repeated at College A, menu could be included in the model. This was not possible for College B, where the menu cycle was not repeated.
	Presence of an additional vegetarian option	At some mealtimes College A served an additional vegetarian option, College B did not

Chapter 3. Impact of increasing vegetarian availability on meal selection and sales in cafeterias

The path of the norm is the path of least resistance; it is the route we take when we're on auto-pilot and don't even realize we're following a course of action that we haven't consciously chosen. Most people who eat meat have no idea that they're behaving in accordance with the tenets of a system that has defined many of their values, preferences, and behaviors. What they call 'free choice' is, in fact, the result of a narrowly obstructed set of options that have been chosen for them.
Melanie Joy (2009) Why we love dogs, eat pigs and wear cows

I once went to a tomato-free buffet. I complained because it gave tomato eaters no option. You wouldn't make tomato-avoiders go to a tomato-only buffet!
Tom Finch (2019) satirising the arguments against meat-free buffets

3.1 Summary

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.

3.2 Introduction

Shifting diets to achieve sustainability outcomes is likely to require an array of strategies for changing human behaviour (Marteau, 2017; Reddy et al., 2016). 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" (Dobbs et al., 2014). A Cochrane review (Hollands et al., 2019) found only five studies on altering availability that met the inclusion criteria (Fiske & Cullen, 2004; Foster et al., 2014; Kocken et al., 2012; Roe, Meengs, Birch, & Rolls, 2013; Stubbs, Johnstone, Mazlan, Mbaiwa, & Ferris, 2001), 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 (Bartholomew & Jowers, 2006); 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% (Pechey, Cartwright, et al., 2019).

Turning to reducing meat consumption, a recent review found no studies on the effects of changing the availability of plant-based meals (Bianchi, Garnett, et al., 2018). 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 (M Clark, 2017; Gravert & Kurz, 2017), 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 (Bacon & Krpan, 2018). 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 (Whitaker, Wright, Finch, & Psaty, 1993). 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 (Gravert & Kurz, 2017; Grech & Allman-Farinelli, 2015); and to have a genuinely additional environmental effect it is important there are no sizeable rebound effects (O'Reilly et al., 2017) whereby meat consumption increases on other occasions. However almost no studies address rebound effects or effects on total sales (Gravert & Kurz, 2017).

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.

3.3 Research setting

We collected data from three University of Cambridge college cafeterias during weekday term-time lunches and dinners. 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 3.1). 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 3.1).

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 (McCulloch, Searle, & Neuhaus, 2008). A 95% confidence level was used to calculate confidence intervals (CIs). Models were evaluated using the Akaike Information Criterion (AIC), interpretability and model diagnostics (Hosmer, Lemeshow, & Sturdivant, 2013).

3.4 Study 1: Observational

3.4.1 Aims and design

For Study 1 we did not experimentally alter the menu (Supporting Information (SI) Appendix, Tables B1 and B2) 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 (Appendix B Tables B3 and B4), vegetarian availability ranged from 16.7% to 75% in College A and 12.5% to 66.7% in College B.

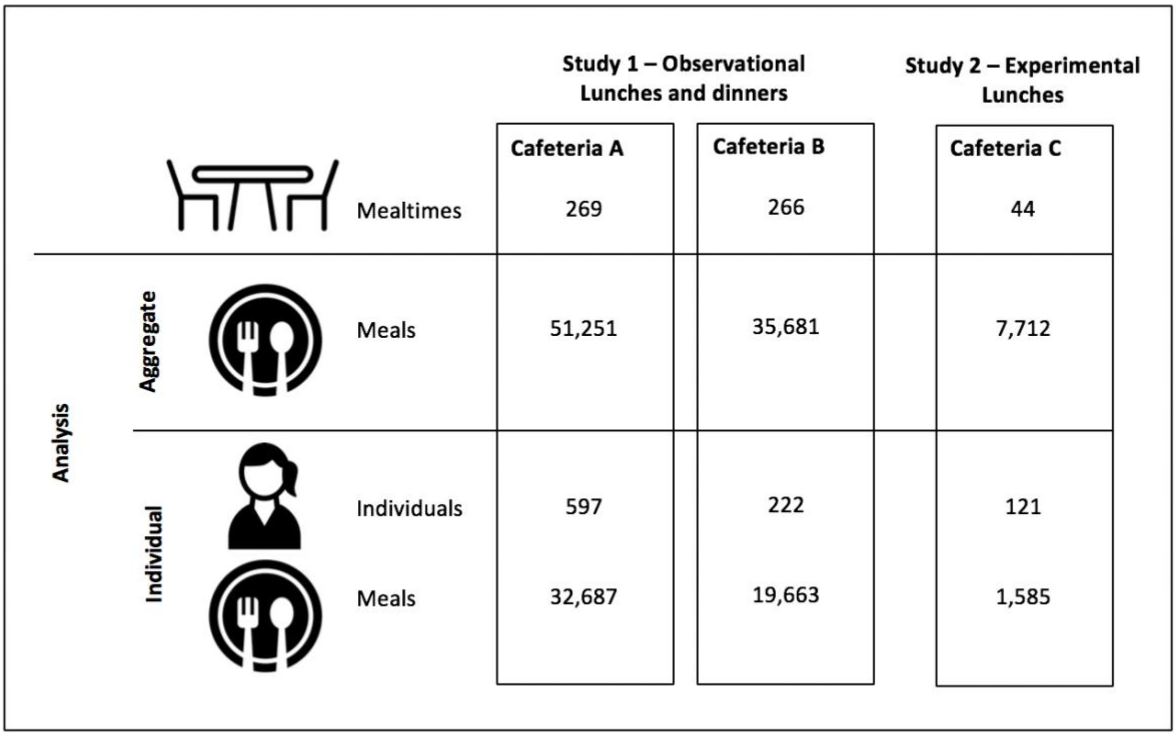

Figure 3.1: Overview of data and levels of analyses in Study 1 and Study 2. Credit: icons from thenounproject.com.

3.4.2 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 (Appendix B Tables B5 and B6), 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 3.2a and Appendix B Tables B5 and B6).

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.

3.4.3 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 3.1, Methods and Appendix B Tables B7 and B8). In both colleges every quartile from the Most Vegetarian to the Least Vegetarian bought more vegetarian meals as vegetarian availability increased (Figure 3.2b&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, Appendix B Tables B9 and B10).

3.4.4 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 3.2d and Appendix B Tables B11 and B12). 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%.

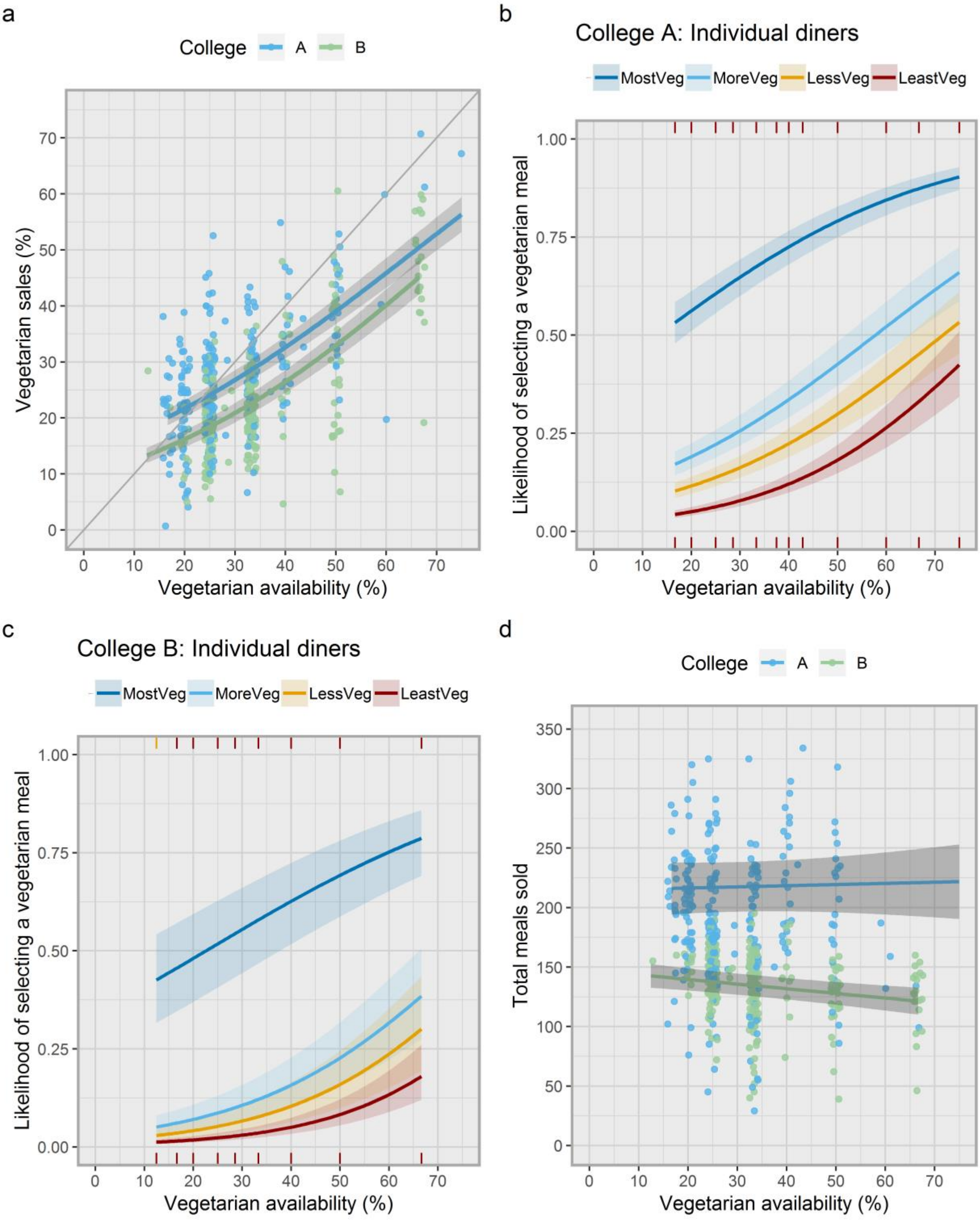

Figure 3.2: Effects of vegetarian availability on vegetarian and total sales for Study 1. a) Raw values (jittered) of vegetarian sales against vegetarian availability; b and c): Modelled likelihood of selecting a vegetarian meal for individual diners at Colleges A and B, with individual diners divided 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) (Breheny & Burchett, 2017).

3.5 Study 2: Experimental

3.5.1 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, Appendix B Tables B13 and B14 and Figure B1). 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, Appendix B Table B15).

3.5.2 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 3.3a and Appendix B Table B16). 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, Appendix B Table B16).

3.5.3 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 3.3, Appendix B Tables B17 and B18). When other variables were controlled for, diners in every quartile (except Most Vegetarian) bought more vegetarian meals in response to increasing vegetarian availability (Appendix B Table B19). 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 Appendix B Table B19).

3.5.4 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 3.3c and Appendix B Table B20). 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 3.3d and Appendix B Table B21). 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.

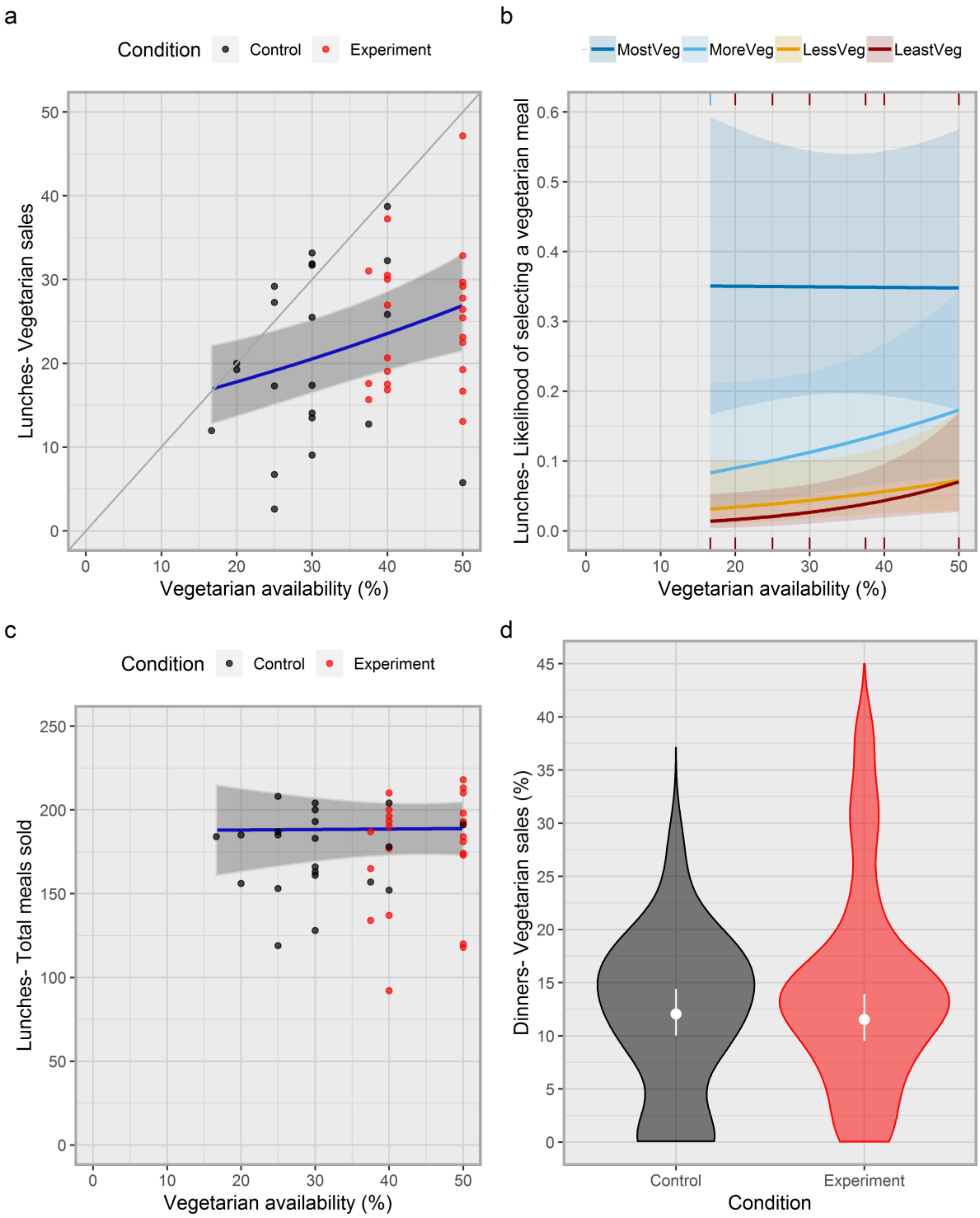

Figure 3.3: Effects of vegetarian availability on vegetarian and total sales for College C, Study 2. a) Raw values of vegetarian sales against vegetarian availability; b) Modelled likelihood of selecting a vegetarian meal for individual diners, divided into Least Vegetarian to Most Vegetarian quartiles; 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).

3.6 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 (Bianchi, Garnett, et al., 2018): 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 (Bianchi, Garnett, et al., 2018): a 40% reduction in red and processed (Ali, Simpson, Clark, Razak, & Salter, 2017), a 54% reduction in spending on meat (Flynn, Reinert, & Schiff, 2013), and a 70% reduction in meat consumed (Holloway, Salter, & Mccullough, 2012). 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 (Ali et al., 2017; Gravert & Kurz, 2017): 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% (Ali et al., 2017). Reducing the serving size of meat portions reduced meat consumption by 13-14% (Reinders, Huitink, Dijkstra, Maaskant, & Heijnen, 2017; Rolls, Roe, & Meengs, 2010); 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 (Bryngelsson et al., 2016; Clune et al., 2017; Godfray et al., 2018; Poore & Nemecek, 2018b) 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 (Bianchi, Garnett, et al., 2018). 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 (Scarborough et al., 2014).

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 (Campbell-Arvai et al., 2014; Volkhardt et al., 2016). Second, in keeping with other similar field studies (Pechey, Cartwright, et al., 2019), 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. Furthermore, at the University of Cambridge students from private schools are over-represented, and students from state-schools underrepresented, compared to other Higher Education Institutions (Montacute & Cullinane, 2018). 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 (Buckwell & Nadeu, 2018a). Shifting both diets and agricultural production towards less meat will require the support of governments and farmers as well as pressure from citizens (Buckwell & Nadeu, 2018a; Committee on Climate Change, 2018).

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 (Lombardini & Lankoski, 2013), and it can save money on ingredients (Gravert & Kurz, 2017). 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 (Volkhardt et al., 2016). Interest in reducing meat consumption and in “flexitarianism” is on the rise (Eating Better, 2017) 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.

3.7 Methods

3.7.1 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.

3.7.2 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 (16th January to 17th March), summer (24th April to 30th June) and autumn terms (2nd October to 1st 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 (Appendix B Table B15). 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 (Appendix B Table B19) but did not have significantly different vegetarian sales (Appendix B Table B15).

3.7.3 Data collection

Sales data were downloaded from the online catering platforms Uniware ("Uniware," n.d.) and Accurate Solutions ("Accurate Solutions," n.d.) 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.

3.7.4 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 (Appendix B Table B3). 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.

3.7.5 Statistical approaches

We carried out analyses in R 3.5 (R Core Team, 2020), using the lme4 (Bates, Bolker, Maechler, & Walker, 2015) 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 (Simmons et al., 2011), 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 3.1). 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 (Fox & Weisberg, 2018) and visreg packages (Breheny & Burchett, 2016).

In the multivariate analyses we included co-variates that could influence vegetarian sales (Table 3.1). Previous studies have used day of the week, ambient temperature and the busyness of cafeterias, as co-variates in analyses on food and drink selections (Pechey, Cartwright, et al., 2019; Pechey et al., 2016) and we include these here. Students may be more likely to select a meat meal at lunchtimes or dinnertimes depending on which mealtime students perceive as the main meal of the day. We included week of term to control for any change over term. The relative difference in price between meat and vegetarian options varied in all three colleges, we included this as a co-variate as price is an important influence on food choices (DEFRA, 2016).

Table 3.1: 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(“Cambridge Daily Weather Graphs,” 2018)
	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	NA
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

Chapter 4. Price of change: does a small alteration to the price of meat and vegetarian options affect their sales?

The better paid workers, especially those in whose families every member is able to earn something have good food as long as this state of things lasts; meat daily and bacon and cheese for supper. Where wages are less, meat is used only two or three times a week, and the proportion of bread and potatoes increases. Descending gradually, we find the animal food reduced to a small piece of bacon cut up with the potatoes; lower still even this disappears, and there remain only bread, cheese, porridge and potatoes
Frederick Engels (1844) The condition of the working classes in England

Gigliotti was born in Argentina, to an Italian mother, a very good cook. Money was often tight and meat was a rare luxury. They only moved to the US when he was nine. Once they built their new American life, his mother couldn't understand when her son brought home vegetarian friends. Meat was the thing you aspired to, so why would you wilfully reject it when it was there in front of you?
Bee Wilson (2016) First Bite

4.1 Summary

Reducing meat and fish consumption in wealthier countries would help mitigate climate change, raising the question of the most effective ways to achieve this. Price influences the food people buy, but to our knowledge no published field study has assessed the impact on sales of experimentally altering the price of meat and vegetarian meal options. We ran an experiment across 106 mealtimes with 13,840 meal selections at a college cafeteria in the University of Cambridge (UK), introducing a small change to the price of vegetarian meals (decreased by 20p from £2.05 to £1.85) and meat meals (increased by 20p from £2.52 to £2.72). Total meal sales did not differ significantly before and after the price change. When controlling for other variables, changing price significantly increased the proportion of vegetarian sales by 3.2 percentage points (p=0.036). However, there was no significant change in meat sales before and after the price change, although fish sales did decline by 2.8 percentage points (p=0.010). When analysed by individual diners' pre-experimental meal choices (N=325), the price intervention significantly affected only the quartile of diners with the highest prior rates of vegetarian and vegan meal selection ("MostVeg" quartile), who increased their vegetarian meal selection by 13.7 percentage points (p=0.011). Students mainly pay for meals on their university cards and rarely pay with cash, which may lessen the impact of a price intervention in this context. Our results suggest price changes may be one lever for increasing vegetarian meal consumption. Further field studies are needed to test different price changes, and in non-university populations.

4.2 Introduction

How best to encourage lower meat consumption is a key question for environmental psychology. Among other interventions, fiscal measures such as reforming taxes, subsidies and prices – are likely to be vital for bringing about healthy and sustainable diets. British citizens self-report price as the most important influence on their food purchases (DEFRA, 2016).

Many academic papers and reports have proposed the introduction of meat taxes (Park, 2020; Springmann et al., 2017; The Danish Council on Ethics, 2016; True Animal Price Protein Coalition, 2020; Wellesley, Happer, & Froggatt, 2015). However, taxes are generally politically unpopular due to their lack of public support (Diepeveen et al., 2013) and no specific meat taxes have yet been introduced. In 2011 Denmark introduced a tax on foods with high levels of saturated fat. This tax predominantly affected meat and dairy products and it is estimated that it did result in a modest decrease in saturated fat consumption (Jorgen Dejgaard Jensen, Smed, Aarup, & Nielsen, 2016). However, due to government concerns about the tax's administrative costs and the regressive effects on low-income households, this tax was removed a little over a year later in 2012 (Vallgårda, Holm, & Jensen, 2015). A more acceptable alternative to taxing meat could be to reduce its subsidies. Industrial-scale livestock farms in the UK received an estimated £70 million in government subsidies in 2016 and 2017 (Wasley et al., 2018). Wellesley et al. (2015) found in focus-group discussions that subsidy removal was more popular than a tax, even though it led to the same effect, i.e. increased consumer prices on individual products.

Due to a lack of empirical experimental data, estimates for the effects of price changes on meat consumption have generally been modelled based on assumptions of price elasticities for different products. In five published modelling studies meat taxes were based on GHGE and other environmental metrics, and therefore beef received a higher price change (12-33% price increases) than pork (5-11%) and poultry (3-11%) (Edjabou & Smed, 2013; Kehlbacher, Tiffin, Briggs, Berners-Lee, & Scarborough, 2016; Säll & Gren, 2015; Springmann et al., 2017; Wirsenius, Hedenus, & Mohlin, 2011). In three of the five studies, price increases were predicted to decrease consumption of all meat types (Kehlbacher, Tiffin, Briggs, Berners-Lee, & Scarborough, 2016; Säll & Gren, 2015; Springmann et al., 2017). However, in the other two studies the large increase in the price of beef, and the modest increase to pork and poultry prices, led to a decrease in beef but an increase in poultry (Edjabou & Smed, 2013; Wirsenius et al., 2011) and pork consumption (Wirsenius et al., 2011). Another possible unintended consequence of meat taxes is increased purchases from discount supermarkets, rather than dietary shifts away from meat (Jørgen Dejgård Jensen & Smed, 2013).

Several reviews on the effects of price on food choices conclude that taxes and subsidies have great potential to bring about healthier diets (Andreyeva, Long, & Brownell, 2010; Epstein et al., 2012; Thow, Downs, & Jan, 2014). One review found that in 23 out of 24 studies, subsidising healthier foods significantly increased their purchase and consumption (An, 2013). In a Belgian university cafeteria, decreasing students' meal price by 10% and 20% if fruit was chosen as a dessert increased fruit purchases by 25.1% and 42.4% respectively (Deliens, Deforche, Annemans, De Bourdeaudhuij, & Clarys, 2016). Increasing the cost of unhealthy food is also effective: increasing the students' meal price by 10% and 20% when they selected fries as a side led to a 10.9% and 21.8% reduction in fries purchased (Deliens et al., 2016). In contrast to health, there are relatively few studies on how price affects selection of more sustainable food options (Hoek, Pearson, James, Lawrence, & Friel, 2017).

Turning to meat, a systematic review on interventions to reduce meat consumption (Bianchi, Garnett, et al., 2018) found only one experimental study on price (Vermeer, Alting, Steenhuis, & Seidell, 2010). Changing the price structure of chicken nuggets from a value system (decreasing price/gram across "small", "medium" and "large" portions) to a proportional system (same price/gram for all three portion sizes) did not increase selection of smaller portions of chicken nuggets (Vermeer et al., 2010). Although this was a field study, the questionnaire measured behavioural intention rather than actual behaviour. Since the systematic review, an online study has been published which used three-option menus (one meat, two vegetarian options) and found that the presence of a "decoy" vegetarian option, priced 30% higher than the other two options, did not increase selection of the cheaper "target" vegetarian option (Attwood, Chesworth, & Parkin, 2020). However, neither of these studies tested the effects of price changes on vegetarian and meat meal consumption through measuring actual rather than hypothetical behaviour.

The current study contributes to this gap in evidence. We conducted a field experiment in a University of Cambridge college cafeteria to test the hypothesis that a small reduction in price increases the selection of vegetarian meals. Halfway through a nine-week university term the price of a vegetarian option was lowered by 20p from £2.05 to £1.85 (-9.8%), and the price of the two meat options was increased by 20p from £2.52 to £2.72 (+7.9%). As well as quantifying meat and vegetarian meal sales before and after the intervention we tested whether the price change affected total meal sales, and sales of fish and vegan meals (whose prices were not manipulated). Importantly we also used anonymized individual-level data to analyse whether changing price had different effects depending on prior levels of vegetarian and vegan meal consumption of individual diners.

4.3 Methods

4.3.1 Study setting

The study was conducted during autumn term 2018 (1st October to 30th November 2018) in a University of Cambridge (UK) college (the university's colleges are broadly equivalent to halls of residence). The studied college admits students of any gender identity, as well as both undergraduate and graduate students. Students who are members of the college can pay for meals by swiping their university cards, which are pre-loaded with credit throughout the academic year. Students can view their spending history online. Approximately 91% of meals are paid for on such university cards, the remaining 9% are paid with cash or a debit card. Meals are not included in tuition or accommodation fees, though students pay a compulsory "Kitchen Fixed Charge" which subsidises the college cafeteria's overheads. The Kitchen Fixed Charge is approximately £50 per term for graduates, £165 for undergraduates who live on the same site as the cafeteria, and £100 for undergraduates who live on a different site. Although many students eat at least some meals in the cafeteria, students can also cook their own meals or eat elsewhere.

This research was approved by the University of Cambridge Psychology Research Ethics Committee. We obtained signed consent forms from the college catering managers. In keeping with research governance for interventions that target environments rather than individuals, college diners were not informed of the study per se, though the price change was advertised (see below).

4.3.2 Study design

The study had a simple clustered A/B design in which meal selections by individuals were observed for four weeks before a price change was introduced and then observed for five weeks after this. We collected data from lunches and dinners, Mondays to Saturdays across the approximately 9 weeks of autumn term 2018. This comprised 106 mealtimes involving 13,840 hot meal selections, with purchases of sides, sandwiches and salads excluded from these analyses. Students who choose a hot meal (hereafter simply "meals") can also buy accompanying vegetables sides (£1 per vegetable), desserts (£1.19) and other items. The college served two meat options, one vegetarian, one fish and one vegan option at all mealtimes, except on Friday lunchtimes where one meat option was replaced with an additional fish option and Saturday lunchtimes where the vegan option was not included (Table C1). The first four weeks of term were the baseline period (original prices) and the final five weeks of term were the intervention period (altered prices). Four weeks into term (from Monday 29th October 2018) the college decreased the price of the vegetarian option by 20p (from £2.05 to £1.85, a 9.8% decrease) and increased the price of meat options by 20p (from £2.52 to £2.72, a 7.9% increase, Table 1). The price of the vegan option (£2.39) and the fish option(s) (£2.85) were not changed. The price difference between the meat and vegetarian option increased from 47p to 87p (85% increase). In absolute terms the price changes were fairly small. According to one review a 20% change in price for a single item is standard in the literature, and our price changes (9.8% price decrease and a 7.9% increase) are of this magnitude, albeit summed for price changes across two items (Zizzo, Parravano, Nakamura, Forwood, & Suhrcke, 2016). We also chose a 20p change as this led to both meat and vegetarian meals having an 80p margin between the customer price and the ingredient costs during the intervention period (Discussion 4.5).

We chose to make a modest change to prices to avoid criticism by the students using the college cafeteria and to not leave the more carnivorous students substantially less well-off. The change may also better reflect what is currently feasible to introduce in other outlets. The price changes were advertised throughout the whole study period on a screen outside the dining hall (which students walk through to reach the cafeteria and where they eat their purchased meals) and on the paper menus posted outside the cafeteria. The notification was worded: "As of Monday 29th October, the meal prices are changing a small amount to reflect the cost of ingredients" (SOM Figure C1 and C2). The price change did result in the meal option prices better reflecting the cost of ingredients (Discussion 4.5).

Table 4.1: Raw data summaries from the study. Mean values reported with standard deviations in square brackets.

	Baseline		**Intervention**	
Mealtimes		48		58
Total Meals		6587		7253
Meals/Mealtime		137.2		125.1
Option (number available)	**Price (£)**	**Mean sales per mealtime (%) [SD]**	**Price (£)**	**Mean sales per mealtime (%) [SD]**
Vegetarian (1)	2.05	21.0 [9.9]	1.85	21.8 [9.2]
Vegan (1)	2.39	4.5 [5.0]	2.39	5.9 [5.6]
Meat (2)	2.52	61.7 [13.7]	2.72	61.2 [11.6]
Fish (1)	2.85	12.7 [10.6]	2.85	11.1 [10.4]

4.3.3 Data collection and preparation

We downloaded sales data from Uniware ("Uniware," n.d.), an online catering platform. Identifiable data were stored on a secure online server at the University. We summarised the sales data into 1) aggregate data, with the total meat, vegetarian, vegan and fish purchases at each mealtime, based on all sales by college members and their guests; and 2) anonymised individual-level data, with which meal option (meat, vegetarian, vegan, fish) each individual diner selected at each mealtime, based on purchases made by college members using university cards (with the 9% of meal purchases made with cash or debit cards excluded). We used the total number of meals bought to analyse if the price intervention affected overall cafeteria sales.

To model individual-level vegetarian sales, a diner who bought no vegetarian meals at a single mealtime was coded as 0 for that mealtime, and a diner who bought only vegetarian meals (one or more) at a single mealtime was coded as 1. Meal choices by diners who bought both vegetarian and another meal type (meat, fish or vegan) at a single mealtime were categorised as NA and excluded (<2.5%, SOM Table C2). The same approach was applied to model individual-level meat sales.

We wanted to test if response to price changes varied with background levels of meat consumption. We used data from the preceding term (summer 2018) to calculate the percentage of meals that were vegetarian or vegan for each diner who had bought 10 or more meals and used these values to estimate quartiles for Most, More, Less and Least vegetarian (MostVeg, MoreVeg, LessVeg and LeastVeg). To increase sample sizes, we also applied these quartile thresholds (Q1=7.6%, median=18.8%, Q3=33.3%, SOM Table C3) to those diners who chose ≤9 meals during the summer term, and so were able to assign each diner in autumn 2018 who had eaten at the cafeteria at least once during summer 2018 to our quartile groups. The mean values of vegan and vegetarian meals selected per individual within each quartile from the summer term were: MostVeg = 70.7%, MoreVeg = 21.2%, LessVeg = 10.7% and LeastVeg = 0.9%, SOM Table C4).

We also combined the data for vegetarian and vegan (veg&vegan) meals, and for meat and fish meals (meat&fish) to investigate the effect of the intervention on meat&fish-free and meat&fish-containing sales. These are meaningful categories to compare (i.e. vegetarian and non-vegetarian) and collapsing meal types into these broader categories has been carried out in previous studies (E. E. Garnett, Balmford, Sandbrook, Pilling, & Marteau, 2019; Jalil, Tasoff, &

Bustamante, 2020). Furthermore, this results in models which are simpler to interpret as we can investigate the effect of the intervention on two categories instead of four (i.e. as a binary contrast).

4.3.4 Analytical approach

For this study the primary outcomes were the effects of the price change on total sales, vegetarian sales (%) and meat sales (%). The secondary outcomes were the effects of the price change to fish sales (%), vegan sales (%), vegetarian and vegan sales (%) and meat and fish sales (%). To avoid repetition, here we describe the analytical approach used for the primary outcomes, the same methods were applied for the secondary outcomes. We carried out analyses in R 3.6.3 using packages lme4, visreg and effects (Bates et al., 2015; Breheny & Burchett, 2016; Fox & Weisberg, 2018; R Core Team, 2020). Following the recommendations of Simmons et al. (2011) we estimated the effects of the price change on total sales, meat sales and vegetarian sales using both univariate and multivariate analyses (Table 4.2 shows the independent variables included in our analyses). To make our experiment feasible for the cafeteria to implement, we could only introduce a one-time change between the baseline and intervention periods, instead of multiple alternations during the term. Therefore, controlling for any potentially confounding time effects is particularly important for our analyses. We considered two time variables, days since the start of the baseline (with an invariant value for the intervention days), and days since the start of the intervention (with an invariant value for the baseline days, Table 4.2).

We estimated the effect of the price change on vegetarian sales (% of total sales) and meat sales (% of total sales) using binomial generalised linear models (GLMs) for the aggregate data. These data were coded using the binomial distribution. For example for vegetarian sales (%), each observation (mealtime) was a composite of two numbers: the total vegetarian meals and the total non-vegetarian meals (meat, fish, vegan) sold at one mealtime. For these analyses, where data were not disaggregated by individual diners, each meal selection was treated as independent. This adds uncertainty to p-value estimates so we focused on effect sizes and 95% confidence intervals. We used linear models (LMs) to model the total meal sales (meat, vegetarian, vegan and fish). For individual-level data, we used binomial generalised linear mixed models (GLMMs) with each diner as a random (rather than fixed) effect, so meal selections were not treated as independent but were grouped longitudinally by diner. The GLMMs allowed each individual to have a different likelihood of selecting a vegetarian or meat meal. For these data, each individual at each mealtime was one observation, coded as 0, 1 or NA.

Conditional regression was used to generate lines of best fit and confidence intervals, with conditions selected to most closely match the raw data means (Figure 4.1). A 95% confidence level was used to calculate confidence intervals and the exponential of the model estimate was used to generate effect sizes. Model diagnostics were run for each model and the models were acceptable, with no models reporting a variance inflation factor (VIF) over 10, with the exception of the individual-level model for fish.

Table 4.2: Independent variables included in the multi-variate models

Model	**Variable**	**Description and notes**
All models	Price condition	Baseline or Intervention
	Days Since Baseline	Time variable for the baseline period. First day of the baseline has a value of -27 and the final baseline day, -1; all days of the intervention period are invariant with a value of 0.
	Days Since Intervention	Time variable for the intervention period. First day of the intervention has a value of 1 and the final intervention day, 32; all days of the baseline period are invariant with a value of 0.
	Mealtime	Lunch or dinner
	Day	Monday, Tuesday, Wednesday, Thursday, Friday, Saturday
	Ambient temperature (centigrade)	Mean outside temperature on that date ("Cambridge Daily Weather Graphs," 2018). Previous studies have found that temperature can correlate with food and drink selections (Garnett et al., 2019; Pechey et al., 2016).
For individual-level models only	Prior level of vegetarian meal consumption	Individual diners were divided into least, less, more and most vegetarian quartiles in order to test for interaction effects with the price change

4.4 Results

4.4.1 Total sales: aggregate data

A mean of 137 meals were sold per mealtime during the baseline period, and 125 meals per mealtime during the intervention period. In a univariate analysis, total meal sales were significantly lower during the intervention period (LM, p=0.048), but when adjusting for other variables in the multivariate analysis there was no significant difference (LM, p=0.783, Table 4.3, SOM Table C5), with a predicted 133 meals [CI= 112, 153] sold during the baseline period and 131 [CI= 111, 148] sold during the intervention period.

4.4.2 Vegetarian and meat sales: aggregate data

The mean proportion of vegetarian sales were 21.0% during the baseline period and 21.8% during the intervention; mean meat sales were 61.7% and 61.2% respectively. In the univariate analysis there was no significant difference in vegetarian sales between the baseline and intervention periods (GLM, p=0.654). In the multivariate analysis, vegetarian sales were significantly higher during the intervention period (GLM, p=0.036, Table C6) by an estimated 3.2 percentage points (from 20.6% [CI= 18.0%, 23.5%] to 23.8% [CI= 21.1%, 26.7%], a 15.5% increase from baseline sales, Table 4.3). For meat sales, the price change made no significant difference to sales in the univariate analysis (GLM, p=0.490, SOM Table C7) nor the multi-variate analysis (GLM, p=0.298, Table 4.3).

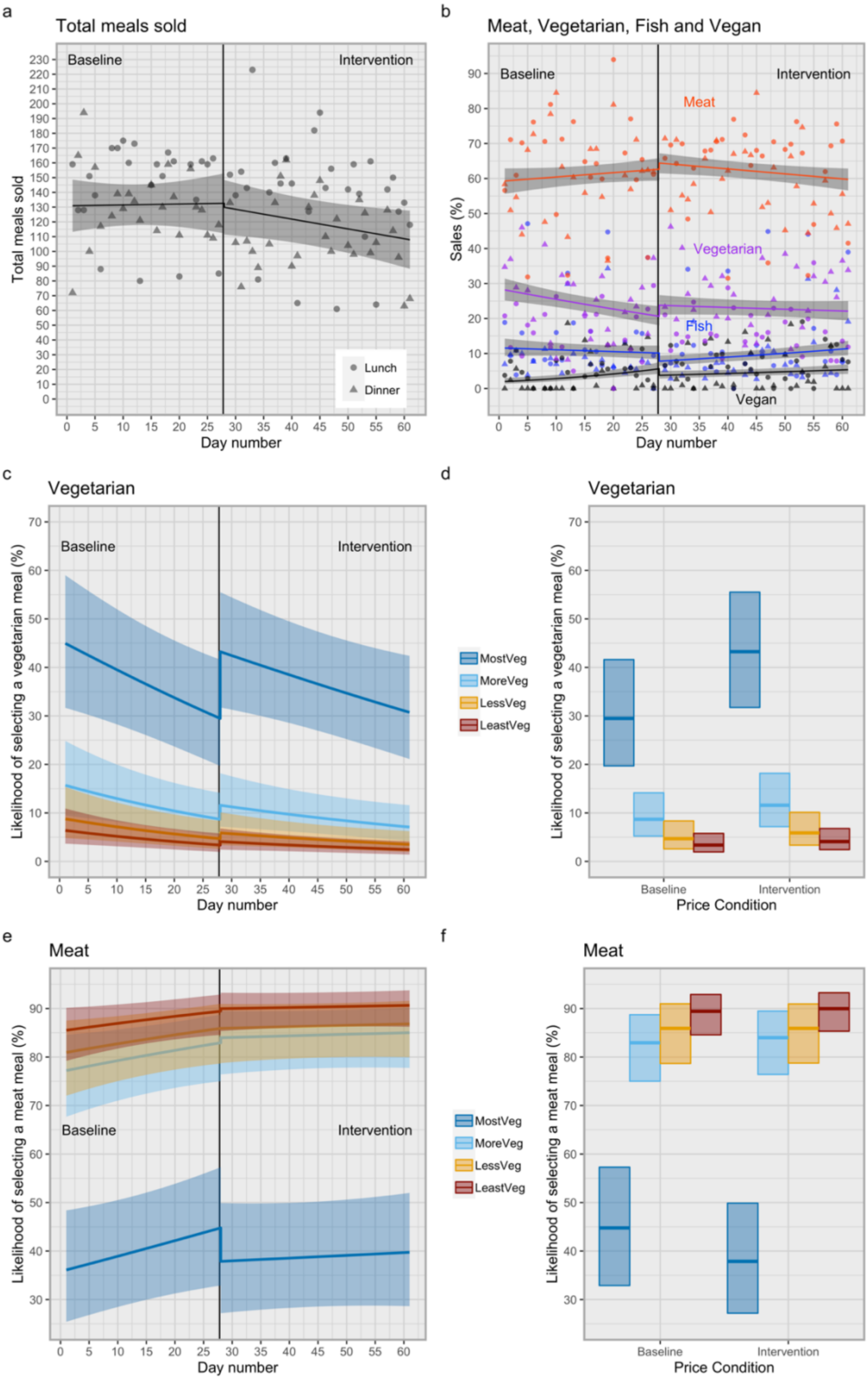

Figure 4.1: Results from the baseline and intervention periods. Raw data: a) Total meals sold. b) Aggregate sales of meat, vegetarian, fish and vegan meals for all diners, including cash sales. Modelled data: c) Likelihood of selecting a vegetarian meal for quartiles of diners over time and d) in the baseline and intervention periods. e) Likelihood of selecting a meat meal for quartiles of diners over time and d) in the baseline and intervention periods. For c) to f), individual diners are divided into MostVeg to LeastVeg quartiles, based on data from a previous term. Lines are modelled estimates and the error bars are 95% confidence regions.

Table 4.3: Modelled results from aggregate data analyses (univariate and multivariate) for total meal, vegetarian (%) and meat (%) sales. 95% confidence intervals reported. [a]Model estimates for sales under baseline prices; [b]Model estimates for sales under intervention prices; [c]Effect size of the price intervention (odds ratio (OR)) compared to the baseline (the reference category).

Data	Model	Sales	[a]Baseline period sales [CIs]	[b]Intervention period sales [CIs]	Difference between Intervention and Baseline periods	[c]Price change effect size [CIs]	Price change p-value
Aggregate	Univariate	Total meals	137 [128, 146]	125 [117, 133]	-12	0.91 [0.81, 1.00]	0.048
Aggregate	Multivariate	Total meals	133 [112, 153]	130 [111, 148]	-3	0.98 [0.83 1.10]	0.783
Aggregate	Univariate	Vegetarian (%)	21.1 [20.1, 22.1]	20.8 [19.9, 21.7]	-0.3	0.98 [0.90, 1.06]	0.654
Aggregate	Multivariate	Vegetarian (%)	20.6 [18.0, 23.5]	23.8 [21.1, 26.7]	3.2	1.20 [1.01, 1.42]	0.036
Aggregate	Univariate	Meat (%)	60.9 [59.7, 62.0]	61.5 [60.3, 62.6]	0.6	1.02 [0.96, 1.10]	0.490
Aggregate	Multivariate	Meat (%)	62.7 [59.4, 65.8]	64.4 [61.5, 67.3]	1.7	1.08 [0.94, 1.24]	0.298
Aggregate	Univariate	Fish (%)	13.2 [12.4, 14.1]	11.7 [10.9, 12.4]	-1.5	0.86 [0.78, 0.95]	0.004
Aggregate	Multivariate	Fish (%)	12.5 [10.2, 15.3]	9.7 [7.8, 12.0]	-2.8	0.75 [0.60, 0.94]	0.010
Aggregate	Univariate	Vegan (%)	4.8 [4.3, 5.3]	6.1 [5.6, 6.7]	1.3	1.30 [1.12, 1.51]	<0.001
Aggregate	Multivariate	Vegan (%)	6.4 [4.8, 8.5]	4.3 [3.2, 5.7]	-2.1	0.66 [0.49, 0.89]	0.006

4.4.3 Vegetarian and meat sales: individual-level data

During the study period in the individual-level analysis dataset, 626 identifiable diners bought a meal at the college cafeteria. Of these, 325 diners (52%) had bought at least one meal during the previous term (summer 2018) and were therefore assigned a quartile based on their level of vegetarian and vegan meal consumption during that time. These 325 diners visited the cafeteria a mean of 16.4 times during the term (number of visits: min =1, Q1=4, median=13, Q3=25, max=75), making 5,330 meal selections which we analyse here (SOM Table C2). Of these 325 individuals, 296 dined during the baseline period and 270 (91%) of these diners were also present during the intervention period. Within the MostVeg quartile, diners who came to the cafeteria less frequently selected a higher proportion of vegetarian (and vegan) meals, and therefore the mean vegetarian sales (%) aggregated across all individuals was substantially lower than the mean vegetarian selection per individual (Table 4.4).

For both meat and vegetarian sales the MostVeg quartile had the strongest response to the price intervention (Figure 4.1c-f). The likelihood of individuals in the MostVeg selecting a vegetarian meal increased by 13.7 percentage points (from 29.5% [CI= 19.7, 41.6] to 43.2% [CI= 31.7, 55.5], a 46.4% increase from the baseline, GLMM, p=0.011, Table 4.4, SOM Table C8). Vegetarian purchases by diners from the other three quartiles (LeastVeg, LessVeg and MoreVeg) did not significantly change under the intervention (Table 4.4, Figure 4.1c and 2d). We found a similar pattern when we divided diners into deciles based on their prior vegetarian and vegan meal consumption (SOM Figure C3 and Table C9). However, none of the quartiles showed significant differences in meat purchases following the intervention (GLMM, p values >0.1, Table 4.4, Figure 4.1e and 2f, SOM Table C10).

4.4.4 Price change and meal displacement

If the price change led to increased vegetarian meal selection but correspondingly lower vegan sales there is a risk that there would be no additional environmental benefit or greenhouse gas savings. Similarly, lower meat sales but higher fish sales could also compromise sustainability objectives. We ran further models to estimate the overall effects of our intervention.

For the aggregate data, the intervention period corresponded with a significant decrease in both fish (GLM, p=0.010) and vegan sales (GLM, p=0.006), by 2.8 and 2.1 percentage points respectively (multivariate analyses, Table 4.3, SOM Tables S11 and S12). However, no significant differences in selection for any of the four quartiles were detected in the individual analysis for vegan and fish selections (GLMMs, p values>0.050, SOM Tables S13 and S14) indicating that it was the sales from guests and diners without a prior quartile (included in the aggregate but not individual analyses) that contributed to a significant reduction in vegan and fish sales.

We combined the data for vegetarian and vegan (veg&vegan) meals, and for meat and fish meals (meat&fish). For the aggregate sales, the price change made no difference to veg&vegan sales (GLM, p=0.555) nor meat&fish sales (GLM, p=0.555). In the individual-level analyses, the difference in selections for diners from the LeastVeg, LessVeg and MoreVeg quartiles, for both veg&vegan and meat&fish sales, were non-significant and no greater than 1 percentage point before and after the price change (GLMMs, p values >0.100, Figure 4.2). However, for diners from the MostVeg quartile the models estimated that the price change led to a 12.2 percentage point increase in veg&vegan selections (from 44.3% [CI=31.4%, 57.9%] to 56.5% [CI=43.3%, 68.8%], GLMM, p=0.035, SOM Table C15), and a 13.1 percentage point decrease in meat&fish selections (from 57.1% [CI= 43.4%, 69.7%] to 44.0% [CI=31.6%, 57.2%]; GLMM, p=0.025, Figure 4.2, SOM Table C16).

Table 4.4: Raw means and modelled results from multivariate analyses for individual-diner vegetarian (%) and meat (%) selections. Standard deviation (SD) and 95% confidence intervals (CIs) reported. For vegetarian analyses, if a diner selected both a vegetarian meal and a meat/fish/vegan meal at the same mealtime, this was designated NA and excluded from analyses. The raw mean for overall selections is weighted towards individuals who visited the cafeteria more frequently; for the raw mean per individual, each individual is weighted equally.

Meal option	**Quartile**	**Number of individuals (excluding NAs)**	**Meal selections (excluding NAs)**	**Raw mean (overall selections) (%)**	**Raw mean (per individual) (%)**	**Baseline period selection (%) [CIs]**	**Intervention period selection (%) [CIs]**
Vegetarian	Most vegetarian	76	924	33.5	44.2	29.5 [19.7, 41.6]	43.2 [31.7, 55.5]
Vegetarian	More vegetarian	68	1270	12.4	14.8	8.7 [5.2, 14.1]	11.6 [7.2, 18.2]
Vegetarian	Less vegetarian	69	1168	8.0	7.2	4.7 [2.6, 8.4]	5.9 [3.4, 10.1]
Vegetarian	Least vegetarian	111	1863	5.6	6.4	3.4 [2.0, 5.8]	4.1 [2.4, 6.8]
Vegetarian	**Total**	**324**	**5225**	**20.5**	**17.2**	**NA**	**NA**
Meat	Most vegetarian	76	925	46.2	34.2	44.8 [32.9, 57.3]	37.8 [27.2, 49.8]
Meat	More vegetarian	68	1266	73.2	70.3	82.9 [75.0, 88.7]	84.0 [76.4, 89.5]
Meat	Less vegetarian	69	1160	75.0	70.8	85.9 [78.7, 91.0]	85.9 [78.7, 90.9]
Meat	Least vegetarian	110	1855	80.4	77.0	89.4 [84.6, 92.9]	90.0 [85.3, 93.2]
Meat	**Total**	**323**	**5206**	**62.2**	**64.2**	**NA**	**NA**

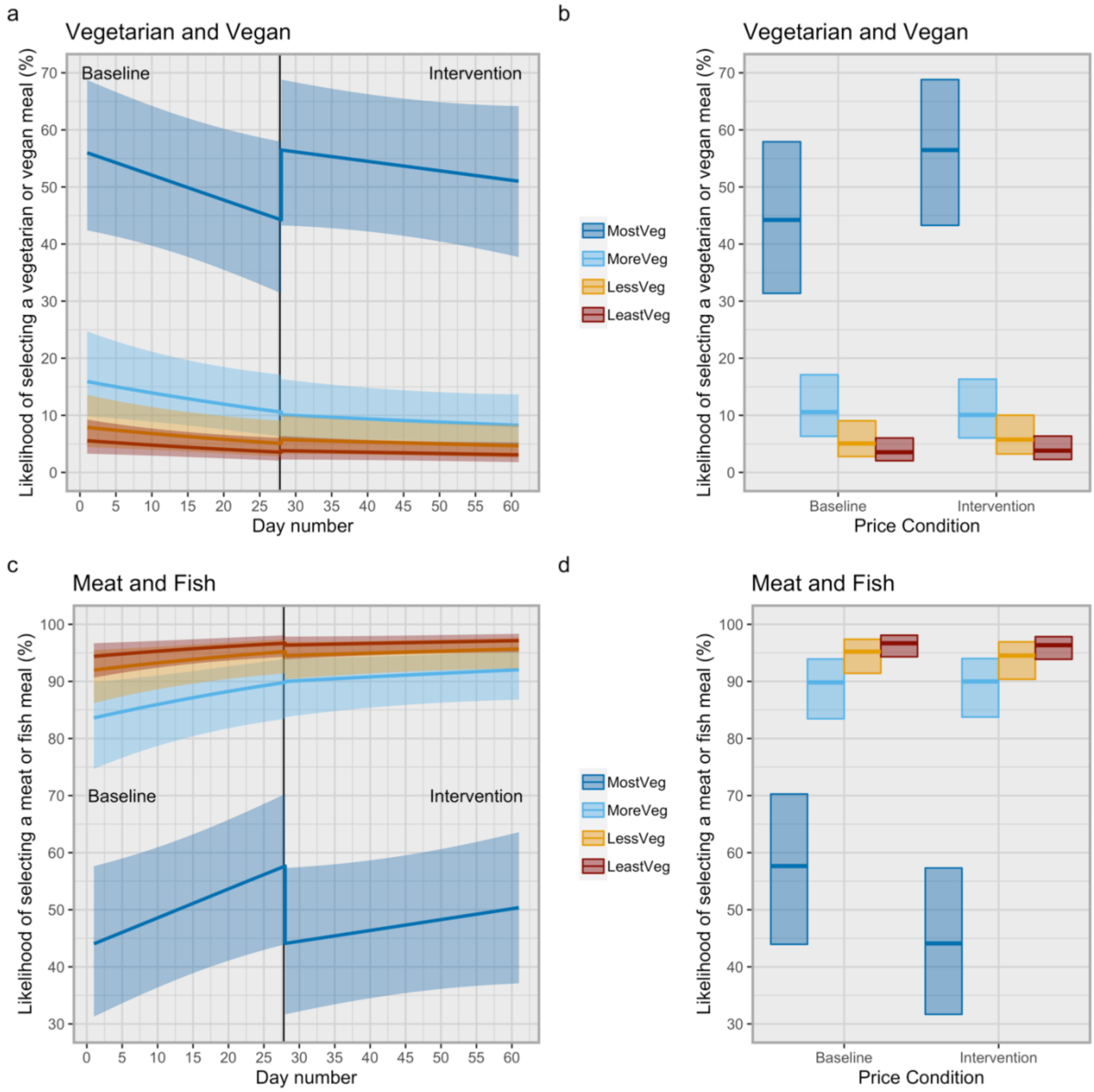

Figure 4.2: Results from the baseline and intervention periods. a) Likelihood of selecting a vegetarian or vegan meal for quartiles of diners over time and b) in the baseline and intervention periods. c) Likelihood of selecting a meat or fish meal for quartiles of diners over time and d) in the baseline and intervention periods. Individual diners are divided into MostVeg to LeastVeg quartiles, based on data from a previous term. Lines are modelled estimates and the error bars are 95% confidence intervals.

4.5 Discussion

Our results show that even a small change in the price of meat and vegetarian options can increase overall vegetarian sales, but did not lead to significantly lower overall meat sales. Individual-level analysis indicates that the increase in vegetarian sales was driven by individuals with a prior disposition to selecting vegetarian food. Meat selections did not decrease significantly for the MostVeg quartile of individuals, but meat&fish selections did decrease significantly by 13.1 percentage points for this quartile. This indicates that the increase in vegetarian selection for the MostVeg quartile was not primarily driven by reductions in vegan meal selection.

To our knowledge this is the first field study to use individual-level data to test if a small price change to meat and vegetarian options can increase vegetarian meal consumption. Although many reports have called for reductions in meat consumption, there are still relatively few field studies testing strategies that might achieve this (Bianchi, Dorsel, et al., 2018; Bianchi, Garnett, et al., 2018). Furthermore, very few studies in cafeterias and restaurants have individual-level data (Epstein et al., 2012). We conducted a field study that tracked hundreds of individuals across 106 cafeteria mealtimes and we were able to look separately at people with varying prior levels of vegetarian and vegan consumption. Our results provide important evidence on how the effects of small economic incentives differ across subgroups: this knowledge is key for designing effective interventions at the population level. A previous study found that dietary behaviour change from a motivated population subgroup can lead to important environmental benefits (Willits-Smith, Aranda, Heller, & Rose, 2020). The modest change to the price of options, and our finding that this did not significantly affect total meal purchases, indicates that an intervention of the magnitude tested here could be safe for caterers to implement without impinging negatively on sales.

However, our study also has several limitations. It was conducted in one cafeteria in one British university. We therefore do not know the extent to which the results generalise beyond that one cafeteria to different populations in the UK and in other countries. We do not know if the change in price of the vegetarian option, the meat options, the increase of the price differential or a combination of all three led to our results. Due to the design of our study, we did not collect information on students' views of the price change or to what extent they had noticed it. The price change was not heavily advertised (Figures C1 and C2) and although this might have resulted in a smaller effect size, this may better reflect how price changes are brought about in real-world contexts. We were unable to extend the study beyond nine weeks thereby limiting our ability to test the sustainability of the effects observed for a relatively short period of time: there is therefore a chance that our study is underpowered to detect changes in sales. Vegetarian sales were lower than meat sales and therefore our analyses for aggregate vegetarian sales have higher power than the analyses for aggregate meat sales, with the same absolute change easier to detect for vegetarian than for meat sales. In the individual-level analyses, the MostVeg quartile showed a significant increase in vegetarian sales after the price change (Table C9), but no significant decrease in meat or fish sales when these were analysed separately (Tables C10 and C13). However, when meat and fish sales were analysed together, the MostVeg quartile's selection of meat&fish meals decreased by 13.1 percentage points (p=0.020, Table C16). This perhaps suggests that the increase in vegetarian selections for the MostVeg quartile were due to a decrease in both meat and fish selections and that there was not enough statistical power to detect a decrease when meat and fish were analysed separately.

Price changes which are more salient – i.e. more noticeable – have a greater influence on demand for those products (Chetty, Looney, & Kroft, 2009). Various factors are likely to have lowered the salience of our intervention to diners. Although the price change was advertised it would still have been easy for students – especially those paying with cards (Greenacre & Akbar, 2019) – to miss, and the meat and vegetarian options in the baseline period already had different rather than identical prices. Students generally buy additional items such as vegetable sides, drinks and desserts which might further have masked the price change to the main meal options. Some factors are likely to have increased the salience and effectiveness of our intervention. The vegetarian option price change resulted in the first numeral changing from £2 to £1: consumers pay less attention to the digits after the decimal point, and associate £1.99 with £1 rather than £2 purchases (Bizer & Schindler, 2005). We might also expect students to be more price sensitive than other groups in the UK. However, students on a small budget tend to avoid college cafeterias and prepare their own meals instead (E.G. pers. obs.). Our sample of students choosing to dine in the cafeteria is therefore likely to be biased towards less price-sensitive students. These factors are idiosyncratic to the study setting and all might have affected the results.

This research presents opportunities for further studies. Our work was conducted in one cafeteria in one UK university, with only one small change in price. The MostVeg quartile of diners in our study may have had a more elastic demand for meat and vegetarian options, and therefore were more sensitive to price changes than other diners who might be more fixed in their preference for meat. Future research could involve staggered field studies with different magnitudes of price changes and initial price parity between options, to ascertain if greater price changes persuade more carnivorous diners to change their behaviour and consequently lead to larger changes in meat and vegetarian consumption, or affect overall sales and revenue. Universities are useful locations to run trials, but further studies in non-student populations and in medium and low-income countries are also clearly needed to test if our findings are generalisable.

Results from chapters 2 and 3 also provide valuable context for the results we present here, as in many of the colleges the price of the meat and vegetarian options varied by mealtime. In College 1 (College A in chapter 2 meal order, College C in chapter 3 vegetarian availability) the average price differential between meat and vegetarian options at a mealtime (i.e. mean price of meat options minus mean price of vegetarian options) ranged from -6p to 42p in chapter 2, and 15p to 45p in chapter 3. As the price differential between meat and vegetarian options increased (i.e. vegetarian options became relatively cheaper), vegetarian sales in College 1 increased in chapter 2 (Order: OR= 2.42 (CI= 1.21, 4.87), p= 0.013, Table A4) but decreased in chapter 3 (Availability: OR= 0.37 (CI= 0.18, 0.77), p=0.007, Table B16). College 3 (A) showed the same pattern as College 1 in chapter 3: vegetarian sales increased as they became relatively cheaper (Price differential range: -18p, 74p, OR= 1.48 (CI= 1.22, 1.78), p<0.001). However, College 4 (B) showed the opposite pattern (Effect size= 0.33 (CI= 0.21, 0.52), p<0.001, -3p to 30p). These results suggest that the effects of small changes in price are hard to disentangle and further experimental evidence in needed. It could be that cheaper meals are more appealing to students in some colleges, and in others perhaps more expensive meat meals are particularly attractive (e.g. steak) and relatively cheaper vegetarian meals are less appealing. In this chapter the differential between the meat and vegetarian option (excluding fish and vegan options) changed experimentally from 47p to 87p (if veg&vegan and meat&fish meals are averaged then the differential is diluted to 47 to 67p). The minimum difference in this chapter (47p) is higher than the maximum values in three out of the four previous experiments (42p, 45p, 30p). This perhaps suggests that for small changes in price to have an effect, it may be important for meat and vegetarian options to have initial price parity.

Besides the arguments for changing the price of meal options to encourage more sustainable diets, the new prices also better reflected the costs of the meal ingredients. During the intervention period both meat and vegetarian meals had an 80p margin between the customer price and the ingredient costs, though the vegetarian meals still had a higher percentage mark up (~76%) than meat (~43%, SOM Table C17). In the absence of fiscal measures which align the market price of food with its environmental cost, institutions could introduce differential pricing on meals to better reflect both environmental and ingredient costs. However, changes in price whilst potentially effective at changing behaviour in the short term, perhaps risk reinforcing the notion of meat as a status symbol and vegetarian options as inferior (Hayley, Zinkiewicz, & Hardiman, 2015; Rogers, 2015; Ruby & Heine, 2011). This could potentially increase the demand for meat in the long-term.

This study provides promising evidence that even small price changes can increase sales of vegetarian and vegan meals and decrease sales of meat and fish meals, but only for diners with the highest prior levels of vegetarian and vegan meal selection. Further field studies are needed to investigate more generally how far shifting prices could reduce meat consumption and thereby mitigate climate change and biodiversity loss.

Chapter 5. Does gender influence the selection of vegetarian and meat meals?

I ate a lot of meat. They show these commercials selling the idea that real men eat meat. But you've got to understand that's marketing, that's not based on reality.
Arnold Schwarzenegger (2018) The Game Changers

There aren't many things I can eat off a pub menu because of my gut condition, so I generally go for steak and chips. Phil often gets a salad. A number of times the waiting-staff have given the steak to Phil and the salad to me. They often get the whiskey and G&T the wrong way round too.
Sarah Hutt Guthrie (2020)

5.1 Summary

Reducing meat consumption in high-income countries, particularly meat from ruminants, is likely to bring a suite of environmental and health benefits. Both vegetarianism and pro-environmental actions are generally perceived as feminine behaviours. Surveys have found that men self-report higher levels of meat consumption and lower levels of vegetarianism than women, but to our knowledge no field studies have repeat measures of actual behaviour and the influence of gender on meat intake. In these three studies we use individual-level data from 87,407 meal selections from four University of Cambridge college cafeterias to investigate the influence of gender on vegetarian, fish and meat selection. We also tested if gender affected individuals' likelihood of selecting a vegetarian meal in response to two cafeteria interventions: 1) increasing the proportion of vegetarian options available, in three colleges (A, B, C); and 2) making a small change to the price of vegetarian vs meat meal options (by +/- 20p) in a fourth college (D). In study 1 we found that in all four colleges men were significantly less likely to select a vegetarian meal than women. In study 2 in the two colleges where we could disaggregate meat and fish sales, men and women were equally likely to select a fish meal, and men were significantly more likely to select ruminant, pork and poultry meals than women. Consequently per 100 meals, men had average GHG emissions 17-19% higher and land-use 28% higher than women (269-270 vs 314-321 kg CO_2eq; 353-367 vs 450-471 m^2-years respectively). In study 3 we found men and women did not respond significantly differently to the cafeteria interventions in three out of four colleges. However, in College B there was a significant interaction between gender and intervention, with men responding more strongly than women to increasing vegetarian availability. These results indicate that increasing vegetarian availability and altering prices to increase vegetarian sales are likely to be equally effective for men and women.

5.2 Introduction

Climate change and environmental degradation affects people of all genders, however surveys in Western countries consistently find that pro-environmental behaviour is considered feminine (Swim, Gillis, & Hamaty, 2020). A series of online studies in the USA found that men were more likely to prefer green products if their masculinity had been affirmed, and conversely were less likely to prefer a green product if their masculinity had been threatened; “masculine” branding increased men’s preference for an environmentally-friendly car (Brough, Wilkie, & Isaac, 2016). In one study men had significantly higher energy use than women in two out of four European countries (Greece and Sweden, but not Norway and Germany), and in all four countries assessed men had much higher transport-related energy use than women from transport (Räty & Carlsson-Kanyama, 2010). Male students had higher carbon footprints than female students at a Filipino university, partly driven by differences in transport behaviour; male students were more likely to drive themselves to schools and female students were more likely to use public transport (Medina & Toledo-Bruno, 2016).

Reducing meat and dairy consumption in high-income countries would likely bring a suite of environmental and health benefits (Clark et al., 2019). Cattle and sheep production has particularly high GHG emissions due to ruminants’ methane production and their high land requirements (Dangal et al., 2017; Searchinger, Wirsenius, et al., 2018). Beef, lamb and cheese all have higher GHG emissions and land-use (per 100g of protein and per kg) than pork and poultry meat (Poore & Nemecek, 2018b). However, evidence indicates that shifting to a more plant-based diet is another pro-environmental behaviour which is perceived as feminine across a variety of different cultures (Schösler, Boer, Boersema, & Aiking, 2015). Meat, red meat in particular, has connotations with masculinity, power and social advantage (Ruby & Heine, 2011). Associating meat with masculinity isn’t confined to meat-eaters: both omnivorous and vegetarian participants in one study rated vegetarians as less masculine and more virtuous (Ruby & Heine, 2011). Male and female Norwegian soldiers cited meat and the armed forces’ association with masculinity when explaining their opposition to a Meat-Free Monday pilot scheme (Kildal & Syse, 2017). Although men on average do have higher protein requirements than women (protein requirements scale with body weight) and therefore this association might appear to have some logic, women on average have much higher iron requirements (70% higher for 19-50 year olds) (British Nutrition Foundation, 2019). Many “masculine” foods such as steak are rich in iron (Wilson, 2016).

The association between meat and masculinity, and vegetarianism and femininity, translates to self-reported differences in meat consumption between men and women (Love & Sulikowski, 2018; Rozin, Hormes, Faith, & Wansink, 2012). In the UK men are more likely to over-eat red and processed meat: the UK Department of Health recommends no more than 70g/day on average but 10% of women and 40% of men eat more than 90g/day, which increases the risk of bowel cancer (NHS Choices, 2015). Women consistently report higher rates of vegetarianism than men (Rozin et al., 2012) and are considered the drivers of the recent shift to reducing meat consumption in the UK (British women are disproportionately responsible for household food shopping) (Forum for the Future, 2016). A survey on self-reported behaviours in the Netherlands found that men preferred larger meat portions and ate meat more frequently, and although both men and women were equally familiar with meat substitutes, women were more likely to use them (Schösler et al., 2015).

A pair of recent systematic reviews on strategies to reduce meat consumption, one considering interventions targeting physical environments (Bianchi, Garnett, et al., 2018) and the other conscious determinants of behaviour (Bianchi, Dorsel, et al., 2018), did not find any studies which targeted gender-related barriers to reduced meat consumption or explicitly analysed if gender influenced responses to the intervention. Since the systematic reviews, a field study in Denmark on vegetarian selections at a conference found an interaction between men and women in response to defaults. There was no significant differences in vegetarian selection between men and women when meat was the default option (6% and 8% respectively), but when vegetarian was the default, men were much less likely to choose a vegetarian option (68% and 96% respectively) (Hansen, Schilling, & Malthesen, 2019). However, this field study had a very small sample size (only 58 women, 45 men) and measured meat and vegetarian selections at only a single time-point. We are not aware of any long-term field studies (i.e. more than a month) which investigate how gender might influence responses to interventions to reduce meat consumption. Furthermore, we are not aware of any field studies which measure differences in men and women’s meat, fish and vegetarian consumption measuring actual behaviour, with repeated measurements from the same individuals, instead of self-reported surveys. Given the association of meat with masculinity, it is possible that men might exaggerate and women under-report their meat consumption to conform to their gender identity.

The current studies contribute to this evidence gap. We use the individual-level data presented in Chapters 3 and 4 from four colleges (A, B, C and D) to research the relationship between gender and meal selections. In studies 1 and 2 we examine the influence of gender on vegetarian, fish and meat (ruminant, pork and poultry) selection, and calculate the mean environmental footprint (GHG emissions and land-use) per 100 meals for men and women using recipes from college C. In study 3 we investigate if gender was associated with individuals' likelihood of selecting a vegetarian meal in response to the manipulations of relative vegetarian meal availability (Chapter 3, colleges A, B and C) and price (chapter 4, college D). It was not possible to carry out these analyses for the order intervention as we do not have individual-level data from those studies.

5.3 Methods

5.3.1 Study Setting and Design

The study setting and data collection are described in detail in chapters 3 and 4 and are briefly recapped here. To allow for a consistent comparison between all four colleges, hereafter unless otherwise specified, "vegetarian" includes both vegetarian and vegan meals, "non-vegan vegetarian" refers to meals which contain dairy and/or eggs but no meat or fish, "meat" does not include fish, and "NonVeg" refers to non-vegetarian sales, ie meat and fish.

In chapter 3 we investigated the effects of vegetarian availability on vegetarian sales and collected data from three University of Cambridge colleges, A, B and C. All three colleges varied the number of total meal options and vegetarian options served at lunches and dinners. Non-experimental data was collected from colleges A and B across the 2017 calendar year (spring, summer and autumn terms). In College C we conducted an experiment in autumn term 2017 and experimentally altered the number of vegetarian options on offer at lunchtimes. In chapter 4 we conducted a study in College D in autumn term 2018 to investigate the effect of a small change in price on vegetarian sales. Halfway through the university term (after four weeks) we decreased the price of the non-vegan vegetarian meals by 20p (from £2.05 to £1.85) and increased meat meals by 20p (from £2.52 to £2.72). The price of fish meals (£2.85) and vegan meals (£2.39) remained unchanged. College D served two meat options, one vegetarian, one fish and one vegan option at all mealtimes, except on Friday lunchtimes where one meat option was replaced with an additional fish option, and Saturday lunchtimes where the vegan option was not included. Sales data were downloaded from Uniware and Accurate solutions ("Accurate

Solutions," n.d.; "Uniware," n.d.). Meals purchased with individuals' university cards could be linked to individual diners.

To test if the response to the intervention varied with background levels of meat consumption, as well as gender, we used data from the preceding term from each college to calculate the percentage of meals that were vegetarian for each diner who had bought 10 or more meals. We used these values to calculate quartile thresholds for Most, More, Less and Least vegetarian (MostVeg, MoreVeg, LessVeg, LeastVeg). To increase sample sizes for the analyses in this chapter, we also applied these quartile thresholds to diners in the preceding term who bought ≤9 meals. Therefore each individual in the study period who had bought at least one meal during the preceding term was assigned to our quartile groups.

5.3.2 Designating gender

The forenames of the individuals who dined in each college were stored on the University's secure data hosting service, but no data was available on the genders of each diner. We therefore used the Scottish government data on registered births from 1974 to 2019 to link names to gender (National Records of Scotland, 2020). For forenames with 10 or more entries we calculated the percentage of boys and girls registered with that name. Additional forenames (those not recorded in Scotland, or with fewer than 10 entries) were sourced from the Data World database, which gives the probability of names being male or female based on USA names from 1930 to 2015 (Howard, 2016). Individual diners at the colleges who had forenames with a >90% probability of being female (e.g. Anoushka, Claire) or male (e.g. Muhammed, Edward) were designated as female or male. Names with a <90% probability of being one gender (e.g. Alex, Lesley, Rowan) and names not listed in either database were assigned "Unknown". Between 15 and 21% of diners from the colleges were designated as "Unknowns" and were excluded from subsequent analyses (Table 5.1).

Table 5.1: Number of individuals and their designated gender in colleges A, B, C and D.

	College A	**College B**	**College C**	**College D**
Female [%]	641 [45.9]	230 [30.8]	183 [29.9]	229 [36.6]
Male [%]	546 [39.1]	393 [52.7]	301 [49.2]	299 [47.8]
Unknown [%]	209 [15.0]	123 [16.5]	128 [20.9]	98 [15.7]
Total	1396	746	612	626

5.3.3 Study 1 analytical approach: Difference in vegetarian meal selection by gender

For study 1, the primary outcomes were the percentage of vegetarian selections by gender for all sales (each meal weighted equally) and per individual (each individual weighted equally). We compared the total vegetarian and non-vegetarian sales by gender using chi square tests. We compared the percentage of vegetarian meal selection per individual using Mann-Whitney tests, due to the high positive skew of the data.

5.3.4 Study 2 analytical approach: Environmental footprint of meal sales by gender

We calculated the environmental footprints per serving of 201 recipes from College C, based on each recipe's list of ingredients (Table 5.2, (Doherty et al. in prep)). Colleges A, B and D did not have recipes and ingredients in a digital format that we could use. We calculated the mean footprint of recipes by meal type: ruminant meat, non-ruminant meat (pork and poultry), fish (all types of seafood), non-vegan vegetarian and vegan. The mean GHG and land-use footprints of each food item and continent of origin were taken from the Poore and Nemecek database (Poore & Nemecek, 2018a); the system boundaries for this dataset are farm-gate to retail and therefore emissions from cooking are not included. Rather than using simple global mean figures we used the continent-specific values of food production impacts and UK trade data (DEFRA, 2019; International Trade Centre, 2016) to calculate the mean environmental footprint of each ingredient, weighted by its likely continent of origin. Life cycle analysis (LCA) values were given per kilogram of food item, requiring the standardisation of all ingredients in the recipes database. The GHG emissions and land use of each recipe were calculated by summing the LCA values for all component ingredients. Impacts were calculated per serving, using serving sizes provided alongside the recipes.

We applied the environmental footprints from College C recipes to the detailed sales data from colleges A and B. In College C it is only possible to distinguish between vegetarian and non-vegetarian sales, whereas in colleges A and B it is possible to distinguish whether meat and fish meals sold are ruminant (beef and lamb), pork, poultry (chicken and turkey) or fish. It is not possible to tell if a vegetarian meal sold is vegan or not from college A and B sales data. In order to calculate the environmental footprint of vegetarian sales we assumed that two-thirds were non-vegan vegetarian and one-third were vegan, in keeping with the proportions on advertised menus at these colleges. In College A some sales could only be identified to the level of meat and these few are classified as "GenericMeat", and are assigned the environmental footprint of pork and poultry meals. The average GHG emissions and land use per 100 meals for men and women were estimated. As the mean environmental footprint per meal category were applied to the total sales, no confidence intervals or errors were generated in this analysis.

We compared the total sales of different meat types by gender in college A and B using chi square tests. We compared the percentage of different meat type meal selection per individual using Mann-Whitney tests, the non-parametric equivalent of an ANOVA, due to the high positive skew of the data.

Table 5.2: Environmental footprint of different meal types from College C. Mean and standard deviation (SD) values are reported.

Meal type	Number of recipes	Mean GHG emissions (kg CO_2-eq per serving)	SD GHG emissions (kg CO_2-eq per serving)	Mean land-use (m^2 years per serving)	SD land-use (m^2 years per serving)
Ruminant	31	7.02	2.36	13.92	8.80
Pork&poultry	68	2.48	0.81	2.93	0.89
Fish	47	2.25	1.42	1.17	0.99
Non-vegan vegetarian	46	1.56	1.17	1.24	0.73
Vegan	14	0.72	0.23	0.81	0.33

5.3.5 Study 3 analytical approach: Response to cafeteria interventions by gender

The primary outcome for these analyses is the likelihood of an individual selecting a vegetarian meal. We tested if there was an interaction between gender and the intervention (vegetarian availability at colleges A, B and C, price at College D), using only these two variables (bivariate analysis), and when controlling for independent variables including prior levels of vegetarian meal selection (multivariate analysis, Table 5.3). For both types of analysis we used binomial generalised linear mixed models (GLMMs) with each diner as a random (rather than fixed) effect. The GLMMs allowed each individual to have a different likelihood of selecting a vegetarian meal. For these data, each individual at each mealtime was one observation, coded as 0 (no vegetarian meals bought), 1 (only vegetarian meals bought) or NA (mixture of non-vegetarian and vegetarian meals bought). The exponential of the model estimate was used to generate effect sizes. Model diagnostics were run for each model and we checked that no models reported a variance inflation factor (VIF) over 10. It was only possible to include one two-way interaction per model (e.g. interaction between gender and intervention, or gender and prior vegetarian quartile) to keep the VIF below 10.

Study 3 uses a subset of the data present in study 1. In the study 3 multivariate analyses only diners with a prior vegetarian quartile can be included. In colleges A and B eight and three mealtimes had no vegetarian options present and were excluded from the study 3 analyses (see Chapter 3, Methods) but are included in study 1. For College C modelling the effect of vegetarian availability only includes data from autumn term 2017 lunchtimes when options were observed directly (44 mealtimes, see Chapter 3 Methods), whereas to investigate the effects of gender on vegetarian meal selection in study 1 we used data from all lunchtimes and dinnertimes across autumn term (109 mealtimes, see Table 5.3).

All analyses in all three studies were carried out in R 3.6.3 using packages lme4, visreg and effects (Bates, Bolker, Maechler, & Walker, 2015; Breheny & Burchett, 2016; Fox & Weisberg, 2018; R Core Team, 2020). For all studies we report p values approximated to: $p>0.10$, $p>0.05$, $p<0.05$, $p<0.01$ and $p<0.001$.

Table 5.3: Independent variables included in the multivariate models. Unlike in colleges A, B and C, the change from the baseline to intervention in College D occurred only once and therefore we control for time at this college (Days since baseline, Days since intervention).

Model	**Variable**	**Description and notes**
All models	Intervention	Vegetarian availability (%) for colleges A, B and C, price change for College D.
	Gender	Male or female
	Prior level of vegetarian meal consumption (PriorVegQuartile)	Individual diners were divided into least, less, more and most vegetarian quartiles based on data prior to the study period
	Day	Monday, Tuesday, Wednesday, Thursday, Friday, Saturday
	Ambient temperature (centigrade)	Mean outside temperature on that date ("Cambridge Daily Weather Graphs," 2018)
Colleges A and B models only	Term time	Spring, summer, autumn. Invariant for colleges C and D (both autumn term).
Colleges A, B and D models only	Mealtime	Lunch or dinner. Invariant in College C (lunchtimes only)
College D only	Days since baseline	Time variable for the baseline period. First day of the baseline has a value of -27 and the final baseline day, -1; all days of the intervention period are invariant with a value of 0.
College D only	Days since intervention	Time variable for the intervention period. First day of the intervention has a value of 1 and the final intervention day, 32; all days of the baseline period are invariant with a value of 0.

5.4 Results

5.4.1 Study 1: Difference in vegetarian sales between genders

Across the study periods 39,202, 28,848, 9,299 and 10,422 meal selections were bought by individuals assigned a gender in Colleges A, B, C and D respectively. In three out of four colleges, 35.0% to 37.4% of meals bought by women were vegetarian, which were significantly higher than men's vegetarian sales, which were between 19.0% and 22.8% (chi-square tests, df=1, $p<0.001$, Table 5.4, Figure 5.1). In College C, which is the sole graduate-only college out of the four, there was no significant difference in vegetarian sales between women and men (21.9% and 20.3% respectively, 1.6 percentage point difference; chi-square test, df=1, $p>0.10$). However, when all individual diners were weighted equally and their percentage of vegetarian meals were compared, women had higher levels of vegetarian meal selection than men in all four colleges (Mann-Whitney tests, df=1, Colleges A, B and D $p<0.001$, College C $p<0.01$).

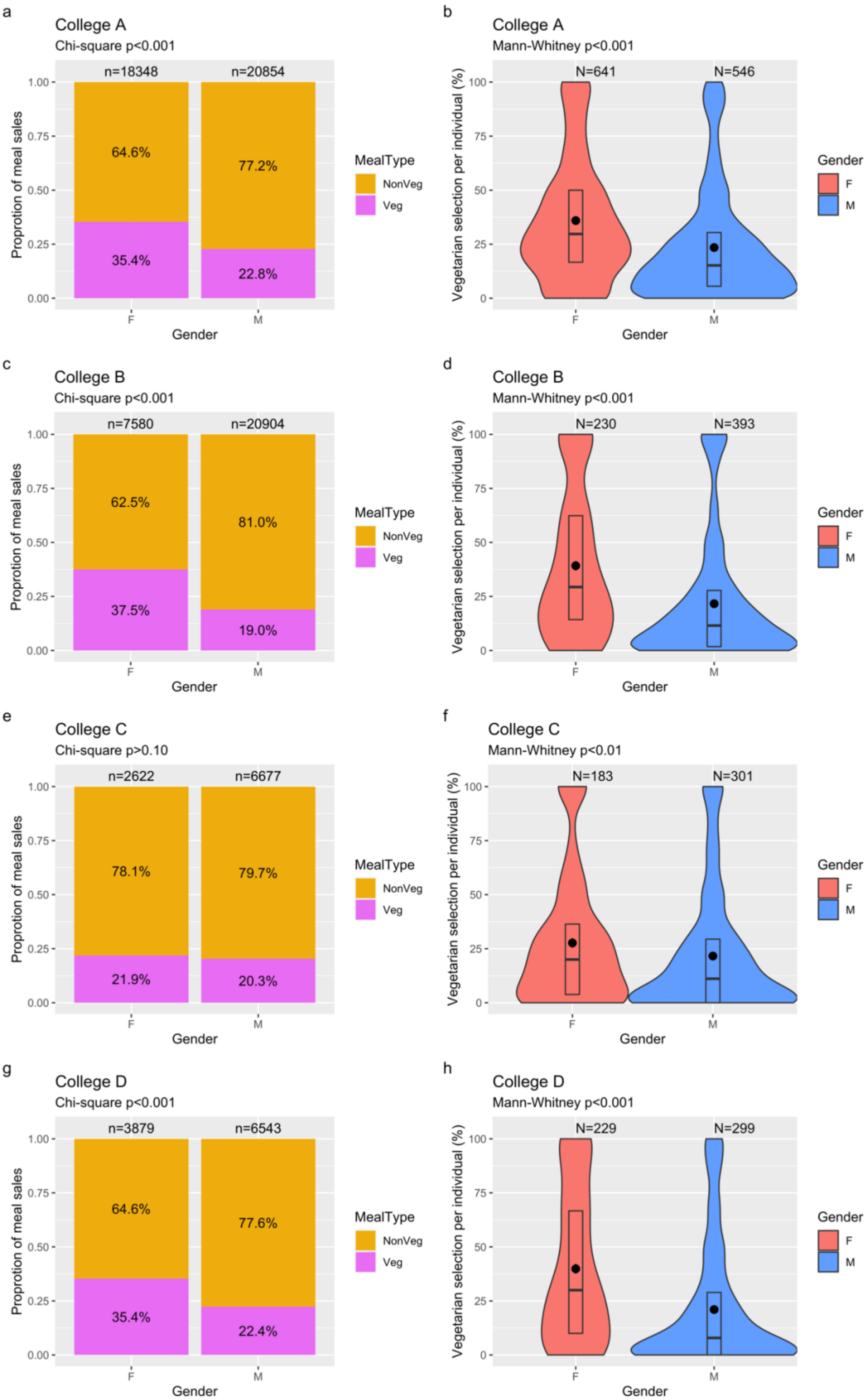

Figure 5.1: Vegetarian selection by gender in Colleges A (a,b), B (c,d), C (d,e) and D(g,h). Panels a, c, e and g show total meal selections by gender. Individuals are weighted equally in panels b, d, f and h. Boxplots show median and lower and upper quartiles, the black dots and whiskers are mean and standard errors. N (uppercase) refers to number of individuals and n (lowercase) to number of meals.

Table 5.4: Vegetarian options available and vegetarian sales by gender for Colleges A and B. a) Chi square value compares the vegetarian and non-vegetarian sales from men and women. b) For College C vegetarian options available is estimated from the menu, as these values cannot be inferred from the sales data. Q1= lower quartile, Q3= upper quartile.

	College Totals				**Men and women: summaries**				**Total vegetarian sales: meals weighted equally**			**Vegetarian meal selection (%): diners weighted equally**		
College	Total options available	Veg options Available [%]	Total meal times	Mealtimes at least one option present [%]	Number women; men	Total sales women; men	Median meals bought per woman (Q1, Q3)	Median meals bought per man (Q1, Q3)	Sales from women [%]	Sales from men [%]	Chi-square test p value	Women. Median (Q1, Q3)	Men. Median (Q1, Q3)	Mann-Whitney test p value
A	1235	346 [28.0]	277	269 [97.1]	641; 546	18,348; 20,854	21 (7, 41)	28 (10, 60)	6495, [35.4]	4756, [22.8]	<0.001	29.7 (16.7, 50.0)	15.2 (5.6, 30.4)	<0.001
B	995	331 [33.2]	270	267 [98.9]	230; 393	7,580; 20,904	25 (7, 45)	37 (12, 78)	2842, [37.5]	3963, [19.0]	<0.001	29.4 (14.3, 62.4)	11.5 (1.8, 27.8)	<0.001
C	436	153.5[a] [35.2%]	109	109 [100.0]	183; 301	2,622; 6,677	8 (3, 23)	14 (3, 34)	573 [21.9]	1358 [20.3]	>0.10	20.0 (3.8, 36.4)	11.1 (0.0, 29.4)	<0.01
D	522	204 [39.1]	106	106 [100.0]	229; 299	3,879; 6,543	14 (5, 25)	16 (6, 35)	1372 [35.4]	1464 [22.4]	<0.001	30.0 (10.0, 66.7)	7.9 (0.0, 28.9)	<0.001

5.4.2 Study 2: Gender, meat type and environmental footprints

We analysed data from 39,202 and 28,848 meal selections, and 1187 and 623 individuals from colleges A and B respectively, to investigate selection and sales of vegetarian, fish and different types of meat meals: ruminant (beef and lamb), pork and poultry (chicken and turkey) (Figure 5.2). Overall sales from men and women were significantly different in both colleges (chi-square tests, College A, df=9, p<0.001; College B, df=8, p<0.001, Table 5.5 and Figure 5.2). The difference in sales was particularly stark for ruminant meat, with sales from men approximately 40% higher than those from women (~21% vs ~15% for both colleges). Weighting every individual equally, in both colleges men were more likely to select ruminant, pork and poultry meals than women (Mann-Whitney tests, colleges A and B, dfs=1, p values<0.001). Men and women were equally likely to select a fish meal (Mann-Whitney tests, colleges A and B, dfs=1, p values>0.10). Therefore the significantly lower vegetarian selection by men in colleges A and B (study 1) was driven by higher selection of meat meals, not by higher selection of fish meals.

The mean GHG emissions per 100 meals were 269 and 270kg CO_2eq for women and 314 and 321kg CO_2eq for men in colleges A and B respectively. The mean land-use per 100 meals was 353 and 367m^2-years for women and 450 and 471m^2-years for men, in colleges A and B (Figure 5.2). The average GHG footprint of men's cafeteria meals was 17-19% higher than women, and land-use was 28% higher. Despite the relatively small proportion of ruminant sales, 15% for women and 22% for men, ruminant meals dominated the environmental footprint for both genders. Ruminant meals were responsible for 39-40% (women) and 48% (men) of GHG emissions, and 58-60% (women) and 64-67% (men) of land-use in colleges A and B (Figure 5.2).

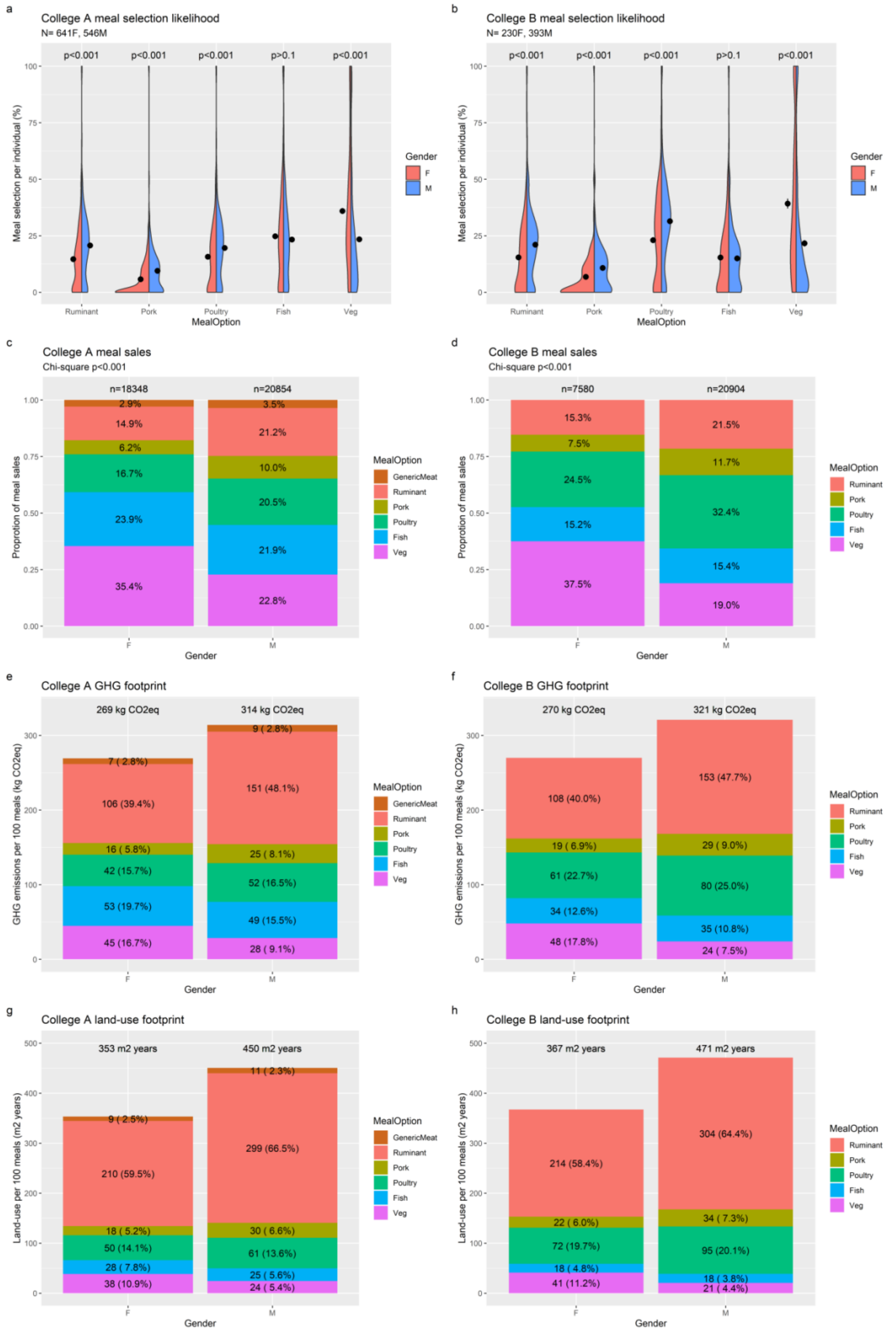

Figure 5.2: Sales and selection of different meal options (a-d) and the environmental footprints per 100 meals (e-h) in colleges A and B. Individuals are weighted equally in panels a and b, the black dots and whiskers show the mean and standard errors, the p values are from Mann-Whitney tests. Every meal selection is weighted equally in panels c and d; these values are used to calculate the GHG emissions (e and f) and land-use (g and h) by gender per 100 meals. N (uppercase) refers to number of individuals and n (lowercase) to number of meals.

Table 5.5: Sales by meal type and gender at colleges A and B. N (uppercase) refers to the number of individuals.

	College A					**College B**			
	Sales: number of meals		**Options**			**Sales: number of meals**		**Options**	
Meal Option	Women [%]. N=641	Men [%]. N=546	Options Available [%]	Mealtimes at least one option present [%]		Women [%]. N=230	Men [%]. N=393	Options Available [%]	Mealtimes at least one option present [%]
Generic Meat	533 [2.9]	740 [3.5]	44 [3.6]	41 [14.8]		NA	NA	NA	NA
Ruminant	2738 [14.9]	4429 [21.2]	184 [14.9]	161 58.1]		1163 [15.3]	4499 [21.5]	186 [18.7]	157 [58.1]
Beef	1827 [10.0]	2980 [14.3]	117 [9.5]	112 [40.4]		754 [9.9]	2586 [12.4]	92 [9.2]	86 [31.9]
Lamb	911 [5.0]	1449 [6.9]	67 [5.4]	62 [22.4]		409 [5.4]	1913 [9.2]	94 [9.4]	82 [30.4]
Pork	1138 [6.2]	2080 [10.0]	100 [8.1]	92 [33.2]		566 [7.5]	2488 [11.7]	91 [9.1]	90 [33.3]
Poultry	3068 [16.7]	4279 [20.5]	181 [14.7]	160 [57.8]		1860 [24.5]	6775 [32.4]	263 [26.4]	198 [73.3]
Chicken	2598 [14.2]	3591 [17.2]	154 [12.5]	143 [51.6]		1780 [23.5]	6503 [31.1]	250 [25.1]	189 [70.0]
Turkey	470 [2.6]	688 [3.3]	27 [2.2]	27 [9.7]		80 [1.1]	272 [1.3]	13 [1.3]	13 [4.8]
Fish	4376 [23.8]	4570 [21.9]	380 [30.8]	242 [87.4]		1149 [15.2]	3219 [15.4]	124 [12.5]	114 [42.4]
Vegetarian (incl. vegan)	6495 [35.4]	4756 [22.8]	346 [28.0]	269 [97.1]		2842 [37.5]	3963 [19.0]	315 [31.7]	267 [98.9]
Totals	18,348	20,854	1235	277		7,580	20,904	995	270

5.4.3 Study 3: Response to cafeteria interventions by gender

Between 47.5% and 66.4% of individuals in study 2 could be assigned a vegetarian quartile based on their meal choices in a prior term (Table 5.6). In all four colleges men had a higher percentage of individuals in the least vegetarian quartile ("LeastVeg") than women (Table 5.6). In colleges A, B and D the proportions of men and women in each quartile were significantly different (Chi square tests, df=3, p values<0.001), the proportions were not significantly different for College C (Chi square test, df=3, p>0.10). This pattern was repeated in the GLMMs: in bivariate analyses men had significantly lower likelihood of selecting a vegetarian meal than women in colleges A, B and D but not C (Table 5.7). In the multivariate analyses, which controlled for PriorVeg quartile, men had significantly lower likelihood of selecting a vegetarian meal in just colleges B and D. Therefore in College A, within prior veg quartiles, there was no significant difference between men and women's likelihood of selecting a vegetarian meal (Figure 5.3).

No significant interaction between gender and the cafeteria interventions was found for colleges A or C (availability intervention) or College D (price intervention) in either the bivariate or multivariate analyses (GLMMs, interaction term p>0.10, Table 5.7). However in College B, men responded more strongly than women to the intervention: in relative terms their likelihood of selecting a vegetarian meal increased more rapidly than women's as vegetarian availability increased (Figure 5.3).

Table 5.6: Prior Vegetarian Quartile by gender and College for individuals analysed in Study 2.

		Prior Veg Quartile [%]					
College	Gender	LeastVeg	LessVeg	MoreVeg	MostVeg	NA	Totals
College A	Female	69 [10.8%]	61 [9.6%]	105 [16.5%]	162 [25.4%]	240 [37.7%]	637
	Male	137 [25.3%]	80 [14.8%]	70 [12.9%]	73 [13.5%]	182 [33.6%]	542
College B	Female	49 [21.5%]	3 [1.3%]	22 [9.6%]	58 [25.4%]	96 [42.1%]	228
	Male	128 [32.7%]	26 [6.6%]	41 [10.5%]	56 [14.3%]	140 [35.8%]	391
College C	Female	24 [17.0%]	10 [7.1%]	16 [11.3%]	17 [12.1%]	74 [52.5%]	141
	Male	52 [22.3%]	19 [8.2%]	18 [7.7%]	31 [13.3%]	113 [48.5%]	233
College D	Female	24 [10.5%]	22 [9.6%]	22 [9.6%]	41 [17.9%]	120 [52.4%]	229
	Male	71 [24.1%]	37 [12.6%]	30 [10.2%]	22 [7.5%]	134 [45.6%]	294

Table 5.7: Model outputs from bivariate and univariate analyses for likelihood of selecting a vegetarian meal. Effect size calculated by taking the exponential of the model estimate. Confidence intervals (CIs) are at 95%. The reference categories in the models are: vegetarian availability =0, price condition=baseline and gender=women.

Model summary				**Intervention**		**Gender**		**Intervention gender interaction**	
College	Intervention	Model	Number of meals; individuals	Effect size [CI]	p value	Effect size [CI]	p value	Effect size [CI]	p value
A	Vegetarian availability	Bi-variate	35878; 1179	25.65 [18.08, 36.40]	<0.001	0.39 [0.30, 0.49]	<0.001	1.35 [0.81, 2.24]	>0.10
B	Vegetarian availability	Bi-variate	26404; 619	26.77 [16.01, 44.77]	<0.001	0.13 [0.09, 0.20]	<0.001	5.04 [2.72, 9.35]	<0.001
C	Vegetarian availability	Bi-variate	3348; 374	12.61 [2.44, 65.10]	<0.01	0.91 [0.38, 2.19]	>0.10	0.54 [0.07, 4.02]	>0.10
D	Price change	Bi-variate	9676; 523	1.02 [0.85, 1.22]	<0.001	0.18 [0.12, 0.27]	<0.001	1.27 [0.99, 1.62]	>0.05
A	Vegetarian availability	Multi-variate	30671; 757	37.52 [24.93, 55.73]	<0.001	0.82 [0.64, 1.03]	>0.05	1.21 [0.70, 2.12]	>0.10
B	Vegetarian availability	Multi-variate	21611; 383	17.38 [9.12, 32.43]	<0.001	0.23 [0.15, 0.37]	<0.001	6.00 [2.93, 12.57]	<0.001
C	Vegetarian availability	Multi-variate	1685; 187	0.40 [0.03, 5.10]	>0.10	0.35 [0.11, 1.21]	>0.05	10.53 [0.48, 192.31]	>0.10
D	Price change	Multi-variate	4039; 269	1.16 [0.73, 1.84]	>0.10	0.27 [0.16, 0.44]	<0.001	1.24 [0.82, 1.88]	>0.10

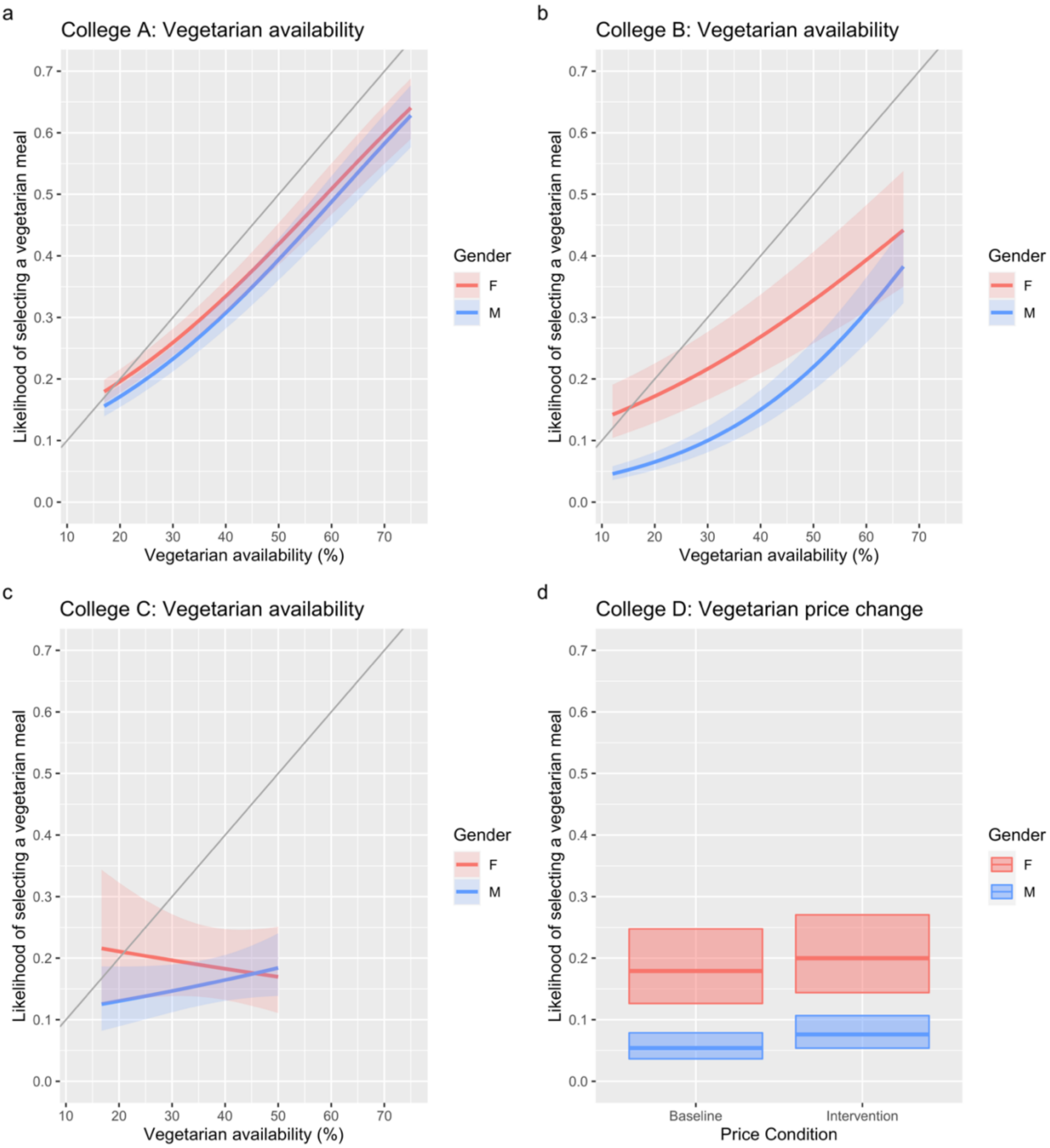

Figure 5.3: Effect of gender on availability (a, b, c) and price (d) interventions. Lines of best fit show modelled likelihood using conditional regression from the multivariate models with 95% confidence intervals. The prior vegetarian quartiles are weighted equally for the estimates. College B is the only college with significant interaction between gender and the intervention (i.e. availability).

5.5 Discussion

We find that in three out of four colleges men bought fewer vegetarian meals than did women, approximately 1 in 5 meals selected by men were vegetarian compared with approximately 1 in 3 selected by women. In College C vegetarian sales were 20-22% for both women and men. When individuals (rather than meals) were weighted equally, men were less likely to select a vegetarian meal than women in all four colleges. Women and men were similarly responsive to the availability and price interventions, with the exception of College B where men had a stronger response to increasing vegetarian availability. Dissecting meat and fish sales further in colleges A and B revealed that men were significantly more likely to select ruminant, pork and poultry meals than women, and there was no significant difference in fish meal selection between men and women. The higher meat sales from men, particularly the higher ruminant sales, resulted in men's meals having more negative environmental impacts, measured either as the GHG emissions or land area required in producing the ingredients. Compared to women, men's meals GHG emissions were 17-19% higher and land-use was 28% higher on average.

Our findings that men are less likely to select a vegetarian meal are consistent with previous studies on self-reported behaviour (Rozin et al., 2012). In College C this pattern was not apparent from the sales; college C is the only graduate college and the demographic is consequently more international and a few years older than the other colleges. This could indicate that the detected difference in vegetarian selection between genders is driven by younger British women, and there is some evidence that in the UK younger women (18-24) are most likely to limit their meat intake (YouGov, 2019). Men were more likely than women to select meat meals, particularly ruminant meat, which concurs with previous studies on self-reported behaviour. In a telephone survey of over 6000 participants in the UK, France, Germany, Switzerland, Italy and the USA men were less likely to report avoiding red meat (22% of men, 31% of women) and avoiding all meat (11% of men, 18% of women) (Rozin et al., 2012). Previous studies also agree with our finding that on average men's diets have higher environmental footprints than women's. A survey on German diets found that on average men's diets (adjusted to a standardised weight of food consumed) had 25% higher GHG emissions and 24% higher land-use due to higher meat consumption; the average women's diet had 11% higher irrigated water use due to higher fruit and vegetable consumption (Meier & Christen, 2012). A similar study from Sweden estimated that the energy use (MJ) per capita from food was 14-21% higher for men than women, due to both men's higher calorie consumption and higher proportion of meat (63kg of meat per year for men, 47kg for women) (Carlsson-Kanyama, Ekström, & Shanahan, 2003).

Calculating the mean environmental footprint for different meal options emphasises the importance of distinguishing between different types of meat because of their differing environmental impacts. Reducing the environmental damage from food is more nuanced than choosing between a binary of vegetarian and non-vegetarian meals and diets. Ruminant meals are outliers in terms of their high environmental impact relative to pork, poultry, fish and vegetarian meals. Furthermore vegan meals have much lower environmental impacts than non-vegan vegetarian meals due to the high GHG emissions and land-use of dairy. One study from Sweden estimated that a hypothetical "climate carnivore" diet (beef and lamb consumption replaced with chicken, and zero dairy consumption) had a lower carbon footprint than a high-dairy vegetarian diet (meat replaced by legumes, eggs and significant quantities of cheese) (Bryngelsson et al., 2016). We found high variation (i.e. high standard deviations) of environmental impacts within meal options: as well as increased sales of vegetarian meals, smaller portions of meat, fish and dairy per meal are important to reduce the environmental footprint of diet (Doherty et al. in prep.; Scarborough et al. 2014).

Although gender influenced vegetarian meal selection, in three out of four colleges it did not influence the response to interventions to increase vegetarian sales (availability and price). This perhaps indicates that effects of gender are mediated by the PriorVeg quartile. Gender influences likelihood of vegetarian selection (and therefore which PriorVeg quartile individuals are in) and PriorVeg quartiles respond differently to the cafeteria interventions (see chapters 3 and 4). For population-wide shifts to a more plant-based diet, increasing vegetarian availability does not widen – and could narrow – the observed "vegetarian-gap" between men and women, and therefore avoids the risk of intervention-generated inequalities (IGI) (White, Adams, & Heywood, 2009).

These studies have several strengths. We measure actual behaviours instead of self-reported data for selections of vegetarian, fish and meat meals. We use continent-specific values for the environmental impact of foods weighted by British production, import and export values to give a highly detailed and accurate estimate of the environmental footprint of British cafeteria meals. However our studies also have limitations and further research is needed. Our approach for designating gender was imperfect at accurately reflecting individuals' self-identification but we expect it to be broadly accurate. Ideally, analyses would be re-run with data on each individual's gender identity provided from the colleges. In addition cafeteria meal sales only represent a subset of individuals' diets. The differences we see on average between men and women within the college cafeterias might be less marked if we included other elements of people's diets such as vegetable sides, desserts, snacks and drinks, which generally have smaller environmental footprints than meat. Future work could include generating an environmental footprint for all items sold in the cafeteria to test if the gender patterns for environmental impact still hold.

It is important to emphasise that by reporting the differences in meal selections between men and women we do not take these to be unchangeable or innate. Preferences for food are heavily influenced by early experiences and social environments (Wilson, 2016). Furthermore, although we found substantial and significant average differences in men and women's meal selections and environmental impacts, there was large variation in meal selections within each gender. The gender associations of food are often arbitrary and surprising: the title of one study summarises its findings as "Meat is male; champagne is female; cheese is unisex" (Dodd & Wilcox, 2013). Another study asked participants to rank different foods based on how male and female they were perceived to be. Foods from female animals (eggs, beef placenta and milk) were not ranked as being "female"; steak, beef, pork and veal were rated as more male; chocolate, peach, chicken salad and sushi were ranked as the most female (Rozin et al., 2012) .

To conclude, we find fewer male students chose vegetarian meals than female students and their average meal selections have higher environmental impacts. Improving the taste and increasing the proportion of vegetarian options offered is likely to increase vegetarian meal selection for diners of all genders, which is vital to improve public and planetary health.

Chapter 6. General Discussion

And yes, I know we need a system change rather than individual change. But you cannot have one without the other.

Greta Thunberg (2019)

We show that we are adventurous by seeking out the hottest chillies; we prove we are easy-going by telling our host we 'eat anything'. We confirm that we are naturally conservative by eating patriotic hunks of red meat. Taste is identity.

Bee Wilson (2016) First Bite

"Jesus," Molly said, her own plate empty, "gimme that [steak]. You know what this costs?" She took his plate. "They gotta raise a whole animal for years and then they kill it. This isn't vat stuff." She forked up a mouthful and chewed.

William Gibson (1984) Neuromancer

6.1 Summary

In this chapter I review the key findings from my thesis and compare the effectiveness of different interventions to increase vegetarian sales. I discuss the strengths and limitations of my approach and field studies. Drawing on my findings, I calculate the potential environmental benefits of increasing vegetarian sales in cafeterias using different sales scenarios. Finally, I discuss the role of citizens, organisations and governments in bringing about a shift to a predominantly plant-based diet and conclude with recommendations to cafeterias.

6.2 Overview of results

I found that increasing the availability of vegetarian options was the most effective strategy (i.e. the largest effect size) to increase vegetarian sales (%) compared to 1) changing the order and placement of meal options and 2) a small change in the price of vegetarian and meat options. Doubling vegetarian availability from 25% to 50% (e.g. from 1 in 4 options to 2 in 4 options) increased vegetarian sales by 7.8, 14.5 and 14.9 percentage points in three colleges. 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. Placing vegetarian options first ("VegFirst") consistently increased their relative sales when there was a long distance between meat and vegetarian options (>1.5 metres) but not when close together (<1.0 metres). Under VegFirst and the long distance condition vegetarian sales increased by 4.6 and 6.2 percentage points in two different terms at one college. However, under VegFirst and a short distance the different experiments produced a mixture of effects on vegetarian sales: no significant change, vegetarian sales 6.7 percentage points lower at lunchtimes in one experiment, and vegetarian sales 2.3 percentage points higher at dinnertimes in another experiment. Introducing a small change in price (decreasing vegetarian price by 20p and increasing meat price by 20p) increased vegetarian (excluding vegan) sales by 3.2 percentage points, but there was no significant effect on combined vegetarian and vegan sales.

For both the availability and price intervention studies I was able to calculate the prior levels of vegetarian consumption for each diner (PriorVeg quartiles: MostVeg, MoreVeg, LessVeg, LeastVeg). As vegetarian availability increased from 25% to 50% all four quartiles of diners in all three colleges (with the exception of the most vegetarian quartile at College C) were more likely to select a vegetarian meal but there were differences in the magnitude of their responses. The least vegetarian quartile of diners responded most strongly to increasing vegetarian availability, in terms of the relative (as opposed to absolute) change in their likelihood of selecting a vegetarian meal (e.g. College B, 25% to 50% vegetarian availability: likelihood of selecting a vegetarian meal increased from 2.3% to 8.2%). A recent online study on vegetarian meal availability noted that they also found the participants who were least likely to eat meat responded most strongly to increasing vegetarian availability (Raghoebar, Kleef, & Vet, 2020). The price intervention only influenced the most vegetarian quartile to change their meal selections; no other quartile of diners responded significantly. After the price change the most vegetarian quartile increased their selection of non-vegan vegetarian meals by 13.7 percentage points and their combined vegetarian and vegan sales increased by 12.2 percentage points. Hence prior levels of vegetarianism appear to influence how individuals respond to interventions – a finding which should be considered in designing interventions, and which could be usefully explored in future research.

With respect to gender, I found that men were less likely than women to select a vegetarian meal (~25% of sales vs ~33% of sales), there was no significant difference in fish selections, and men were more likely to select poultry, pork and ruminant meals. Consequently, on average, men's meals had 18% higher GHG emissions and 28% higher land-use than women's. In three out of four colleges men and women were similarly responsive to the cafeteria interventions (i.e. there was no statistically significant interaction between the intervention and gender), when the PriorVeg quartile was both included and excluded from the models. Encouragingly, in the one college where I found an interaction, men responded more strongly to women as vegetarian availability increased. This suggests that increasing vegetarian availability does not widen – and could narrow – the observed "vegetarian-gap" between men and women, and therefore avoids the risk of intervention-generated inequalities (IGI) (White et al., 2009). Increasing vegetarian availability also narrowed the relative "vegetarian-gap" between the most vegetarian quartile and other diners. However, the price intervention only affected the most vegetarian quartile of diners and therefore increased the difference in vegetarian selection amongst students. Many interventions designed to improve health outcomes also risk widening existing health inequalities (White et al., 2009).

6.3 Strengths, limitations and future research

My thesis has several strengths. I achieved my thesis aim to evaluate the effectiveness of different interventions to increase vegetarian sales. The field studies I have carried out measure actual – rather than hypothetical or self-reported – behaviour in real-world settings over moderately long time intervals (weeks and months). I collected data from 1142 mealtimes and 213,627 meal selections; a recent systematic review found a combined total of only 11,290 observations across all 18 studies testing other forms of choice architecture interventions aimed at lowering meat consumption (Bianchi, Garnett, et al., 2018). Many previous studies measure theoretical behaviour, or real-world behaviour at just a single time-point (Bianchi, Garnett, et al., 2018; Hollands et al., 2019) and there is a risk they are statistically underpowered (DellaVigna & Linos, 2020). Unlike previous experiments, each of my studies tested one intervention only, thus avoiding the confounding effects present in many other similar studies (Cohen et al., 2015; Greene et al., 2017; Kongsbak et al., 2016). In three out of four data chapters I was able to obtain individual-level data, which enabled me to track repeated choices over time. This not only increased the robustness of my statistical analyses – as I did not need to assume that each data point was independent – it also allowed me to investigate if gender and prior vegetarian meal selection affected the response to the cafeteria interventions. Although I conducted all of my experiments within one university, this is a strength as well as a limitation. It means comparing the different approaches to increase vegetarian sales is more valid, as I am comparing across one pool of students at the same university within the same city.

One of the most valuable outcomes from my research is that I have been able to test approaches to increasing vegetarian sales which seem intuitive but which have not produced results in line with expectations. Approaches which seem obvious don't always work and our assumptions can be misleading. It is commonly stated that items placed nearer consumers are preferentially selected (Thaler & Sunstein, 2009) and in one of our order experiments (under a short distance) the catering manager was confident that the vegetarian option had higher sales when it was placed first. My analysis of the data showed that there was no significant difference in vegetarian sales. This highlights the importance of robust measurements and evidence to verify impressions and assumptions. Increasing vegetarian availability was an intuitive approach to increase sales, and I found that this was indeed effective. To my knowledge no-one had tested this intervention and I was able to estimate the magnitude of the effect size. I found that meal selection (between meat and vegetarian options) is neither fixed (which would mean doubling vegetarian meal availability would not alter people's choice of vegetarian vs meat options), nor random (which would mean doubling vegetarian availability would double vegetarian sales), but is instead partially determined by availability.

The studies presented in this thesis also have limitations, and considering how to address these suggests potential avenues for future research. All of the research was carried out in one British university and future studies need to be conducted in non-university populations and other countries (particularly low and medium-income countries) to see if the results presented here hold in other contexts. Additionally, University of Cambridge undergraduate students are not representative of British students generally: Cambridge had the second lowest proportion of entrants from state schools (63%) of the Russel Group universities in 2016 (Montacute & Cullinane, 2018). Students from private schools and comprehensives (a subset of state-schools) make up 42% and 25% respectively of the student body at Oxford and Cambridge; compared to 11% and 42% respectively for all higher education institutions (Montacute & Cullinane, 2018). Furthermore, even within the University of Cambridge the cafeteria sales may not be representative of the student body. Students on a tight budget are more likely to cook for themselves to save money (EEG pers. comms.) and in exploratory analyses I found that students who are more likely to select a vegetarian meal visit the cafeterias less frequently (e.g. Table 4.4). This further limits the generalisability of our findings.

Further research in other British universities could be valuable to build on these studies and gain a greater understanding of how order and price interventions affect sales. In this thesis I was also not able to empirically disentangle why under the short distance condition placing the vegetarian option first produced such mixed results, and often led to lower vegetarian sales. Further research is needed on the interactions between order and other aspects of the choice environment. I carried out only one experiment at one college which involved changing price, and at this cafeteria there was already a price differential between meat and vegetarian options. Future studies could test a sliding scale of price differentials between meat and vegetarian options (similar to the spectrum of vegetarian availability) and include cafeterias with a baseline where meat and vegetarian options have the same price. Future research could also try combining interventions to investigate if their effects on vegetarian sales are additive, synergistic or antagonistic. I hope to be able to conduct some of the proposed research myself in the future.

I used data on first names and registered births as a heuristic to designate gender for individual diners, and although I anticipate this approach was broadly accurate, it is possible that some individuals may have been assigned to the wrong gender. Furthermore a proportion of individuals with unusual and androgynous names were left as “Unknown” which decreased our sample size. It has not currently been possible to obtain data on the gender of each diner. Before submitting this work for publication I hope to be able to assign genders accurately using college records.

My studies also focus exclusively on quantitative measures of behaviour. Valuable insights could be uncovered by carrying out qualitative research. For example, my results demonstrate that simple interventions can be made to increase sales of plant-based foods without loss of sales or any complaints from diners, but there may be other cultural or economic factors to be overcome before these could be rolled out more broadly. Future research should involve conducting interviews with universities' (and other organisations') catering managers, financial managers and other key organisational figures to gain their perspectives on the barriers and opportunities of shifting catering operations so that they encourage more plant-based diets.

I did not measure the palatability or the nutritional content of the different meal options to student customers. This was outside the remit of my research, but how appealing we find different foods has a huge influence on our choices and diet (Wilson, 2016). Taste is the fourth most important factor for British citizens when shopping for food (after price, quality and special offers) (DEFRA, 2016). One study in the USA found that menus which listed more appealing vegetarian options had higher vegetarian meal selection (Campbell-Arvai et al., 2014). Sometimes labelling options to emphasise taste is enough to make dishes more appetising and increase sales: a USA study found that identical vegetable side dishes had higher sales when they had labels which emphasised taste and enjoyment ("twisted citrus-glazed carrots") compared to basic labels ("carrots") and labels which emphasised health ("smart-choice vitamin C citrus carrots") (Turnwald, Boles, Crum, & MZ, 2017). A survey conducted at the University of Oxford on colleges' vegetarian offerings recorded many comments from students who wanted better vegetarian and vegan options from their colleges: "They have a long way to go provide nutritionally adequate and tasty food for veggies", "All colleges need to improve. Vegetarians need protein. Vegetarians don't all want cheese! I want nice, varied vegan options e.g. dhal, bean curry, bean burgers etc. not just bean spicy stew all the time." (Oxford University Animal Ethics Society, 2016). Catering managers at the University of Cambridge organised two vegan training days for college chefs, designed by Humane Society International and chef Jenny Chandler (Wilson, 2018b), which received overwhelmingly positive feedback. Chefs reported they planned to serve more vegan options in their cafeterias and share the training with their colleagues.

6.4 Potential environmental benefits of the cafeteria interventions

The underlying motivation for increasing vegetarian sales is to reduce the environmental footprint of catering operations. I calculated the environmental footprint (GHG emissions and land-use) and savings across different meal sales scenarios across the university, to estimate the possible environmental benefits for nature and the climate of scaling the cafeteria interventions

(Table 6.1). I made a conservative back-of the-envelope estimate that across the University 12,000 meals are sold per day across 200 days in the year to students and conference guests, which adds up to 2.4 million meals per year. For most of the scenarios, I calculated the environmental benefits of increasing vegetarian sales from 22% to 37% (68% and 15 percentage point increase), which is approximately the effect I observed from doubling vegetarian availability from 25% to 50% (Chapter 3). It is possible that combining the different interventions could lead to additive effects, but I will model 22% to 37% as a scenario which is realistic for many cafeterias to achieve.

In the baseline scenario of 22% vegetarian sales across 2.4 million meals, annual GHG emissions are 7491 tonnes and land-use is 10.71km^2-years (Table 6.1). If the increase in vegetarian sales (from 22% to 37%) replaces meat and fish proportionately, GHG emissions decline by 11% and land-use by 15%. However, if the increase in vegetarian meal sales exclusively replaces ruminant meals (sales decline from 21% to 6%) GHG emissions and land-use decline by 28% and 43%. If vegetarian sales stay fixed at 22%, but all ruminant sales (21% to 0%) are replaced with pork and poultry sales (36% to 57%), the savings are even greater with a 31% decline in GHG emissions and a 52% decline in land-use. For a sales scenario which approximates the Planetary Health diet (Willett et al., 2019) (28 main meals across two weeks: 23 vegan meals, two vegetarian, two fish, two poultry/pork and one ruminant meal) GHG and land-use savings are higher again, at 62% and 69% respectively. The environmental benefits of increasing vegetarian sales are strongly dependent on whether they replace ruminant or non-ruminant meals. According to my calculations, if cafeterias increased vegetarian sales by 15 percentage points and ruminant sales increased by 5 percentage points there would be net environmental harm with a 2% increase in GHG emissions and a 9% increase in land-use (Table 6.1).

To reduce the environmental footprint of meals, cafeterias should particularly focus on increasing vegan meal provision and sales, and decreasing ruminant sales. Vegan meals have much lower environmental impacts than non-vegan vegetarian meals due to the high GHG emissions and land-use of dairy products (Table 6.1, Poore & Nemecek 2018). Although switching from ruminant meat to pork and poultry meat does bring substantial GHG and land-use savings, this approach should only be used as a temporary measure. Substituting one meat for another does not bring about the reduction in total meat consumption needed for a diet compatible with avoiding 2 degrees global heating, conserving nature and wild species, and reducing the risk of pandemics (Machovina & Feeley, 2014; Petrovan et al., 2020; Willett et al., 2019).

Although the cafeteria interventions are promising, a 68% increase in vegetarian sales (22% to 37%) corresponds to only a 19% decrease in meat and fish consumption (78% to 63%). The consumption of the average UK citizen for meat and fish needs to decline by 80% (from 80kg meat per year to 16kg) and 50% (from 20kg fish per year to 10kg) respectively to align with the Planetary Health diet (FAO, 2017a; Ritchie, 2017; Willett et al., 2019). A broader suite of policies and interventions are therefore needed to bring British diets within planetary boundaries.

Table 6.1: Environmental benefits of increasing vegetarian sales from 22% to 37%, hypothetical scenarios based on real-world sales data. GHG emissions and land-use values estimated for 2.4 million meals (estimated University dining operations over a year). The baseline scenario is an approximate representation of the real-world sales data at 25% vegetarian availability in colleges A and B. I assume that two-third of vegetarian sales are non-vegan and one-third are vegan for the baseline scenario.

		Vegetarian sales increase from 22% to 37%				**Other scenarios**		
Sales (%)	**Baseline scenario**	**Vegetarian replacing meats proportionally**	**All vegetarian sales are vegan**	**Vegetarian sales replacing ruminant only**	**Vegetarian replacing pork/poultry only**	**Replace all ruminant meals with pork/poultry**	**Planetary Health diet approximation**	**Increase vegetarian and ruminant sales**
Non-vegan vegetarian (%)	15	25	0	25	25	15	7	25
Vegan (%)	7	12	37	12	12	7	76	12
Ruminant (%)	21	17	17	6	21	0	3	26
Pork, poultry (%)	36	29	29	36	21	57	7	24
Fish (%)	21	17	17	21	21	21	7	13
Environmental impacts								
GHG emissions (t)	7491	6641	6139	5425	7059	5203	2866	7652
GHG savings (t) compared to baseline [%]	NA	849 [11]	1352 [18]	2066 [28]	432 [6]	2288 [31]	4624 [62]	-161 [-2]
Land use (km^2-years)	10.71	9.16	8.90	6.10	10.06	5.17	3.37	11.72
Land use savings compared to baseline (km^2-years) [%]	NA	1.55 [15]	1.81 [17]	4.62 [43]	0.66 [6]	5.54 [52]	7.34 [69]	-1.01 [-9]

6.5 Role of citizens, governments and organisations in bringing about sustainable diets

Bringing about healthy and sustainable diets which limit global heating to 2 degrees and protect biodiversity will require action from all sectors and across society. Reducing meat consumption in high-income countries is a vitally important approach and is one of the most straightforward things citizens can do to reduce the environmental footprint of food. Other changes are also needed including technological innovation, sustainable intensification and reducing food waste from farm-gate to retail (Searchinger, Waite, et al., 2018; Springmann et al., 2018) but these changes are difficult for citizens to influence with their day-to-day behaviour. Reducing food waste at the consumer stage of the supply chain, choosing in-season produce and buying sustainably certified seafood are actions that can be taken at the individual-citizen level. However, these are unlikely to bring about as many gains on environmental metrics as reducing meat consumption (Bryngelsson et al., 2016; Clune et al., 2017; T. Garnett, 2011). In theory all British citizens could individually reduce their meat and dairy consumption to levels compatible with the Planetary Health diet (an 80% reduction on average) (FAO, 2017a; Ritchie, 2017; Willett et al., 2019). However, while meat is so cheap and readily available in the UK, and embedded into British culture, this mass citizen action would require a high-level of individual agency on a national scale and is therefore highly unlikely (Adams et al., 2016).

Ambitious national policies are also needed to transition to lower meat diets and to align British government policies with their own recommendations (Buckwell & Nadeu, 2018b; Committee on Climate Change, 2018). The government's Committee on Climate Change has called for a 20% reduction in ruminant meat consumption (Committee on Climate Change, 2020). Our current meat-heavy diet is partly a result of UK and EU agricultural policies (Buckwell & Nadeu, 2018b; Wasley et al., 2018). Farming profits – particularly profits from grass-fed beef and lamb – are dominated by subsidies (DEFRA, 2019) which could be redirected towards legume production, vegetable and fruit horticulture and restoring some areas to nature at landscape scale (Harwatt & Hayek, 2019; Jones, 2020; Searchinger, Wirsenius, et al., 2018). Governments could incentivise product innovation and reformulation by introducing a food industry carbon tax for products with the worst environmental impacts (Park, 2020). There are also non-fiscal policy measures that could be introduced: governments could follow Portugal's example and make it mandatory for public cafeterias to include a vegan option (Nagesh, 2017). Governments could redesign their nationally recommended diets to be compatible with the Paris Climate Agreement to limit global heating to 2°C (Springmann et al., 2020). The impacts of different foods on climate change and wildlife, and practical cooking skills for plant-based dishes could be introduced onto the national curriculum (Park, 2020). Successive governments in the UK and other countries appear reluctant to align policies with their own stated objectives on reducing meat consumption. This may be due to opposition from the livestock industry (National Farmers' Union, 2019b; Tasker, 2016) and a fear that such policies would be perceived as "nanny state-ism" (Harrabin, 2018; Zee, 2018).

Action from local and regional governments can be more ambitious than national policies. Analyses have found that city and regional climate commitments generally exceed the ambition of national commitments under the Paris Agreement, and could reduce GHG emissions by a further 3.8-5.5% below national policies scenario projections (Global Covenant of Mayors, 2018; Kuramochi et al., 2020). Mayors from 14 cities (including London, Tokyo, Lima and Los Angeles) have signed up to the Good Food Cities Declaration, pledging to reduce meat served at public institutions to align with the Planetary Health diet (C40 Cities, 2019).

Organisations (businesses, NGOs, charities, university colleges) have a vital role to play in combatting climate change. Organisations make decisions which influence the choices available for hundreds and sometimes thousands of citizens. Sustainability decisions taken by organisations are therefore much more powerful and influential than actions taken by one individual alone. Although organisations (generally) have less power than national governments, they can also act more quickly and ambitiously. Most organisations do need to make decisions which benefit profits and consider expenditure, but unlike local and national governments they do not need to consider electability. Organisations can also influence many individuals outside their own immediate sector through conferences and media stories. Furthermore, individuals might find it easier to change their own domestic dietary habits if they have experienced good vegetarian food in an organisational setting such as a workplace cafeteria. Organisations adopting more sustainable practices could shift social norms and lead to positive spill-over effects.

A case study by way of example: in 2016 the Cambridge University Catering Service (UCS, this does not include college catering), led by Nick and Paula White, introduced an ambitious sustainable food policy (SFP). This included taking ruminant meat off the menu, sourcing sustainable fish, reducing food waste and promoting and increasing vegetarian and vegan food (White, 2016). These priority actions were recommended by Andrew Balmford, Chris Sandbrook and me. In 2019 UCS commissioned a piece of research (carried out by Anya Doherty and Sophie Satchell) to estimate the environmental benefits of the SFP. Since the introduction of the policy GHG emissions decreased by 33% and land-use by 28% per kg of food purchased (University Catering Service, 2019). The sustainable food policy has been highly effective at reducing the cafeterias' environmental impact whilst influencing the choices for thousands of customers. Furthermore the report's publication also made national news (BBC, 2019). There was considerable backlash from some farmers who argued that British ruminant meat should have stayed on the menu (National Farmers' Union, 2019c), but other universities and organisations interested in pursuing similar policies have contacted Cambridge UCS for advice. Cambridge's SFP has also won national catering awards (Environmental Association of Universities and Colleges, 2017). The University's work on sustainable food (the SFP and my thesis research) was a finalist in a global solution search competition on behavioural approaches to combatting climate change (Lumb, 2018) which has resulted in further publicity. Changes within organisations, such as the UCS, can influence both their own members and external citizens.

Valuing the role of organisations to combat climate change necessitates expanding the view of who is considered a policy maker. For many people the term "policy makers" conjure up images of officials in Whitehall and MPs in the Houses of Parliament. I would argue our definition needs to be broader than that: anyone who makes decisions that affects other citizens (outside of your household and immediate family) is a policy maker. Catering managers and chefs are key policy makers for transitions to sustainable diets: by curating menus and choosing which foods to source when and from where, they set the parameters for hundreds of diners for what they can choose to buy and eat. Public sector catering in the UK recently announced their outlets will serve 20% less meat (9 million kg: equivalent to 45,000 cows or 16 million chickens) to meet the Committee on Climate Change's recommendations (Carrington, 2020; Committee on Climate Change, 2020; Public Sector Catering, 2020). One quarter of the UK population eats meals from these caterers so this change will affect millions of people (Carrington, 2020).

In this thesis I argue that we should focus on introducing choice architecture changes, fiscal incentives and other low agency interventions, and avoid information provision and other high agency interventions (Adams et al., 2016), to encourage shifts towards predominantly plant-based diets amongst the general public. Ironically, bringing about these changes is likely to require information provision and mutual collaboration between researchers and policy makers. Information provision, mandates, bans and similar approaches levelled at one segment of society, can lead to choice architecture changes for others. The Portuguese government's decision to dictate that public cafeterias must provide a vegan option (Nagesh, 2017) has expanded the choice for public cafeteria customers (and my research indicates this is likely to be an effective approach to reduce meat consumption) but has limited the choice for catering managers, who cannot choose to not serve a vegan option.

6.6 Co-producing research and feasibility of the interventions

In my opinion there have been many benefits of this research and the University of Cambridge's sustainable food policy (SFP) being co-produced by catering managers, colleges and researchers. Nick White commented: "I have often been asked why it [the SFP] has been so successful. I think it was a really good idea for everyone to sign up to, but also, because we collaborated with a whole range of people - from senior academics, students, college and more - everybody was engaged in the process and that really made the difference in this" (Wilson, 2018a). This thesis would not have been possible without the participation and cooperation of catering managers, chefs and kitchen staff. As a researcher I have benefitted enormously from catering managers granting me access to reams of high-quality data and gamely carrying out field experiments, often across multiple terms and academic years. Their insights and expertise on running college cafeterias, and all the different considerations they have to juggle besides sustainability, have been incredibly valuable. I hope the catering managers have benefited from my analyses into their sales and the information I provided on the environmental impacts of food. Taking part in these studies has changed caterers' operations: the college cafeterias involved with the availability studies now serve more vegetarian and fewer meat options. The college cafeteria that took part in the price experiment, after initially reverting to the original prices, has made vegetarian meals in cafeterias and at college formal halls (three course served meals) even cheaper.

Carrying out these studies in real-world locations with regular and paying customers, instead of online, also provides de facto information about intervention feasibility. To my knowledge none of our studies resulted in any complaints or objections made to the cafeterias. This hopefully indicates that these approaches could be safely implemented in other outlets. The success of our studies contrasts strongly with the backlash many colleges have faced from introducing Meat Free Mondays (MFMs), which are often rescinded after a few terms. In one college MFMs led to some students forming a "Monday Steak Club" which now has its own Facebook page with 221 followers. In another college which conducted a survey on introducing MFMs two-thirds of the respondents were in favour of the scheme. However, there were several strongly negative comments, many of which included the view that MFMs restricted choice: “nobody should be limited in their choice of food”, “We live in a society that allows choice. Imposing your views to [sic] people is what kids do”, “I don’t think forcing food habits onto people is a good idea.” The cafeteria interventions outlined in this thesis were implemented without surveys of the student body and – with the exception of the price study – the changes were not advertised. Therefore it is theoretically possible that the changes we made to cafeterias would have proved as unpopular as MFMs had they been similarly publicised. However, I think this is unlikely as our interventions did not edit choices by removing meat or fish meals at any point; it is this perceived removal of free choice which seems to be the main reason students object.

There is also evidence that choice editing in cafeterias goes unnoticed if it is not advertised. When Nick and Paula White introduced the UCS sustainable food policy (SFP), they did not advertise that they were removing ruminant meat from the menu, anticipating objections from customers if they did so. When the SFP report was released and publicised some people online expressed outrage (“I would have complained!”) but the UCS were able to point out that between 2016 and 2019 they did not receive a single complaint that beef and lamb were not being served. This illustrates an interesting tension for introducing sustainable food policies, and sustainability initiatives more generally. On the one hand it is valuable and important to involve people in decision-making that affects them, but on the other hand this risks further polarising different viewpoints and initiating a backlash which might not have materialised if the changes were announced post-hoc. Furthermore, we cannot expect organisations to copy ambitious sustainability policies if these policies are not advertised and celebrated.

6.7 Concluding remarks and recommendations

My research suggests that cafeterias can play a key role in transitioning citizens to a more plant-based diet. Based on the results from my thesis I would make several recommendations to cafeterias aiming to reduce meat sales and the environmental footprint of their food:

1. Increase the proportion of vegetarian meal options (particularly vegan options) and price vegetarian options more cheaply than meat and fish.

2. Any physical rearrangement of the cafeteria with the aim of increasing vegetarian sales should be piloted first to ensure that it doesn't actually reduce vegetarian sales.

3. Reducing servings of ruminant meat is particularly important to reduce the GHG emissions and land-use footprint of catering operations; the environmental benefits are much smaller if vegetarian sales only replace pork, poultry and fish sales.

From evidence published elsewhere, I would also recommend that catering managers provide their chefs with training on producing delicious and nutritionally balanced vegetarian meals. Sustainable and healthy meal options should be marketed as delicious rather than restrictive or virtuous. Last, the serving sizes of meat and fish in meals should be reduced and servings bulked-out with vegetables and pulses. To conclude, we need action from across society – including individuals, organisations and governments – to limit climate change, protect nature, and reduce biodiversity loss from land use change. Shifting to a more plant-based diet is one of the most powerful ways to bring about positive environmental change.

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Appendix A. Supplementary Information for Chapter 2

Supplementary Information for:

Chapter 2. Not going the distance: effects of order on student cafeteria vegetarian sales

This Appendix contains Supplementary Figures A1 to A3 and Supplementary Tables A1 to A10.

Figure A1: Photo of the College A cafeteria in the “VegFirst” configuration (Vegetarian lasagne, dish on far right). College B did not wish for photos of their cafeterias to be included.

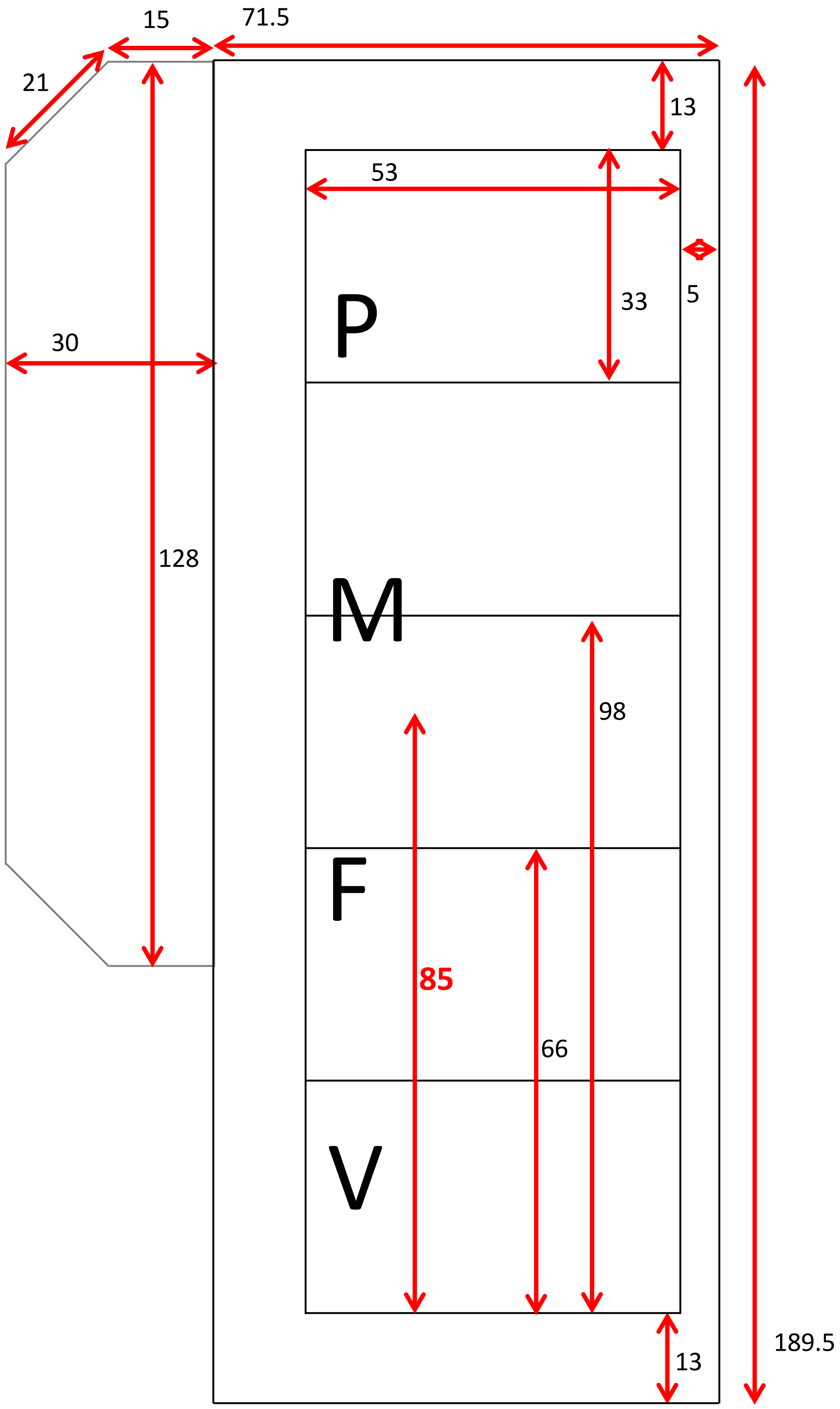

Figure A2: College A cafeteria layout to scale under VegFirst condition. Numbers refer to distances in cm. Outline indicates counter top, small rectangles indicate hotplates within the counter where trays of main meals, side dishes and plates are placed. V indicates the position of the vegetarian option under VegFirst condition with this meal option nearest the cafeteria entrance. F indicates the position of the fish option, M the meat and P the pasta bar or street food. The distance between the vegetarian and meat options was approximately 85cm; when 4 options were present (as shown) this distance was nearer to 90cm, when there were 5 options the distance was nearer to 80cm.

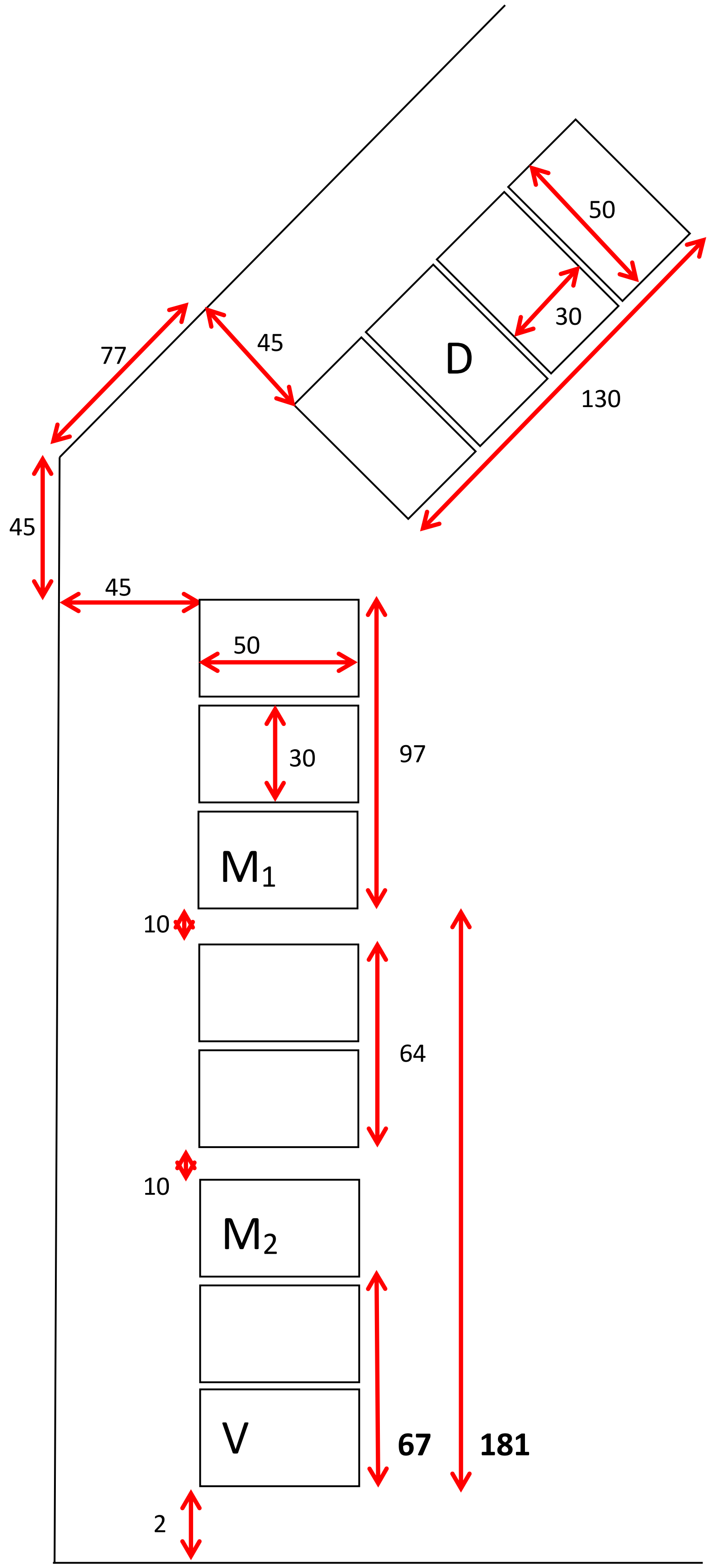

Figure A3: College B cafeteria layout to scale under VegFirst condition. Numbers refer to distances in cm. Outline indicates counter top, small rectangles indicate hotplates within the counter where trays of main meals, side dishes and plates are placed. V indicates the position of the vegetarian option under VegFirst condition with this meal option nearest the cafeteria entrance. M_1 indicates the position of the meat option during the long-distance (181cm) treatment. M_2 indicates the position of the meat option during the short-distance (67cm) treatment. D indicates the position of the third option “Dish of the day” under all conditions (VegFirst and MeatFirst, long and short-distance).

Table A1: College A. Example of a menu listed online in spring term 2017. (v)=vegetarian, (ve)=vegan.

Lunch Option	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Main Course	Turkey Milanese with tomato sauce and spaghetti	Caribbean Chicken with Mango and Rice	Kashmir lamb curry with tomato sambal	Steak and ale pie with puff pastry crust	Hoisin Chicken kebab with noodles and cucumber
Vegetarian/ Vegan Main Course	Vegetable and Quorn lasagne (v	Beetroot, pumpkin and goat's cheese tarte tatin (v)	Enchiladas with rice and corn salad (ve)	Polenta and parmesan fritters with apple relish (v)	Sundried tomato and red pepper risotto with rocket salad (ve)
Fish Main Course	Grilled Salmon with Balsamic Onion Glaze	Braised Italian style cod loin	Fillet of Pollack with Veronique sauce	Mustard-Grilled Scandinavian Salmon	Deep fried fish With tartar sauce
Pasta bar or fast food item	Roast beef po boy with dill pickle and kettle crisps	Today's pasta with choice of two sauces	Falafel wrap with humus cucumber yoghurt, red onion and chopped tomato (v)	Today's pasta with choice of two sauces	Crispy catfish with cucumber pickle banh mi
Dinner Option	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Main Course	Caramel chilli chicken	Pork loin steak with onion rings and sweet corn	Coq au vin	Half roast chicken with bread sauce and natural jus	Moroccan turkey with salad and flat bread
Main Course	Irish coddled pork with cider	Lamb filo pie	Duck tagine with clementines	Daube of pork	Spaghetti Bolognaise
Fish Main Course	Malay-style braised fish	Smoked haddock with chive and mussel risotto	Teriyaki hoki With stir-fried veg and sesame	Nori Crusted Salmon	Breaded fish fillet with herb mayonnaise
Vegetarian/ Vegan Main Course	Mexican vegetable chilli corn pie (v)	Wild mushroom gnocchi with goats cheese (v)	Carrot cakes with harissa yoghurt and flat bread (v)	Bean and spinach korma with rice (ve)	Vegetable and Quorn gumbo (ve)
Street food	Hot dog with brioche bun caramelized onion and homemade ketchup	Sticky Caribbean Chicken Wings	Roasted sweet potato wrap with houmous and cucumber (ve)	Chicken in a bun with caramelized onion and coleslaw	Pizza 2 x slices and rocket salad

Table A2: College B. Example of a menu listed online in summer term 2017. The Dish of the Day (third option) was always a meat option. (v)=vegetarian, (ve)=vegan.

Lunch				
Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Chili con Carne; Jacket Potato; Sweetcorn	Roasted Suprême of Salmon; Pea Risotto; Mediterranean Vegetables	Roast Chicken; Garlic & White Wine Sauce; Herby Diced Potatoes; Broccoli	Chicken, Chorizo & Prawn Paella; Peas; Rustic Bread	Cod & Pancetta Fishcakes; Skinny Fries; Pois à la Française
Pitta Bread filled with Grilled Halloumi, Aubergine, Humous & Raw Onion, Spicy Potato Wedges (v)	Roasted Vegetables & Pinenuts on a bed of Cous-cous (v)	Yellow Pepper, Tomato & Mozzarella Filo Pie; Lyonnaise Potatoes; Sweetcorn (v)	Goats Cheese, Mozzarella & Sun-dried Tomato Ravioli (v)	Cabbage Rolls stuffed with Quorn & Rice; Mashed Potatoes; Vegetarian Gravy (v)
Dish of the Day	Dish of the Day	Dish of the Day	Dish of the Day	Dish of the Day
Dinner				
Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Grilled Rib-Eye Steak; Madeira Sauce; Dauphinoise Potatoes; Grilled Plum Tomatoes & Mushrooms (v)	Wiener Pork Schnitzel; Parsley & Butter Potatoes; Sautéed Courgettes (v)	Salami, Pepperoni & Rocket Pizza; Curly Fries; Corn on the Cob (v)	Shepherd's Pie; Crusty Bread; Cabbage with Shredded Carrot (v)	Turkey and Leek Pie; Saute Potatoes; Green Beans (v)
Vegetarian Toad in the Hole; Vegetarian Gravy; Yorkshire Pudding	Vegetable & Blackbean Stir-fry; Steamed Basmati Rice	Tofu & Mushroom Burger	Farfalle with Gorgonzola and Courgette Sauce	Vegetarian Moussaka Focaccia
Dish of the Day	Dish of the Day	Dish of the Day	Dish of the Day	Dish of the Day

Table A3: College B. Example of a menu listed online in spring term 2018. The Dish of the Day (third option) was always a meat option. (v)=vegetarian, (ve)=vegan.

Lunch				
Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Smoked Kessler, Majoram Tagliatelle; Broccoli; Garlic Bread	Turkey Steak; Choron Sauce; French Fries; Grilled Tomatoes; Peas	Welsh Dragon's; Onion Gravy; Creamy Mash Potato Carrots & French Beans	Grilled Chicken; New Potatoes; Ratatouille	Breaded Plaice Fillet; Chips; Mushy Peas
Mixed Pepper, Mozzarella & Olive Quiche (v)	Quorn Mince Chilli con Carne; Basmati Rice (v)	Sun-dried Tomato, Red Onion & Ricotta Pastry Slice (v)	Spinach, Feta & Filo Pie; Duchess Potatoes (v)	Squash & Chickpea Stew; Croquette Potatoes (v)
Jacket Potato With Baked Beans (ve)	Durum Wheat Pasta with Arrabiata Sauce (ve)	Jacket Potato with Lentil Chilli Con Carne (ve)	Rice with Stir Fry Vegetables & Chickpeas (ve)	Jacket Potato with Ratatouille (ve)
Dinner				
Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Chicken Breast with Cream & Butter Sauce; Herby Diced Potatoes; Green Beans	Salmon & Spinach Conchiglie; Tomato and Oregano Focaccia; Peas	Lamb Jalfrezi with Mango Chutney; Poppadum; Steamed Basmati Rice; Sautéed Onions & Peppers	Bourbon Glazed Beef Brisket; Pitta Bread; Sweet Potato Fried	Korean BBQ Chicken Kebabs; Red Cabbage Colslaw; Kimchi Fried Rice
Lentil & Egg Curry Garlic Naan; Basmati Rice (v)	Potato, Onion & Pepper Tortilla (v)	Mediterranean Pasta Bake Ciabatta Bread (v)	Four Cheese Tortellini with Pinenuts, Basil Sauce, Garlic Bread (v)	Vegetarian Moussaka Sweetcorn (v)
Dish of the Day	Dish of the Day	Dish of the Day	Dish of the Day	Dish of the Day

Detailed model outputs

For these detailed model output tables, the effect size (i.e. the odds ratio) is calculated by taking the exponential of the model estimate and 95% CIs are used. Veg sales refer to sales of the focal vegetarian option that was placed first, as a percentage of overall sales.

Table A4: Study 1 – College A, short-distance, weekly alternation, spring term 2017. VegSales ~ Order + Day + DaysSince + Mealtime + MeanTemp + Menu.Rotation + VegNonVegPriceDifferential + VegOptionsAvailable

Variable	**Effect size [CIs]**	**p-value**	**Narrative**
Order: VegFirst	0.88 [0.77, 1.00	0.058	Veg sales were non-significantly lower under VegFirst.
Tuesday	1.05 [0.90, 1.22]	0.544	Veg sales on Tuesdays, Thursdays and Fridays did not significantly differ compared to Mondays' sales; veg sales were higher on Wednesdays.
Wednesday	1.20 [1.03, 1.39]	0.019	
Thursday	1.11 [0.96, 1.30]	0.170	
Friday	0.92 [0.77, 1.09]	0.336	
DaysSince	1.00 [1.00, 1.00]	0.646	Veg sales did not change over the time of the experiment.
Mealtime: Dinner	0.79 [0.70, 0.88]	<0.001	Veg sales were lower at dinnertimes compared with lunchtimes.
Mean temp (^{o}C)	1.03 [1.00, 1.06]	0.033	Veg sales were higher on warmer days.
Menu Rotation B	1.12 [0.96, 1.31]	0.154	Veg sales did not differ significantly between menu rotations B and C compared to A; menu rotation D had higher veg sales.
Menu Rotation C	1.02 [0.89, 1.17]	0.805	
Menu Rotation D	1.20 [1.04, 1.40]	0.015	
Veg NonVeg price differential	2.42 [1.21, 4.87]	0.013	When meat options are relatively more expensive than veg options, veg sales significantly increase.
Additional veg options available	0.64 [0.54, 0.76]	<0.001	Veg sales (of the focal veg option) were lower when an additional veg option was present.

Table A5: Study 1 – College B, long-distance, weekly alternation, summer term 2017. VegSales ~ Order + Day + DaysSince + Mealtime + MeanTemp

Variable	**Effect size [CIs]**	**p-value**	**Narrative**
Order: VegFirst	1.33 [1.24, 1.42]	<0.001	Veg sales were significantly higher under VegFirst.
Tuesday	1.06 [0.95, 1.18]	0.282	Veg sales on Tuesdays and Thursdays did not significantly differ compared to Mondays' sales; veg sales were higher on Wednesdays and Fridays.
Wednesday	1.23 [1.11, 1.36]	<0.001	
Thursday	1.07 [0.96, 1.19]	0.227	
Friday	1.13 [1.01, 1.27]	0.028	
DaysSince	1.00 [1.00, 1.00]	0.783	Veg sales did not change over time of the experiment.
Mealtime: Dinner	1.03 [0.96, 1.11]	0.365	Veg sales were not different at dinnertimes compared to lunchtimes.
Mean temp (^{o}C)	1.00 [0.99, 1.01]	0.640	Veg sales did not change with ambient temperature.

Table A6: Study 1 – College B, long-distance, monthly alternation, autumn term 2017. VegSales ~ Order + Day + DaysSince + Mealtime + MeanTemp

Variable	**Effect size [CIs]**	**p-value**	**Narrative**
Order: VegFirst	1.51 [1.30, 1.75]	<0.001	Veg sales were significantly higher under VegFirst.
Tuesday	1.04 [0.94, 1.16]	0.438	Tuesdays, Wednesdays, Thursdays and Fridays did not have significantly different veg sales compared with Monday.
Wednesday	0.95 [0.85, 1.06]	0.346	
Thursday	0.94 [0.85, 1.05]	0.260	
Friday	1.09 [0.98, 1.21]	0.120	
DaysSince	1.00 [1.00, 1.00]	0.922	Veg sales did not change over the time of the experiment.
Mealtime: Dinner	0.83 [0.78, 0.89]	<0.001	Veg sales were significantly lower at dinner compared to lunchtimes.
Mean temp (^{o}C)	0.97 [0.96, 0.99]	<0.001	Veg sales were lower on warmer days.

Table A7: Study 2 – College B, short-distance, weekly alternation, spring term 2018. VegSales ~ Order + Day + DaysSince + Mealtime + MeanTemp

Variable	**Effect size [CIs]**	**p-value**	**Narrative**
Order: VegFirst	0.77 [0.72, 0.83]	<0.001	Veg sales were significantly lower under VegFirst.
Tuesday	0.96 [0.86, 1.06]	0.412	Tuesdays, Wednesdays and Fridays did not have significantly different veg sales compared with Mondays'; Thursday had significantly lower veg sales.
Wednesday	1.04 [0.93, 1.15]	0.487	
Thursday	0.88 [0.79, 0.97]	0.015	
Friday	1.03 [0.92, 1.16]	0.563	
DaysSince	1.00 [1.00, 1.00]	0.138	Veg sales did not change over the time of the experiment.
Mealtime: Dinner	0.86 [0.80, 0.92]	<0.001	Veg sales were significantly lower at dinner compared to lunchtimes.
Mean temp (^oC)	0.95 [0.94, 0.96]	<0.001	Veg sales were lower on warmer days.

Table A8: Study 2 – College B, short-distance, monthly alternation, summer term 2018. VegSales ~ Order + Day + DaysSince + Mealtime + MeanTemp

Variable	**Effect size [CIs]**	**p-value**	**Narrative**
Order: VegFirst	1.04 [0.92, 1.18]	0.560	Veg sales did not differ significantly with order.
Tuesday	1.09 [1.00, 1.20]	0.057	Tuesdays and Fridays did not have significantly different veg sales compared to Mondays'; Wednesdays and Thursdays had significantly lower veg sales.
Wednesday	0.54 [0.48, 0.59]	<0.001	
Thursday	0.80 [0.72, 0.88]	<0.001	
Friday	0.91 [0.82, 1.00]	0.061	
DaysSince	1.00 [1.00, 1.00]	0.918	Veg sales did not change over the time of the experiment.
Mealtime: Dinner	0.68 [0.64, 0.72]	<0.001	Veg sales were significantly lower at dinner compared to lunchtimes.
Mean temp (^oC)	1.02 [1.00, 1.03]	0.008	Veg sales were higher on warmer days.

Table A9: Summary of multi-variate model estimates for order in Studies 1 and 2 for Main meat option sales in College B. 95% confidence intervals reported.

Study	Distance; alternation	Meat First: Main meat sales % [CIs]	VegFirst: Main meat sales % [CIs]	Meal order effect size [CIs]	p-value
1	Long; Weekly	54.2 [52.2, 56.1]	47.5 [45.5, 49.5]	0.77, [0.72, 0.81]	<0.001
1	Long; Monthly	74.2 [72.3, 75.9]	63.8 [61.7, 65.9]	0.61, [0.54, 0.70]	<0.001
2	Short; Weekly	65.7 [63.8, 67.6]	71.5 [69.8, 73.2]	1.31, [1.23, 1.39]	<0.001
“	Lunch	64.7 [62.6, 66.6]	72.5 [70.6, 74.2]	NA	NA
“	Dinner	69.9 [68.0, 71.8]	73.3 [71.5, 75.0]	NA	NA
2	Short; Monthly	69.7 [68.1, 71.3]	66.2 [64.2, 68.1]	0.85, [0.77, 0.94]	0.002
“	Lunch	69.3 [67.7, 71.0]	66.9 [64.7, 69.0]	NA	NA
“	Dinner	74.9 [73.4, 76.3]	70.8 [68.7, 72.8]	NA	NA

Table A10: Summary of multi-variate model estimates for order in Studies 1 and 2 for Third option sales in College B. 95% confidence intervals reported.

Study	Distance; alternation	Third option	Meat First: Third option sales % [CIs]	VegFirst: Third option sales % [CIs]	Meal order effect size [CIs]	p-value
1	Long; Weekly	Meat at lunch and dinner	27.5 [25.8, 29.4]	29.8 [27.9, 31.7]	1.11, [1.04, 1.19]	0.002
1	Long; Monthly	Vegan at lunch, meat at dinner	10.0 [8.9, 11.3]	14.0 [12.6, 15.6]	1.47, [1.24, 1.73]	<0.001
“	Lunch	Vegan	10.3 [9.0, 11.8]	13.7 [12.1, 15.5]	NA	NA
“	Dinner	Meat	13.9 [12.3, 15.7]	18.2 [16.2, 20.4]	NA	NA
2	Short; Weekly	Vegan at lunch, meat at dinner	11.5 [10.3, 12.8]	9.8 [8.7, 11.0]	0.84, [0.77, 0.92]	<0.001
“	Lunch	Vegan	11.1 [9.9, 12.5]	10.1 [8.9, 11.4]	NA	NA
“	Dinner	Meat	11.3 [10.1, 12.8]	9.1 [8.0, 10.3]	NA	NA
2	Short; Monthly	Vegan at lunch, meat at dinner	12.0 [10.9, 13.1]	15.1 [13.6, 16.8]	1.31, [1.13, 1.51]	<0.001
“	Lunch	Vegan	11.5 [10.4, 12.7]	16.1 [14.4, 18]	NA	NA
“	Dinner	Meat	12.7 [11.6, 14.0]	14.6 [13.0, 16.4]	NA	NA

Appendix B. Supplementary Information for Chapter 3

Supplementary Information for:

Chapter 3. Impact of increasing vegetarian availability on meal selection and sales in cafeterias

This Appendix contains Supplementary Figure B1 and Supplementary Tables B1 to B21.

Figure B1. Photo of College C cafeteria with four options served.

Study 1: Example menus

Table B1. College A, example of a menu listed online. (v)=vegetarian, (ve)=vegan. Although the menus present 3 options, the number of meals served at the cafeteria often varied.

Lunch				
Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Creamy Chicken & Bacon Pasta with Basil	Beef, Mushroom, & Guinness Flaky Pastry Pie	Shepherd's Pie	Teriyaki Marinated Pork Steak with Toasted Cashews	Chicken Tikka
Vegetable Samosa with Coriander Lentil Dahl (ve)	Glamorgan Sausage & Red Onion Gravy (Veggie of Course) (v)	Tofu & Cashew Nut Stir Fry, with Hoi Sin & Spring Onion (ve)	Sweet Potato & Leek Gratin with a Crispy Oregano Topping (v)	Butternut Squash & Field Mushroom Moussaka (v)
Oriental Loin of Cod With Asian Vegetables	Chestnut Mushroom & Spinach Pasta Bake (v)	Grilled Fillet of Hake, Tomato & Chorizo Sauce	Quorn Fajita, with peppers, tortillas, salsa and sour cream (v)	Chip Shop Style Fried Fish With Homemade Tartare Sauce
Dinner				
Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Beef & Broccoli Stir Fry with Ginger.	Honey Glazed Gammon Steak with Char Grilled Pineapple	Lemon, Thyme, & Garlic Butterflied Chicken Fillet	Lamb Hotpot	Beef Cobbler
Kadala Curry, with Chick Peas & Spinach (ve)	Baked Potato Skins filled with Vegetable Chilli & topped with Sour Cream & Chives (v)	Mushroom Stroganoff (v)	Red Pepper & Aubergine Lasagne (v)	Moroccan Spiced Vegetable Tagine with Apricots (ve)
Smoked Haddock & Spring Onion Fishcakes, Pea & Mint Sauce	Beef Lasagne	Moqueca	Chicken & Mushroom Pie	Fresh Fish of The Day

Table B2: College B, example of a menu listed online. (V)=vegetarian, (ve)=vegan. Although the menus present 3 options, the number of meals served at the cafeteria often varied.

Lunch				
Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Chicken, Mediterranean vegetable and Chorizo Paella	Maple glazed bacon chop with an apple and sage fritter	Roast leg of English lamb with sautéed tarragon and pears	Mediterranean vegetable and galbani mozzarella en croute with a Provençale sauce (v)	Barbecue Quorn, roasted pepper and plum tomato pizza with mozzarella (v)
Spaghetti Bolognese with parmesan	Moroccan chicken on garlic flatbread with tomato and coriander salsa and Monterey jack cheese	Roast loin of pork with mustard crackling and apple sauce	Cauliflower florets in a spicy batter with a curried tikka masala sauce (v)	Puy lentil and Mexican vegetable fajitas with guacamole (ve)
Mushroom, spinach, and sweet potato wellington with camembert cheese, tomato sauce (v)	Chick pea, local fenland vegetable and basil tagine, red onion cous-cous (ve)	Leek, mushroom and goats cheese filo pastry strudel with a grain mustard sauce (v)	Griddled rump of beef with tomato, onion rings and a peppercorn sauce	Piri-Piri fillet of chicken with a coriander and tomato guacamole
Dinner				
Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Roasted tofu, broccoli and courgette pad Thai with sesame and cilantro (ve)	Deep fried scampi with lemon and lime wedges	Jamaican jerk pork curry with a coconut, mango and pea rice	Minced beef and spinach lasagne	Beer battered fillet of cod with lemon
Winter vegetable and cannellini bean stew with crispy herb dumplings (v)	Braised topside of beef steak in local ale, grelots and wild mushrooms	Creamy garlic and basil baked fillet of chicken with a warm Caesar salad	Panko breaded butterfly chicken breast with a Katsu sauce and rice	Lamb and minted winter vegetable casserole with redcurrants and crusty bread
Lamb jalfrezi with a mushroom and coriander rice pilau, poppadum's	Broccoli, cashew nut and halloumi curry, herb pilaff rice (v)	Roasted asparagus, sun blushed tomato and chestnut mushroom carbonara (v)	Sri Lankan dahl and Vegetable curry with wholemeal rice (ve)	Wild mushroom, roasted butternut squash and sun blushed tomato risotto with parmesan (v)

Study 1: Effect of removing meals with no vegetarian options

Table B3: Comparing GLMs with vegetarian availability as the only predictor when meals with no vegetarian options are included and excluded. Including mealtimes with no vegetarian options increases the level of variation explained by vegetarian availability (McFadden's pseudo R^2) but this risks overestimating its effect on vegetarian sales. Mealtimes with no vegetarian options were excluded from the main analyses.

	College A		**College B**	
	Mealtimes with no veg options excluded	**Mealtimes with no veg options included**	**Mealtimes with no veg options excluded**	**Mealtimes with no veg options included**
Number of meals	269	277	266	269
McFadden's R^2 (univariate GLM)	0.209	0.267	0.319	0.332

Study 1: Frequency of vegetarian and total options

Table B4: Frequency of vegetarian options by total options in College A and B across all meals assessed.

		Total options available						
		2	*3*	*4*	*5*	*6*	*7*	*8*
College	Vegetarian options available							
A	0	0	1	5	1	1	0	0
	1	3	41	89	51	20	0	0
	2	0	2	13	21	13	3	1
	3	0	0	1	3	5	2	1
B	0	2	1	0	0	0	0	0
	1	0	99	89	13	1	0	1
	2	0	20	28	11	1	3	0

Study 1: Best models for vegetarian sales - aggregate data

Table B5: Best model for vegetarian sales at College A. VegSales ~ VegAvailPercent + TotalMealsSold + TotalOptionsAvailable + Term + Meal + MeanTemp + VegNonVegPriceDifferential + Day + Week. AIC = 3082.8, log-likelihood =-1518.4, McFadden's pseudo R^2 = 0.261. Conditions used to generate predictions: VegAvailPercent=25, TotalMealsSold=180, TotalOptionsAvailable=4, Term=Summer, Meal=Lunch, MeanTemp=10, VegNonVegPriceDifferential=0.2, Day=Wed, Week=5. Effect size calculated by taking the exponential of the model estimate.

Variable	Effect size	Effect size 95% CIs	p-value	Narrative	Example value	Predicted veg sales (%)	Example value	Predicted veg sales (%)
Veg Availability (%)	1.028	1.026, 1.030	<0.001	Meals with higher vegetarian availability had higher vegetarian sales.	25	24.1	50	39.0
Total meals sold	1.001	1.001, 1.002	<0.001	Mealtimes with more meals sold had higher vegetarian sales.	100	22.1	200	24.6
Total options available	0.971	0.950, 0.992	<0.01	Mealtimes with more total options had lower vegetarian sales.	3	24.6	5	23.7
Summer term	0.844	0.784, 0.909	<0.001	Summer term has lower vegetarian sales than spring.	Spring	27.3	Summer	24.1
Autumn term	0.830	0.784, 0.878	<0.001	Autumn term has lower vegetarian sales than spring.	Spring	27.3	Autumn	23.8
Meal	1.087	1.037, 1.139	<0.001	Dinner has higher vegetarian sales than lunch.	Lunch	24.1	Dinner	25.7
Mean temperature	1.011	1.005, 1.016	<0.001	Warmer temperatures had higher vegetarian sales.	5ºC	23.2	15ºC	25.1
Veg NonVeg price differential	1.475	1.224, 1.777	<0.001	Meals with relatively cheaper vegetarian options had higher vegetarian sales.	£0.05	23.1	£0.50	26.3
Tuesday	1.130	1.060, 1.205	<0.001	Tuesdays and Thursdays had higher vegetarian sales than Monday. Wednesdays' and Fridays' vegetarian sales do not differ significantly from Mondays'.	Mon	23.1	Tue	25.4
Wednesday	1.056	0.995, 1.121	0.073		-	-	Wed	24.1
Thursday	1.196	1.124, 1.272	<0.001		-	-	Thu	26.4
Friday	0.953	0.892, 1.018	0.153		-	-	Fri	22.3
Week 2	1.210	1.111, 1.318	<0.001	Weeks 2, 4, 5 and 8 had higher vegetarian sales than Week 1. Weeks 3, 6, 7, 9, 10 and 11 week do not had significantly different vegetarian sales than Week 1.	Week 1	21.8	Week 2	25.2
Week 3	1.058	0.971, 1.153	0.198		-	-	Week 3	22.8
Week 4	1.097	1.008, 1.194	0.032		-	-	Week 4	23.4
Week 5	1.140	1.045, 1.244	0.003		-	-	Week 5	24.1
Week 6	1.009	0.923, 1.103	0.846		-	-	Week 6	21.9
Week 7	1.034	0.950, 1.125	0.440		-	-	Week 7	22.4
Week 8	1.185	1.076, 1.304	<0.001		-	-	Week 8	24.8
Week 9 (Spring and Autumn term)	1.046	0.940, 1.162	0.408		-	-	Week 9	22.6
May Week (Summer term only)	1.149	0.942, 1.310	0.172		-	-	Week 10	24.2
Grad Week (Summer term only)	1.111	0.940, 1.400	0.210		-	-	Week 11	23.6

Table B6: Best model for vegetarian sales at College B. VegSales ~ VegAvailPercent + TotalOptionsAvailable + Term + Meal + MeanTemp + VegNonVegPriceDifferential + Day + Week. AIC=2146.7, log-likelihood=-1052.3, McFadden's pseudo R2 = 0.393. Conditions used to generate predictions: VegAvailPercent=25, TotalOptionsAvailable=4, Term=Summer, Meal=Lunch, MeanTemp=10, VegNonVegPriceDifferential=0.2, Day=Wed, Week=5. Effect size calculated by taking the exponential of the model estimate.

Variable	**Effect size**	**Effect size 95% CIs**	**p-value**	**Narrative**	**Example value**	**Predicted veg sales (%)**	**Example value**	**Predicted veg sales (%)**
Veg Availability (%)	1.032	1.029, 1.034	<0.001	Meals with higher vegetarian availability had higher vegetarian sales.	25	18.4	50	32.9
Total meals sold	NA	NA	NA	Not included in best model.	100	NA	200	NA
Total options available	1.099	1.060, 1.139	<0.001	Mealtimes with more total options had higher vegetarian sales.	3	17.0	5	19.9
Summer term	1.163	1.064, 1.272	<0.001	Summer term has higher vegetarian sales than spring.	Spring	16.2	Summer	18.4
Autumn term	1.402	1.306, 1.504	<0.001	Autumn term has higher vegetarian sales than spring.	Spring	16.2	Autumn	21.4
Meal	1.209	1.148, 1.273	<0.00 1	Dinner has higher vegetarian sales than lunch.	Lunch	18.4	Dinner	21.4
Mean temp	0.992	0.985, 0.999	0.0254	Warmer temperatures had lower vegetarian sales.	5°C	19.0	15°C	17.8
Veg NonVeg price differential	0.327	0.207, 0.517	<0.001	Meals with relatively cheaper vegetarian options had lower vegetarian sales.	£0.05	21.1	£0.50	13.9
Tuesday	0.986	0.909, 1.069	0.726	Tuesdays did not have significantly different vegetarian sales to Mondays; Wednesdays and Fridays had higher vegetarian sales, and Thursdays lower, than Mondays.	Mon	16.1	Tue	15.9
Wednesday	1.173	1.083, 1.271	<0.001		-	-	Wed	18.4
Thursday	0.880	0.812, 0.954	<0.01		-	-	Thu	14.5
Friday	1.098	1.010, 1.192	0.027		-	-	Fri	17.4
Week 2	1.078	0.965, 1.204	0.181	Weeks 2 and 10 did not have significantly different vegetarian sales from Week 1, Weeks 3, 4, 5, 6, 7, 8 and 9 had higher vegetarian sales than Week 1.	Week 1	15.0	Week 2	16.0
Week 3	1.153	1.033, 1.286	0.011		-	-	Week 3	16.9
Week 4	1.148	1.029, 1.282	0.0138		-	-	Week 4	16.9
Week 5	1.275	1.141, 1.425	<0.001		-	-	Week 5	18.4
Week 6	1.216	1.085, 1.364	<0.001		-	-	Week 6	17.7
Week 7	1.163	1.043, 1.296	<0.01		-	-	Week 7	17.1
Week 8	1.261	1.123, 1.417	<0.001		-	-	Week 8	18.2
Week 9 (Spring and Autumn term)	1.209	1.069, 1.366	<0.01		-	-	Week 9	17.6
May Week (Summer term only)	1.171	0.921, 1.482	0.192		-	-	Week 10	17.2

Study 1: Percentage of vegetarian meals bought by diners

Table B7: Levels of vegetarian meal consumption during the study period (2017) and the previous term (autumn 2016) used to calculate prior levels of vegetarian meal consumption.

		College A		College B	
		Autumn term 2016	**2017 terms**	**Autumn term 2016**	**2017 terms**
All diners	Number of diners	940	1394	495	746
Diners who bought 10 or more meals	Number of diners	605	1013	227	565
	Omnivores, vegetarians and carnivores				
	Number of obligate vegetarians, (vegetarian =100%)	12	6	7	14
	Number of omnivores	533	970	144	496
	Number of obligate carnivores, (vegetarian =0%)	60	37	76	55
	Percentage of vegetarian meals bought by individual diners				
	Lower quartile	7.7%	10.8%	0%	6.3%
	Median	18.9%	21.4%	7.1%	16.4%
	Mean	26.9%	28.3%	17.0%	24.9%
	Upper quartile	36.4%	37.9%	22.7%	32.6%

Study 1: Data included in individual-level analyses

Table B8: Number of cafeteria visits, meals bought and diners in the individual-level data included in analyses. We used a binomial ("VegModel") variable, representing each cafeteria visit made by identifiable diners, to analyse the data: if one or more vegetarian meals were bought at one mealtime this was coded as 1, and 0 for one or more meat meals. If a diner bought a vegetarian meal(s) and a meat meal(s) at one meal time this was coded as NA and excluded from the analysis.

		College A			**College B**		
Data type	**Data**	**Cafeteria visits**	**Meals bought**	**Diners**	**Cafeteria visits**	**Meals bought**	**Diners**
Aggregate data	Data from both guests and identifiable diners	NA	51,251	NA	NA	35,681	NA
Individual-level data	All data	43,751	46,109	1,394	31,956	34,191	746
	Data with a prior-level of vegetarian meals consumption value	33,180	34,804	597	19,950	21,514	222
	Data with a VegModel variable	43,052	44,568	1,386	31,488	33,147	741
	Data included in analysis (values for prior-level of vegetarian meal consumption and VegModel variable)	32,687	33,729	597	19,663	20,856	222

Study 1: Best models for likelihood of choosing a vegetarian meal - individual-level data

Table B9: College A, best model for likelihood of selecting a vegetarian meal. VegModelVariable ~ (VegAvailPercent*PriorVegConsumptionQuartile) + TotalMealsSold + TotalOptionsAvailable + Term + Meal + MeanTemp + Day + Week + (1|CardUser). AIC= 29499.7, log-likelihood= -14719.8. Conditions used to generate predictions: VegAvailPercent=25, TotalMeals=180; TotalOptionsAvailable=4; Term=Easter; Meal=Lunch; Mean temp=10; VegNonVegPriceDiff=£0.20; Day=Wed; Week=5; Vegetarian consumption quartiles weighted equally. Effect size calculated by taking the exponential of the model estimate.

Variable	Effect size	Effect size 95% CIs	p-value	Narrative	Example value	Likelihood of selecting a veg meal	Example value	Likelihood of selecting a veg meal
Veg Availability (%)	1.037	1.031, 1.042	<0.001	Likelihood of selecting a vegetarian meal increased as vegetarian availability increased. The likelihood of the Most Vegetarian quartile selecting a vegetarian meal > MoreVeg > LessVeg > LeastVeg.	25	0.605	50	0.791
Quartile-MoreVeg	0.174	0.128, 0.237	<0.001		25	0.221	50	0.426
Quartile-LessVeg	0.095	0.069, 0.131	<0.001		25	0.137	50	0.299
Quartile-LeastVeg	0.032	0.023, 0.045	<0.001		25	0.062	50	0.181
VegAvail:MoreVeg	1.002	0.995, 1.010	0.522	Only the Least Vegetarian quartile has a stronger response to increasing vegetarian availability than the MostVeg.	NA	NA	NA	NA
VegAvail:LessVeg	1.003	0.996, 1.011	0.382		NA	NA	NA	NA
VegAvail:LeastVeg	1.012	1.004, 1.020	0.004		NA	NA	NA	NA
Total meals sold	1.002	1.001, 1.003	<0.001	Likelihood of selecting a vegetarian meal increased as more meals were sold.	100	0.181	250	0.231
Total options available	0.952	0.922, 0.983	0.002	Lower likelihood of selecting a vegetarian when there were more total options.	3	0.215	5	0.199
Summer term	0.821	0.735, 0.918	<0.001	Higher likelihood of selecting a vegetarian meal in Spring term than Summer and Autumn.	Spring	0.241	Summer	0.207
Autumn term	0.779	0.710, 0.854	<0.001		-		Autumn	0.198
Meal	1.155	0.797, 0.943	<0.001	Higher likelihood of selecting a vegetarian meal at lunch than dinner.	Lunch	0.207	Dinner	0.184
Mean temp	1.010	1.001, 1.019	0.030	Higher likelihood of selecting a vegetarian meal at higher ambient temperatures.	5ºC	0.198	15ºC	0.215
Veg NonVeg price differential	1.779	1.359, 2.343	<0.001	Higher likelihood of selecting a vegetarian meal when they are relatively cheaper compared to meat meals	£0.05	0.193	£0.50	0.237
Tuesday	1.270	1.156, 1.394	<0.001	Tuesdays and Thursdays had higher likelihoods of selecting a vegetarian meal than Mons. No significant difference in likelihood between Mondays, Wednesdays and Fridays.	Mon	0.201	Tue	0.242
Wednesday	1.035	0.947, 1.130	0.449		-	-	Wed	0.207
Thursday	1.336	1.218, 1.464	<0.001		-	-	Thu	0.252
Friday	0.896	0.810, 0.987	0.030		-	-	Fri	0.184
Week 2	1.237	1.092, 1.401	<0.001	Weeks 3, 4, 6, 7, 9 and 10 did not have significantly different likelihoods of selecting a vegetarian meal than Week 1; Weeks 2, 5, 8 and 11 had higher vegetarian sales than Week 1.	Week 1	0.183	Week 2	0.217
Week 3	1.082	0.953, 1.230	0.228		-	-	Week 3	0.195
Week 4	1.019	0.900, 1.155	0.770		-	-	Week 4	0.186
Week 5	1.162	1.018, 1.328	0.027		-	-	Week 5	0.207
Week 6	1.009	0.882, 1.158	0.894		-	-	Week 6	0.185
Week 7	0.976	0.860, 1.109	0.703		-	-	Week 7	0.180
Week 8	1.232	1.062, 1.431	0.006		-	-	Week 8	0.216
Week 9	1.105	0.935, 1.304	0.242		-	-	Week 9	0.198
May Week (Summer term only)	1.223	0.939, 1.600	0.138		-	-	Week 10	0.215
Grad Week (Summer term only)	1.353	1.002, 1.832	0.049		-	-	Week 11	0.233

Table B10: College B, best model for likelihood of selecting a vegetarian meal. VegModelVariable ~ (VegAvailPercent*PriorVegConsumptionQuartile) + TotalOptionsAvailable + Term + Meal + MeanTemp + VegNonVegPriceDifferential + Day + Week + (1|CardUser). AIC=12906.6, log-likelihood= -6426.3. Conditions used to generate predictions: VegAvailPercent=25, TotalOptionAvailables=4; Term=Easter; Meal=Lunch; VegNonVegPriceDiff=£0.20; Day=Wed; Week=5; Vegetarian consumption quartiles weighted equally. Effect size calculated by taking the exponential of the model estimate.

Variable	Effect size	Effect size 95% CIs	p-value	Narrative	Example value	Likelihood of selecting a veg meal	Example value	Likelihood of selecting a veg meal
Veg Availability (%)	1.030	1.023, 1.037	<0.001	Likelihood of selecting a vegetarian meal increased as vegetarian availability increased. The likelihood of the Most Vegetarian quartile selecting a vegetarian meal > MoreVeg > LessVeg > LeastVeg.	25	0.517	50	0.692
Quartile-MoreVeg	0.059	0.030, 0.116	<0.001		25	0.086	50	0.227
Quartile-LessVeg	0.031	0.015, 0.067	<0.001		25	0.052	50	0.159
Quartile-LeastVeg	0.012	0.006, 0.024	<0.001		25	0.023	50	0.082
VegAvail:MoreVeg	1.016	1.007, 1.025	<0.001	All other quartiles had a stronger response to increasing vegetarian availability than the MostVeg quartile.	NA	NA	NA	NA
VegAvail:LessVeg	1.020	1.010, 1.030	<0.001		NA	NA	NA	NA
VegAvail:LeastVeg	1.024	1.014, 1.034	<0.001		NA	NA	NA	NA
Total meals sold	NA	0.997, 1.141	NA	Not included in best model	100	NA	250	NA
Total options available	1.067	0.103, 0.545	0.061	Higher likelihood of selecting a vegetarian when there were more total options.	3	0.091	5	0.102
Summer term	1.106	0.983, 1.245	0.094	Higher likelihood of selecting a vegetarian meal in Autumn term than Spring term, no significant difference between Spring and Summer terms.	Spring	0.088	Summer	0.097
Autumn term	1.397	1.229, 1.587	<0.001		-	-	Autumn	0.119
Meal	1.114	1.007, 1.233	0.036	Higher likelihood of selecting a vegetarian meal at dinner than lunch.	Lunch	0.097	Dinner	0.107
Mean temp	NA	NA	NA	Not included in best model	5ºC	-	15ºC	-
Veg NonVeg price differential	0.237	0.103, 0.545	<0.001	Lower likelihood of selecting a vegetarian meal when they were relatively cheaper compared to meat meals	£0.05	0.117	£0.50	0.065
Tuesday	1.145	0.991, 1.323	0.067	No difference for likelihood of selecting a vegetarian meal on Tuesdays and Fridays, higher likelihood on Wednesdays and lower likelihood on Thursdays, compared to Mondays.	Mon	0.071	Tue	0.080
Wednesday	1.408	1.222, 1.623	<0.001		-	-	Wed	0.097
Thursday	0.846	0.731, 0.980	0.026		-	-	Thu	0.060
Friday	1.136	0.980, 1.317	0.091		-	-	Fri	0.079
Week 2	1.273	1.053, 1.539	0.013	Higher likelihood of selecting a vegetarian meal during Weeks 2, 3, 5, 6, 7 and 8 compared to Week 1. No difference in likelihood of selecting a vegetarian meal in Weeks 4, 9 and May Week compared to Week 1.	Week 1	0.077	Week 2	0.096
Week 3	1.281	1.064, 1.542	0.009		-	-	Week 3	0.096
Week 4	1.147	0.948, 1.386	0.157		-	-	Week 4	0.087
Week 5	1.284	1.067, 1.545	0.008		-	-	Week 5	0.097
Week 6	1.392	1.151, 1.683	<0.001		-	-	Week 6	0.104
Week 7	1.275	1.054, 1.544	0.013		-	-	Week 7	0.096
Week 8	1.459	1.199, 1.776	<0.001		-	-	Week 8	0.108
Week 9 (Spring and Autumn term)	1.177	0.939, 1.475	0.158		-	-	Week 9	0.089
May Week (Summer term only)	1.05	0.720, 1.530	0.801		-	-	Week 10	0.080

Study 1: Best models for total sales

Table B11: College A, best model for total sales. TotalMealsSold ~ VegAvailPercent + TotalOptionsAvailable + Term + Meal + Day + Week.
AIC=2788.1, log-likelihood= -1373.0, Adjusted R^2=0.425. Conditions used to generate predictions: VegAvailPercent=25; TotalOptionsAvailable=4, Term=Easter, Meal=Lunch, Day=Wed, Week=5.
Effect size calculated by adding the model estimate to the intercept (162) and dividing by the intercept.

Variable	Effect size	Effect size CIs	p-value	Narrative	Example value	Predicted total sales	Example value	Predicted total sales
Veg Availability (%)	1.001	0.997, 1.003	0.707	Vegetarian availability had no significant effect on total sales.	25	216.8	50	219.2
Total options available	1.064	1.041, 1.078	<0.001	Higher total sales when there were more total options available, an average of 10.3 additional meals sold for every additional meal option.	3	206.5	5	216.8
Summer term	1.157	1.097, 1.195	<0.001	Higher total sales in Summer term than Spring term.	Spring	191.4	Summer	216.8
Autumn term	1.011	0.916, 1.072	0.783	No difference in total sales between Autumn term and Spring term.	-	-	Autumn	193.1
Meal	1.140	1.100, 1.166	<0.001	On average 22.7 more meals sold at dinner than lunch.	Lunch	216.8	Dinner	239.5
Mean temperature	NA	0.698, 0.965	NA	Not included in best model	5°C	NA	15°C	NA
Veg NonVeg price differential	NA	0.876, 1.077	NA	Not included in best model	£0.05	NA	£0.50	NA
Tuesday	0.861	0.765, 1.008	0.005	Tuesday and Friday had lower total sales than Monday; Wednesday and Thursday did not have significantly different total sales from Monday.	Mon	217.0	Tue	194.4
Wednesday	0.999	0.648, 0.932	0.979		-		Wed	216.8
Thursday	0.913	0.676, 1.014	0.080		-		Thu	202.9
Friday	0.821	0.741, 1.055	<0.001		-		Fri	188.0
Week 2	0.882	0.679, 1.013	0.087	Weeks 2, 3, 4, 5 and 7 did not have significantly different total sales from Week 1; Weeks 6, 8, 9, May Week and Grad Week had significantly lower total sales than Week 1.	Week 1	231.2	Week 2	212.0
Week 3	0.933	0.717, 1.036	0.325		-	-	Week 3	220.2
Week 4	0.882	0.609, 0.966	0.084		-	-	Week 4	212.1
Week 5	0.911	0.722, 1.041	0.190		-	-	Week 5	216.8
Week 6	0.827	0.450, 0.869	0.011		-	-	Week 6	203.0
Week 7	0.916	0.439, 0.885	0.217		-	-	Week 7	217.6
Week 8	0.706	-0.061, 0.641	<0.001		-	-	Week 8	183.4
Week 9 (Spring and Autumn term)	0.711	-0.403, 0.434	<0.001		-	-	Week 9	184.3
May Week 10 (Summer term)	0.366	0.674, 1.308	<0.001		-	-	Week 10	128.3
Week 11 (Summer term)	0.107	1.041, 1.078	<0.001		-	-	Week 11	86.3

Table B12: College B, best model for total sales. TotalMealsSold ~ VegAvailPercent + Day + Week
AIC=2378.3, log-likelihood= -1173.1, Adjusted R^2=0.421. Conditions used to generate predictions: VegAvailPercent=25, Day=Wed, Week=5. Effect size calculated by adding the model estimate to the intercept (166) and dividing by the intercept.

Variable	Effect size	Effect size 95% CIs	p-value	Narrative	Example value	Predicted total sales	Example value	Predicted total sales
Veg Availability (%)	0.998	0.997, 0.999	<0.001	Significantly fewer main meals were sold as vegetarian availability increased.	25	137.6	50	127.8
Total options available	NA	NA	NA	Not included in best model	3	NA	5	NA
Summer term	NA	NA	NA	Not included in best model	Spring	NA	Summer	NA
Autumn term	NA	NA	NA	Not included in best model	Spring	NA	Autumn	NA
Meal	NA	NA	NA	Not included in best model	Lunch	NA	Dinner	NA
Mean temperature	NA	NA	NA	Not included in best model	5°C	NA	15°C	NA
Veg NonVeg price differential	NA	NA	NA	Not included in best model	£0.05	NA	£0.50	NA
Tuesday	0.927	0.872, 0.976	0.003	Thursday did not have significantly different sales from Mondays. Tuesdays, Wednesdays and Fridays had significantly lower total sales than Mondays.	Mon	157.7	Tue	145.6
Wednesday	0.879	0.820, 0.931	<0.001		-		Wed	137.6
Thursday	0.963	0.910, 1.009	0.120		-		Thu	151.5
Friday	0.863	0.802, 0.917	<0.001		-		Fri	135.0
Week 2	0.976	0.906, 1.036	0.449	Weeks 2, 3, 4, 5, 6 and 7 did not have significantly different sales compared to Week 1. Weeks 8, 9, May Week and Grad Week had lower total sales than Week 1.	Week 1	136.4	Week 2	132.3
Week 3	1.004	0.937, 1.062	0.910		-	-	Week 3	137.0
Week 4	0.990	0.922, 1.049	0.747		-	-	Week 4	134.7
Week 5	1.007	0.941, 1.066	0.816		-	-	Week 5	137.6
Week 6	0.983	0.914, 1.044	0.603		-	-	Week 6	133.6
Week 7	0.982	0.913, 1.042	0.565		-	-	Week 7	133.3
Week 8	0.895	0.820, 0.961	0.001		-	-	Week 8	118.9
Week 9 (Spring and Autumn term)	0.924	0.844, 0.995	0.035		-	-	Week 9	123.8
May Week (Summer term)	0.532	0.398, 0.648	<0.001		-	-	May Week	58.5

Study 2: Example menus

Table B13: College C, control menu with no change to the number of vegetarian options on offer (usually one). (v)=vegetarian, (ve)=vegan. Although the menus present 4 options, the number of meals served at the cafeteria often varied.

Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Brocolli and brie quiche (v)	Welsh Glamorgan vegetarian sausages with onion gravy (v)	Sundried tomato gnocchi with rocket (v)	Beef tomatoes stuffed with coconut vegetables (ve)	Vegetable jambalaya (ve)
Herby seafood crumble	Roast trout with spinach, sage and prosciutto	Hake with braised artichokes, peas and bacon	Catfish with chipotle and ancho chilli recado	Deep fried fish with tartar sauce
Breaded chicken with garlic and parsley butter	Denham farm state game and red wine pie	Sweet potato and chicken curry	Lamb and root vegetable cobbler	Chicken, mushroom and tarragon pie with shortcrust pastry
Vegetable chimichangers (ve)	Today's pasta with choice of two sauces	Spicy chicken pasty with sticky pickle	Today's pasta with choice of two sauces	Pork fajita

Table B14: College C, experimental menu with two designated vegetarian options. (v)=vegetarian, (ve)=vegan. Although the menus present 4 options, the number of meals served at the cafeteria often varied.

Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Agadeshi with buckwheat noodles (ve)	Mediterranean stuffed peppers (ve)	Roasted pepper and applewood smoked cheese quiche (v)	Porcini mushroom bolognaise with wholemeal spaghetti (v)	Lentil and barley burger with spicy fruit salsa (ve)
Fish pie with a cheese and pretzel crust	Smoked haddock fish cakes with creamed leeks	Pan roasted salmon with three tomatoes	Fish and prawn pasties	Deep fried fish with tartar sauce
Chilli con carne finished with 70% dark chocolate	Chicken, smoked pancetta and bean stew with crispy sage	Spicy beef South African curry	Crispy fennel pork belly with herb salsa	Harissa and lime yoghurt lamb steak
Gluten free pasta with roasted red pepper and tomoato sauce (ve)	Korean noodles with garlic and ginger stir-fried vegetables and noodles (v)	Gluten free pasta with wild mushroom and mascarpone sauce (v)	Blackened aubergine veggie chilli (ve)	Gluten free pasta with roasted butternut (ve)

Study 2: Frequency of vegetarian and total options

Table B15: Frequency of vegetarian options by the total options available and by experimental allocation, observations made at 44 lunchtimes.

	Total Options Available				*Experimental allocation of number of vegetarian options*	
Vegetarian options available	*4*	*5*	*6*		*1 (Control)*	*2 (Experimental)*
1	5	2	1		8	0
1.5	4	8	0		9	3
2	13	11	0		4	20

Study 2: Best model for vegetarian sales - aggregate data

Table B16: Best model for vegetarian sales at College C. VegSales~VegAvailPercent+TotalMealsSold+MeanTemp+VegNonVegPriceDifferential+Day+Week. AIC = 464.6, log-likelihood = -212.3, McFadden's pseudo R^2 = 0.318. Conditions used to generate predictions: VegAvailPercent=25, Total meals sold=150, Total options available=4, MeanTemp=10, VegNonVegPriceDifferential=0.2, Day=Wed, Week=5. Effect size calculated by taking the exponential of the model estimate.

Variable	Effect size	Effect size 95% CIs	p-value	Narrative	Example value	Predicted veg sales (%)	Example value	Predicted veg sales (%)
Veg Availability (%)	1.018	1.007, 1.028	<0.001	Meals with higher vegetarian availability had higher vegetarian sales.	25	19.1	50	26.9
Total meals sold	1.010	1.005, 1.015	<0.001	Mealtimes with more meals sold had higher vegetarian sales.	100	12.5	200	28.0
Total options available	1.101	0.949, 1.277	0.205	Mealtimes with more total options had lower vegetarian sales.	3	17.7	5	20.6
Mean temperature	0.938	0.912, 0.966	<0.001	Days with colder temperatures had higher vegetarian sales.	5°C	24.5	15°C	14.7
Veg NonVeg price differential	0.374	0.182, 0.766	0.007	Mealtimes with relatively cheaper vegetarian options had lower vegetarian sales.	£0.05	21.5	£0.50	15.0
Day: Tue	1.693	1.380, 2.078	<0.001	Tuesdays and Wednesdays had higher vegetarian sales than Mondays. Thursdays' and Fridays' vegetarian sales do not differ significantly from Mondays'.	Mon	12.5	Tue	19.5
Day: Wed	1.650	1.343, 2.029	<0.001		-		Wed	19.1
Day: Thu	1.167	0.960, 1.420	0.123		-		Thu	14.3
Day: Fri	1.048	0.843, 1.303	0.675		-		Fri	13.1
Week 2	0.955	0.537, 1.712	0.876	Week 9 had lower vegetarian sales than Week 1. All other weeks did not have significantly different vegetarian sales than Week 1.	Week 1	15.7	Week 2	15.1
Week 3	0.924	0.498, 1.740	0.804				Week 3	14.7
Week 4	1.409	0.853, 2.382	0.189				Week 4	20.8
Week 5	1.266	0.803, 2.052	0.323				Week 5	19.1
Week 6	1.127	0.685, 1.894	0.644				Week 6	17.4
Week 7	0.855	0.512, 1.458	0.556				Week 7	13.8
Week 8	1.130	0.690, 1.894	0.635				Week 8	17.4
Week 9	0.585	0.352, 0.994	0.043				Week 9	9.8
Week 10 (Christmas holidays)	1.186	0.715, 2.007	0.516				Week 10	18.1
Week 11 (Christmas holidays)	1.229	0.715, 2.157	0.463				Week 11	18.7

Study 2: Percentage of vegetarian meals bought by diners

Table B17: College C, levels of vegetarian meal consumption during the study period (lunches autumn term 2017) and the term (lunches and dinners summer term 2017) used to calculate prior levels of vegetarian meal consumption.

		Summer term 2017	**Autumn term 2017**
All diners	Number of diners	481	491
Diners who bought 10 or more meals	Number of diners	224	314
	Omnivores, vegetarians and carnivores		
	Number of obligate vegetarians, (vegetarian =100%)	0	1
	Number of omnivores	194	283
	Number of obligate carnivores, (vegetarian =0%)	30	30
	Percentage of vegetarian meals bought by individual diners		
	Lower quartile	5.9%	6.3%
	Median	12.5%	14.7%
	Mean	19.8%	19.9%
	Upper quartile	27.0%	26.9%

Study 2: Data included in individual-level analyses

Table B18: College C, number of cafeteria visits, meals bought and diners in the individual-level data included in analyses. We used a binomial (“VegModel”) variable, representing each cafeteria visit made by identifiable diners, to analyse the data: if one or more vegetarian meals were bought at one mealtime this was coded as 1, and 0 for one or more meat meals. If a diner bought a vegetarian meal(s) and a meat meal(s) at one meal time this was coded as NA and excluded from the analysis.

Data type	**Data**	**Cafeteria visits**	**Meals bought**	**Diners**
Aggregate data	Data from both guests and identifiable diners	NA	7712	NA
Individual-level data	All data	4565	5153	491
	Data with a prior-level of vegetarian meals consumption value	1661	1977	121
	Data with a VegModel variable	4358	4716	482
	Data included in analysis (values for prior-level of vegetarian meal consumption and VegModel variable)	1585	1718	121

Study 2: Best models for individual-level analyses

Table B19: College C, best model for likelihood of selecting a vegetarian meal. VegModelVariable~ (VegAvail *PriorVegConsumptionQuartile) +ObservedTotalOptionsAvailable+ TotalMealsSold+MeanTemp+Day+Week+(1|CardUser). AIC=1341.5, log-likelihood=-644.8. Conditions used to generate predictions: VegAvail=25, TotalMealsSold=150, TotalOptionsAvailable=4, MeanTemp=10, Day=Wed, Week=5, Vegetarian consumption quartiles weighted equally. Effect size calculated by taking the exponential of the model estimate.

Variable	Effect size	Effect size 95% CIs	p-value	Narrative	Example value	Likelihood of selecting a veg meal	Example value	Likelihood of selecting a veg meal
Veg Availability (%)	1.000	0.967, 1.034	0.983	Likelihood of selecting a vegetarian meal increased as vegetarian availability increased. The likelihood of the Most Vegetarian quartile selecting a vegetarian meal > MoreVeg > LessVeg > LeastVeg.	25	0.350	50	0.348
Quartile-MoreVeg	0.110	0.025, 0.493	0.004		25	0.101	50	0.173
Quartile-LessVeg	0.038	0.006, 0.236	<0.001		25	0.039	50	0.072
Quartile-LeastVeg	0.011	0.001, 0.086	<0.001		25	0.021	50	0.070
VegAvail:MoreVeg	1.026	0.989, 1.063	0.168	Only the Least Vegetarian quartile had a stronger response to increasing vegetarian availability than the MostVeg.	NA		NA	
VegAvail:LessVeg	1.027	0.983, 1.074	0.234		NA		NA	
VegAvail:LeastVeg	1.053	1.002, 1.106	0.041		NA		NA	
Total meals sold	1.016	1.002, 1.030	<0.001	Likelihood of selecting a vegetarian meal increased as more meals are sold.	100	0.036	200	0.159
Observed total options available	1.219	0.850, 1.749	0.273	Higher likelihood of selecting a vegetarian meal when there are more total options.	3	0.065	5	0.093
Mean temp	0.880	0.812, 0.955	0.002	Lower likelihood of selecting a vegetarian meal at higher ambient temperatures.	5ºC	0.138	15ºC	0.043
Veg NonVeg price differential	NA	NA	NA	Not included in best model.	£0.05	NA	£0.50	NA
Tuesday	2.109	1.252, 3.550	0.005	Tuesdays and Wednesdays had higher likelihood of selecting a vegetarian meal than Mondays. No significant difference in likelihood between Mondays, Thursdays and Fridays.	Mon	0.042	Tue	0.084
Wednesday	1.933	1.179, 3.171	0.010		-		Wed	0.078
Thursday	1.101	0.665, 1.822	0.710		-		Thu	0.046
Friday	0.743	0.423, 1.304	0.292		-		Fri	0.031
Week 2	1.165	0.290, 4.684	0.830	Lower likelihood of selecting a vegetarian meal in Week 9 than Week 1, no significant difference between Week 1 and other weeks.	Week 1	0.107	Week 2	0.122
Week 3	0.445	0.087, 2.267	0.229		-		Week 3	0.051
Week 4	1.061	0.299, 3.766	0.920		-		Week 4	0.113
Week 5	0.706	0.224, 2.230	0.541		-		Week 5	0.078
Week 6	0.567	0.161, 1.996	0.320		-		Week 6	0.064
Week 7	0.467	0.129, 1.689	0.200		-		Week 7	0.053
Week 8	0.811	0.240, 2.738	0.713		-		Week 8	0.088
Week 9	0.181	0.049, 0.673	0.008		-		Week 9	0.021
Week 10 (Christmas holidays)	0.868	0.246, 3.054	0.825		-		Week 10	0.094
Week 11 (Christmas holidays)	0.793	0.198, 3.178	0.736		-		Week 11	0.087

Study 2: Best models for total sales

Table B20: College C, best model for total sales. TotalMealsSold ~ VegAvailPercent + Week. AIC= 384.3, log-likelihood =-179.2 , Adjusted R^2 = 0.679. Conditions used to generate predictions: VegAvail=25; Week=4. Effect size calculated by adding the model estimate to the intercept (160) and dividing by the intercept.

Variable	Effect size	Effect size 95% CIs	p-value	Narrative	Example value	Predicted total sales	Example value	Predicted total sales
Veg Availability (%)	1.000	0.993, 1.004	0.942	Vegetarian availability had no effect on total meals sold.	25	188.0	50	188.8
Total options available	NA	NA	NA	Not included in best model.	NA		NA	
Mean temperature	NA	NA	NA	Not included in best model.	NA		NA	
Veg NonVeg price differential	NA	NA	NA	Not included in best model.	NA		NA	
Tuesday	NA	NA	NA	Not included in best model.	Mon		Tue	
Wednesday	NA	NA	NA		-		Wed	
Thursday	NA	NA	NA		-		Thu	
Friday	NA	NA	NA		-		Fri	
Week 2	1.022	0.679, 1.223	0.865	Weeks 3 had significantly higher, and Week 11 significantly lower, total sales than Week 1. Weeks 2, 3, 4, 5, 6, 7, 8, 9 and 10 did not have significantly different total sales from Week 1.	Week 1	160.9	Week 2	164.4
Week 3	1.325	1.082, 1.468	0.018				Week 3	212.9
Week 4	1.170	0.901, 1.327	0.164				Week 4	188.0
Week 5	1.069	0.779, 1.239	0.549				Week 5	171.9
Week 6	1.231	0.999, 1.367	0.051				Week 6	197.9
Week 7	1.165	0.891, 1.325	0.181				Week 7	187.2
Week 8	1.155	0.882, 1.315	0.202				Week 8	185.7
Week 9	1.106	0.828, 1.268	0.363				Week 9	177.8
Week 10 (Christmas holidays)	0.884	0.512, 1.102	0.340				Week 10	142.2
Week 11 (Christmas holidays)	0.743	0.324, 0.988	0.038				Week 11	119.7

Study 2: Best model for vegetarian sales at dinner

Table B21: College C, Best model for vegetarian sales at dinner, only including meals bought by diners who attended 1 or more lunchtimes during the autumn term. VegSales ~ ExperimentalCondition + MenuVegAvail + TotalMealsSold + MeanTemp + VegNonVegPriceDifferential+Day. AIC=424.4 , log-likelihood=-202.2 , McFadden's pseudo R^2 =0.246 . Conditions used to generate predictions: Experimental Condition=Control, VegAvail=25, TotalMealsSold=100, MeanTemp=10, VegNonVegPriceDifferential=0.2, Day=Wed. The total number of options served was not observed at dinnertimes, and therefore relative vegetarian availability was calculated from the listed menu options, however the actual options served may have differed. Effect size calculated by taking the exponential of the model estimate.

Variable	Effect size	Effect size 95% CIs	p-value	Narrative	Example value	Predicted veg sales (%)	Example value	Predicted veg sales (%)
Condition: Experimental week	0.953	0.795, 1.141	0.601	Vegetarian sales at dinners in experimental and control weeks were not significantly different.	Control	8.0	Experimental	7.6
Veg Availability (%) listed on menu	1.000	1.000, 1.000	<0.001	Vegetarian sales increased with the vegetarian availability listed on the menu.	25	8.0	50	15.7
Total meals sold	1.007	1.002, 1.011	0.005	Dinners with higher sales sold relatively more vegetarian options.	80	7.0	120	9.0
Total options available	NA	NA	NA	The menu always listed 4 options (although in reality sometimes 5 or 6 options were sometimes served).	NA		NA	
Mean temperature	1.048	1.026, 1.070	<0.001	Days with higher temperatures had higher vegetarian sales.	5ºC	6.4	15ºC	9.8
Veg NonVeg price differential	5.247	1.067, 26.072	0.042	Mealtimes with relatively cheaper vegetarian options had higher vegetarian sales.	£0.05	6.3	£0.50	12.4
Tuesday	1.248	0.978, 1.594	0.076	Fridays and Wednesdays had lower vegetarian sales than Mondays. Thursdays' vegetarian sales were higher than Mondays' and Tuesdays' were not significantly different..	Mon	11.3	Tue	13.7
Wednesday	0.682	0.493, 0.938	0.019		-		Wed	8.0
Thursday	1.364	1.037, 1.792	0.026		-		Thu	14.7
Friday	0.602	0.376, 0.958	0.033		-		Fri	7.1

Appendix C. Supplementary Information for Chapter 4

Supplementary Information for:
Chapter 4. Price of change: does a small decrease in the relative price of a vegetarian option increase its sales?

This Appendix contains Supplementary Figures C1 to C3 and Supplementary Tables C1 to C18.

Table C1. Menu example, listed online and in the cafeteria. (v)=vegetarian, (ve)=vegan.

LUNCH	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
Vegan and gluten free	Green Thai Sweet Potato Curry (ve)	Pan fried Tofu with Spiced Black Eyed Beans (ve)	Vegetable Chow Mein with Edamne Beans (ve)	Hot and Sour Vegetable Broth with Tofu (ve)	Sweet & Sour Soy Stir Fry (ve)	[No option]
Meat main	Lamb Moussaka	Japanese Ramen Noodles with Soy Poached Chicken	Slow Braised Beef Stew With , Baby Onions , Mushrooms	Slow Roast Shoulder of Pork with Apple sauce	Catch of the day	St Catz Cheese Burger
Main course	Tandoori Spiced Chicken on Pitta with Raita	Breaded Pork With Coleslaw & Spicy Salsa	Moroccan Chicken on Flatbread with Tomato Salsa & Yoghurt Dressing	Smokey Bacon & Chicken Carbonara with Parmesan	Deep South Chicken With Sticky Glaze	Pork Chop with Mozzarella & Bacon
Vegetarian	Quorn Moussaka (v)	Japanese Ramen Noodles with Spicy Egg (v)	Feta Mint & Pea Fritarta with Tomato Chutney (v)	Nut Roast with Redcurrants & Cashews (v)	Sun Blushed Tomato, Artichoke & Edamame Bean Pasta (v)	Falafel with Avacardo Salad on Pitta Bread (v)
Fish Option	Sea trout	Rainbow trout	Cod	Coley	Cod	Coley
Dinner						
DINNER	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
Vegan	VegeTable Cheppard's Pie (ve)	Aubergine and Chick Pea Penne with Harissa (ve)	Thai Sweet Potato and Bean Stew (ve)	Chick Pea Tagine (ve)	Stir Fried Vegetables with Tofu and Noodles (ve)	[Unlisted]
Main course 1	Lamb Rogan Josh with Naan	Moroccan Spiced Chicken with Giant Cous Cous & Tzatziki	Cottage Pie	Chicken Thighs in Chasseur Sauce	Sweet & Sour Crispy Pork	Brazilian Style Grilled Lamb Steak
Main course 2	Hot Roast Pork with Apple Sauce in a Wholegrain Bap	Balsamic Glazed Minute steak with Roasted Onion & Tomato	Oak Smoaked Pork Strogganoff	Cajun Breaded Pork with Chili Coleslaw	Jerk Chicken with Rice n Pea	Beef Spaghetti Bolognaise
Main course 3	Roasted Aubergine Curry with Naan (v)	Gnocchi with Pomodoro & Basil (v)	Vegetable Cottage Pie (v)	Thai Red Vegetable and Tofu (v)	Roasted Mediterranean Vegetables with Fresh Basil & Crème Freshe (v)	Brazilian Feijoada Spicy Bean Stew (v)
Fish Option	Haddock	Sea Bass	Trout	Cod/Coley	Grilled fish of the day	Sea Bass

Figure C1: Advertised price change on a slide, "As of Monday, 29th October, the meal prices are changing a small amount to reflect the cost of ingredients". This is one slide of approximately five which rotated round on an electronic screen display outside the College's cafeteria hall.

Figure C2: A photo of the price list which is at the entrance of the college cafeterias. This is the baseline price list (Meat £2.52, Vegetarian £2.05). The blue box obscures the college name.

Table C2: Data included in the individual-level analyses: number of identifiable diners, cafeteria visits and meals bought. We used a binomial ("VegModel") variable, representing each cafeteria visit made by identifiable diners, to analyse the data: if one or more vegetarian meals were bought at one mealtime this was coded as 1, and 0 for no vegetarian meals. If a diner bought a vegetarian meal(s) and another meal type (meat, fish, vegan) at one meal time this was coded as NA and excluded from the analysis. The same logic was applied for the MeatModel variable.

Data type	Data	Diners	Cafeteria visits	Meals purchased
Aggregate data	Data from both guests and identifiable diners	NA	NA	13,840
Individual-level data	All data	626	11,729	12,603
	Data with a Prior Veg quartile value	325	5330	5722
	Data with VegModel variable and Prior Veg Quartile	324	5225	NA
	Data with MeatModel variable and Prior Veg Quartile	323	5206	NA

Table C3: Levels of vegetarian and vegan meal selection in the individual-level data during the previous term (summer 2018). Quartile thresholds of vegetarian&vegan selection from diners who bought 10 or more meals were used to assign all diners to a "PriorVeg" quartile. N represents the number of individuals in the sample For the mean vegetarian&vegan selection within each quartile, see Table C4.

Diners	Statistical summary	Vegetarian&vegan meals bought by individual diners (%)	Total number of meals purchased
All diners. N=574.	Min	0.0	1
	Lower quartile (Q1)	2.4	4
	Median	17.4	13
	Mean	28.3	19.7
	Upper quartile (Q3)	40.0	30
	Max	100.0	109
Diners who bought 10 or more meals. N=339	Min	0.0	10
	Lower quartile (Q1)	7.6	16
	Median	18.8	27
	Mean	27.1	30.8
	Upper quartile (Q3)	33.3	41
	Max	100.0	109

Table C4: Comparison of the mean vegetarian&vegan and vegetarian selection in the individual-level data across quartiles during the study term (autumn 2018) and the prior term (summer 2018).
The MostVeg quartile selected fewer vegetarian&vegan meals in autumn 2018 compared to summer 2018, the LeastVeg quartile selected more.
The mean values are calculated by taking the mean of the model variables used in the individual analyses (1s and 0s, excluding NAs). The mean overall selection is weighted towards individuals who visited the cafeteria more frequently (weights = number of visits); for the mean selection per individual, individuals are weighted equally. N represents the number of individuals in the sample.
[a] These values are reported in Methods, Data Collection and Preparation. [b] These values are the same as those reported in Table 4.

		Mean overall selection, per quartile (%)			Mean selection per individual, per quartile (%)		
Meal selection	**Quartile**	**Summer 2018: all diners. N=574**	**Summer 2018: diners present in autumn 2018. N=325**	**Autumn 2018: all diners with a prior quartile. N=325**	**Summer 2018: all diners. N=574**	**Summer 2018: diners present in autumn 2018. N=325**	**Autumn 2018: all diners with a prior quartile. N=325**
Vegetarian &vegan	MostVeg	69.9	68.7	44.8	[a]70.7	67.5	56.5
	MoreVeg	22.2	21.4	15.2	[a]21.2	21.1	17.7
	LessVeg	10.6	10.3	10.5	[a]10.7	10.1	9.8
	LeastVeg	2.1	2.3	7.6	[a]0.9	1.4	8.0
Vegetarian	MostVeg	54.5	52.8	[b]33.5	56.8	51.1	[b]44.2
	MoreVeg	16.9	16.1	[b]12.4	16.1	15.7	[b]14.8
	LessVeg	7.5	7.2	[b]8.0	7.5	7.1	[b]7.2
	LeastVeg	1.5	1.6	[b]5.6	0.7	1.0	[b]6.4

Table C5: Linear model (LM) output for total meal sales per mealtime. Effect size calculated by adding the model estimate to the intercept and dividing by the intercept. Monday is the reference categories for day of the week.

Variable	Model estimate	Effect size	Effect size 95% CIs	p-value	Narrative
Price change (Ref=Baseline)	-2.72	0.98	0.83, 1.10	0.783	Price change had no significant effect on total meal sales.
Days Since Baseline	0.06	1.00	0.99, 1.01	0.902	Total meal sales did not change with time during the baseline period.
Days Since Intervention	-0.66	1.00	0.99, 1.00	0.052	Total meal sales did not change with time during the intervention period.
Mealtime (Ref=Lunch)	-20.64	0.86	0.77, 0.94	<0.001	Dinnertimes had significantly lower sales than lunchtimes.
Mean temperature (°C)	0.08	1.00	0.99, 1.01	0.918	Total sales did not change significantly with mean ambient temperature.
Tuesday	4.93	1.03	0.91, 1.12	0.559	Tuesdays, Wednesdays, Thursdays and Fridays did not have significantly different total sales from Mondays; Saturdays had significantly lower total sales.
Wednesday	7.68	1.05	0.93, 1.14	0.369	
Thursday	-0.60	1.00	0.87, 1.09	0.943	
Friday	1.28	1.01	0.88, 1.10	0.880	
Saturday	-42.57	0.72	0.54, 0.85	<0.001	

Table C6: Generalised linear model (GLM) output for aggregate vegetarian sales (%). Effect size calculated by taking the exponential of the model estimate. Monday is the reference categories for day of the week.

Variable	Model estimate	Effect size	Effect size 95% CIs	p-value	Narrative
Price change (Ref=Baseline)	0.18	1.20	1.01, 1.42	0.036	Vegetarian sales were significantly higher after the price change.
Days Since Baseline	-0.02	0.98	0.98, 0.99	<0.001	Vegetarian sales significantly decreased with time during the baseline period.
Days Since Intervention	0.00	1.00	0.99, 1.00	0.348	Vegetarian sales did not significantly decline with time during the intervention period.
Mealtime (Ref=Lunch)	0.54	1.72	1.59, 1.87	<0.001	Dinnertimes had higher vegetarian sales than lunchtimes.
Mean temperature (°C)	-0.02	0.98	0.97, 0.99	0.007	Days with warmer temperatures had lower vegetarian sales.
Tuesday	-0.13	0.88	0.77, 1.01	0.080	No days of the week had significantly different vegetarian sales from Mondays.
Wednesday	-0.09	0.92	0.79, 1.05	0.221	
Thursday	0.04	1.04	0.9, 1.19	0.616	
Friday	-0.06	0.94	0.82, 1.08	0.402	
Saturday	0.03	1.03	0.88, 1.20	0.728	

Table C7: GLM output for aggregate meat sales (%). Effect size calculated by taking the exponential of the model estimate. Monday is the reference categories for day of the week.

Variable	Model estimate	Effect size	Effect size 95% CIs	p-value	Narrative
Price change (Ref=Baseline)	0.08	1.08	0.94, 1.24	0.298	Meat sales were not significantly higher after the price change.
Days Since Baseline	0.01	1.01	1.00, 1.01	0.142	Meat sales did not significantly decline with time during the baseline period.
Days Since Intervention	-0.01	0.99	0.99, 1.00	0.020	Meat sales significantly decreased with time during the intervention period.
Mealtime (Ref=Lunch)	-0.09	0.91	0.85, 0.98	0.010	Dinnertimes had lower meat sales than lunchtimes.
Mean temperature (°C)	0.01	1.01	0.99, 1.02	0.273	Days with warmer temperatures had higher meat sales.
Tuesday	0.09	1.09	0.97, 1.23	0.140	Tuesdays and Thursdays did not have significantly different meat sales compared to Mondays. Wednesdays and Saturdays had significantly higher meat sales than Mondays, and Fridays had significantly lower meat sales than Mondays.
Wednesday	0.13	1.14	1.01, 1.28	0.036	
Thursday	0.02	1.02	0.90, 1.15	0.788	
Friday	-0.82	0.44	0.39, 0.50	<0.001	
Saturday	0.19	1.21	1.06, 1.39	0.006	

Table C8: Generalised linear mixed model (GLMM) output for likelihood (%) of individuals selecting a vegetarian meal. Effect size calculated by taking the exponential of the model estimate. Monday is the reference categories for day of the week.

Variable	**Model estimate**	**Effect size**	**Effect size 95% CIs**	**p-value**	**Narrative**
Price change (Ref=Baseline)	0.60	1.82	1.15, 2.90	0.011	Likelihood of selecting a vegetarian meal increased after the price change for the MostVeg quartile.
Quartile- MoreVeg	-1.48	0.23	0.13, 0.39	<0.001	The likelihood of the MostVeg quartile selecting a vegetarian meal > MoreVeg > LessVeg > LeastVeg.
Quartile- LessVeg	-2.14	0.12	0.06, 0.22	<0.001	
Quartile- LeastVeg	-2.48	0.08	0.05, 0.15	<0.001	
Days Since Baseline	-0.02	0.98	0.96, 0.99	0.007	Likelihood of selecting a vegetarian meal decreased with time during the baseline period.
Days Since Intervention	-0.02	0.98	0.97, 1.00	0.019	Likelihood of selecting a vegetarian meal decreased with time during the intervention period.
Mealtime (Ref=Lunch)	0.51	1.67	1.32, 2.11	<0.001	Higher likelihood of selecting a vegetarian meal at dinnertimes than lunchtimes.
Mean temperature (^{o}C)	-0.02	0.98	0.94, 1.01	0.134	Likelihood of selecting a vegetarian meal was not significantly affected by ambient temperature.
Tuesday	-0.51	0.60	0.44, 0.83	0.002	Likelihood of selecting a vegetarian meal was not significantly different on Wednesdays, Thursdays, Fridays and Saturdays compared to Mondays. Tuesdays had significantly lower likelihood of vegetarian selection than Mondays.
Wednesday	-0.27	0.77	0.56, 1.04	0.091	
Thursday	-0.11	0.90	0.65, 1.22	0.487	
Friday	0.05	1.05	0.77, 1.44	0.747	
Saturday	-0.21	0.81	0.54, 1.21	0.313	
Price change: MoreVeg	-0.28	0.75	0.46, 1.23	0.257	MoreVeg, LessVeg and LeastVeg did not respond significantly differently to the price change compared to the MostVeg quartile.
Price change: LessVeg	-0.36	0.70	0.40, 1.21	0.201	
Price change: LeastVeg	-0.40	0.67	0.39, 1.14	0.140	

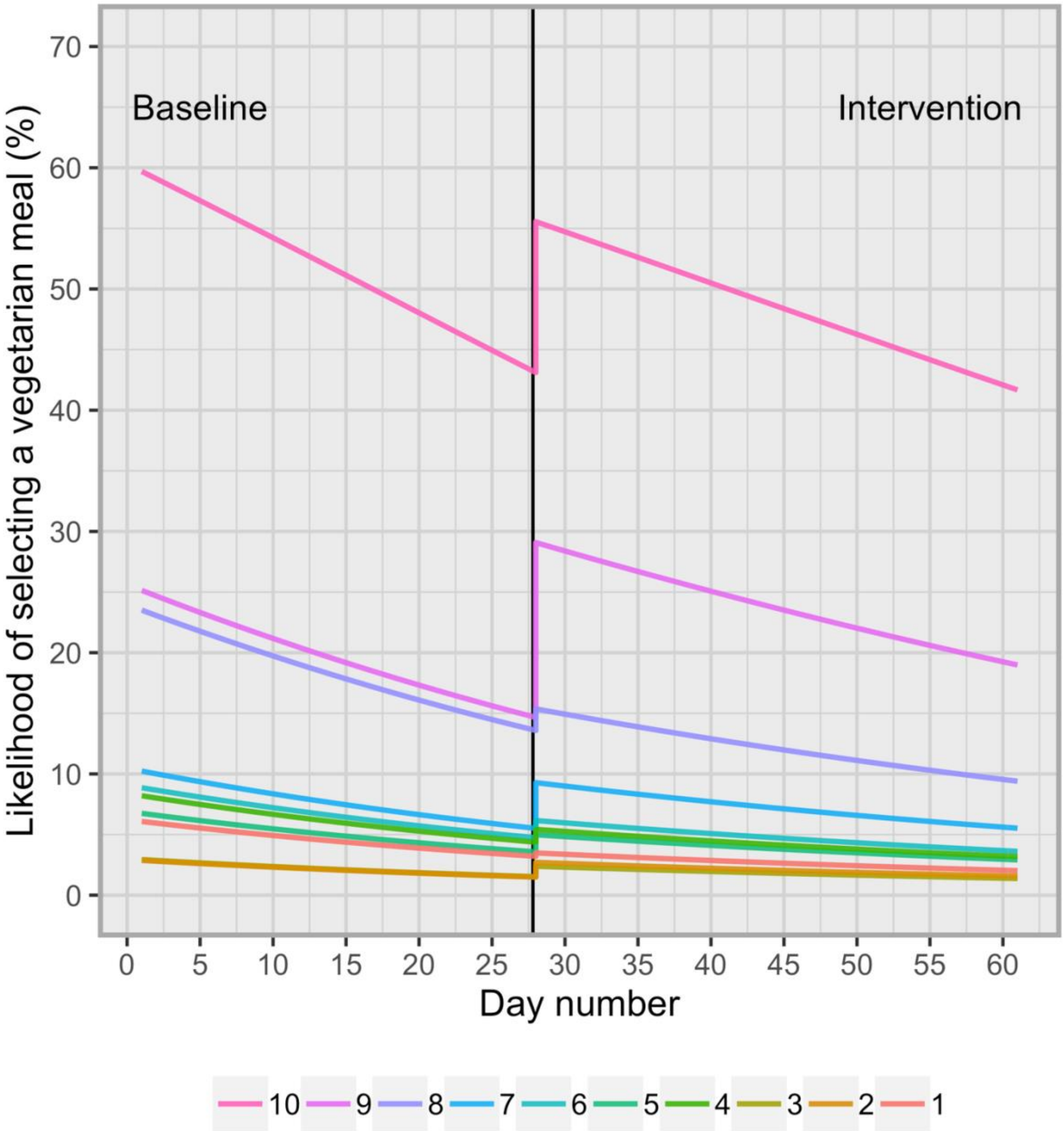

Figure C3: Likelihood of vegetarian deciles selecting a vegetarian meal during the baseline and intervention periods, based on model predictions and conditional regression.

Table C9: Generalised linear mixed model (GLMM) output for likelihood (%) of individuals selecting a vegetarian meal, with PriorVeg deciles instead of prior veg quartiles (10= the most vegetarian, 1= least vegetarian). Effect size calculated by taking the exponential of the model estimate. The results here are non-significant, but show the same pattern as the quartile analyses: diners with the highest prior likelihood of selecting a vegetarian and vegan meal respond most strongly to the price change intervention (Figure C2). Decile 10 and Monday are the reference categories for diner decile and day of the week respectively. This model should be interpreted cautiously, due to the high number of explanatory variables from the deciles, the variance inflation factor for the veg deciles are above 10.

Variable	Model estimate	Effect size	Effect size 95% CIs	p-value	Narrative
Price change (Ref=Baseline)	0.50	1.65	0.83, 3.28	0.154	Likelihood of selecting a vegetarian meal did not significantly increase after the price change for Decile 10.
Decile 9	-1.48	0.23	0.10, 0.51	<0.001	The likelihood of Decile 10 selecting a vegetarian meal > Decile 9 > Decile 8 >Decile 7 > Decile 6 > Decile 4 > Decile 5 > Decile 1 > Decile 3 = Decile 2.
Decile 8	-1.57	0.21	0.09, 0.47	<0.001	
Decile 7	-2.56	0.08	0.03, 0.18	<0.001	
Decile 6	-2.72	0.07	0.03, 0.15	<0.001	
Decile 5	-3.02	0.05	0.02, 0.12	<0.001	
Decile 4	-2.81	0.06	0.03, 0.14	<0.001	
Decile 3	-3.89	0.02	0.01, 0.07	<0.001	
Decile 2	-3.91	0.02	0.01, 0.06	<0.001	
Decile 1	-3.13	0.04	0.02, 0.09	<0.001	
Days Since Baseline	-0.02	0.98	0.96, 0.99	0.007	Likelihood of selecting a vegetarian meal decreased with time during the baseline period.
Days Since Intervention	-0.02	0.98	0.97, 1.00	0.015	Likelihood of selecting a vegetarian meal decreased with time during the intervention period.
Mealtime (Ref=Lunch)	0.50	1.65	1.31, 2.08	<0.001	Higher likelihood of selecting a vegetarian meal at dinnertimes than lunchtimes.
Mean temperature (°C)	-0.02	0.98	0.95, 1.01	0.151	Likelihood of selecting a vegetarian meal was not significantly affected by ambient temperature.
Tuesday	-0.50	0.61	0.44, 0.83	0.002	Likelihood of selecting a vegetarian meal was not significantly different on Wednesdays, Thursdays, Fridays and Saturdays compared to Mondays. Tuesdays had significantly lower likelihood of vegetarian selection than Mondays.
Wednesday	-0.26	0.77	0.56, 1.05	0.098	
Thursday	-0.09	0.91	0.67, 1.25	0.572	
Friday	0.06	1.06	0.78, 1.45	0.708	
Saturday	-0.22	0.81	0.54, 1.20	0.292	
Price change: Decile 9	0.37	1.45	0.68, 3.08	0.339	The other deciles did not respond significantly differently to the price change compared to Decile 10.
Price change: Decile 8	-0.36	0.70	0.32, 1.53	0.371	
Price change: Decile 7	0.06	1.06	0.46, 2.46	0.886	
Price change: Decile 6	-0.22	0.80	0.34, 1.86	0.604	
Price change: Decile 5	-0.15	0.86	0.35, 2.14	0.744	
Price change: Decile 4	-0.27	0.76	0.33, 1.77	0.527	
Price change: Decile 3	-0.04	0.96	0.24, 3.74	0.949	
Price change: Decile 2	0.11	1.12	0.34, 3.67	0.857	
Price change: Decile 1	-0.41	0.66	0.31, 1.42	0.289	

Table C10: GLMM output for likelihood (%) of individuals selecting a meat meal. Effect size calculated by taking the exponential of the model estimate. MostVeg and Monday are the reference categories for diner quartile and day of the week respectively.

Variable	**Model estimate**	**Effect size**	**Effect size 95% CIs**	**p-value**	**Narrative**
Price change (Ref=Baseline)	-0.29	0.75	0.49, 1.14	0.182	Likelihood of selecting a meat meal did not increase after the price change for the MostVeg quartile.
Quartile- More Veg	1.79	6.00	3.38, 10.63	<0.001	The likelihood of the MostVeg quartile selecting a meat meal < MoreVeg < LessVeg < LeastVeg.
Quartile- Less Veg	2.02	7.52	4.18, 13.53	<0.001	
Quartile- Least Veg	2.35	10.45	6.10, 17.89	<0.001	
Days Since Baseline	0.01	1.01	1.00, 1.03	0.069	Likelihood of selecting a meat meal did not significantly change with time during the baseline period.
Days Since Intervention	0.00	1.00	0.99, 1.01	0.657	Likelihood of selecting a meat meal did not significantly change with time during the intervention period.
Mealtime (Ref=Lunch)	0.22	1.25	1.03, 1.51	0.024	Higher likelihood of selecting a meat meal at dinnertimes than lunchtimes.
Mean temperature (°C)	0.02	1.02	0.99, 1.04	0.205	Likelihood of selecting a meat meal was not significantly affected by ambient temperature.
Tuesday	0.48	1.62	1.26, 2.09	<0.001	Likelihood of selecting a meat meal was not significantly different on Wednesdays, Thursdays, and Saturdays compared to Mondays. Tuesdays had significantly higher likelihood of meat selection, and Fridays significantly lower, than Mondays.
Wednesday	0.25	1.28	1.00, 1.64	0.053	
Thursday	0.12	1.13	0.88, 1.46	0.331	
Friday	-1.55	0.21	0.17, 0.27	<0.001	
Saturday	0.22	1.25	0.90, 1.73	0.176	
Price change: More Veg	0.36	1.44	0.92, 2.23	0.108	MoreVeg, LessVeg and LeastVeg did not respond significantly differently to the price change compared to the MostVeg quartile.
Price change: Less Veg	0.29	1.33	0.85, 2.09	0.215	
Price change: Least Veg	0.34	1.41	0.92, 2.15	0.112	

Table C11: GLM output for aggregate fish sales (%). Effect size calculated by taking the exponential of the model estimate. Monday is the reference categories for day of the week.

Variable	Model estimate	Effect size	Effect size 95% CIs	p-value	Narrative
Price change (Ref=Baseline)	-0.29	0.75	0.60, 0.94	0.010	Fish sales were significantly lower after the price change.
Days Since Baseline	-0.01	0.99	0.98, 1.01	0.318	Fish sales did not significantly decline with time during the baseline period.
Days Since Intervention	0.01	1.01	1.00, 1.02	0.002	Fish sales significantly increased with time during the intervention period.
Mealtime (Ref=Lunch)	-0.64	0.53	0.47, 0.59	<0.001	Dinnertimes had lower fish sales than lunchtimes.
Mean temperature (°C)	0.01	1.01	0.99, 1.02	0.503	Fish sales were not significantly affected by ambient temperature.
Tuesday	-0.04	0.96	0.78, 1.18	0.702	Tuesdays, Wednesdays, Thursdays and Saturdays did not have significantly different fish sales compared to Mondays. Fridays had significantly higher fish sales than Mondays.
Wednesday	0.11	1.12	0.91, 1.37	0.277	
Thursday	0.04	1.04	0.85, 1.28	0.701	
Friday	1.56	4.76	4.00, 5.67	<0.001	
Saturday	0.20	1.23	0.97, 1.55	0.084	

Table C12: GLM output for aggregate vegan sales (%). Effect size calculated by taking the exponential of the model estimate. Monday is the reference categories for day of the week.

Variable	Model estimate	Effect size	Effect size 95% CIs	p-value	Narrative
Price change (Ref=Baseline)	-0.42	0.66	0.49, 0.89	0.006	Vegan sales were significantly lower after the price change.
Days Since Baseline	0.04	1.04	1.02, 1.06	<0.001	Vegan sales significantly increased with time during the baseline period.
Days Since Intervention	0.01	1.01	1.00, 1.02	0.028	Vegan sales significantly increased with time during the intervention period.
Mealtime (Ref=Lunch)	-0.13	0.87	0.75, 1.01	0.078	No significant difference between vegan sales at dinnertimes and lunchtimes.
Mean temperature (°C)	0.02	1.02	0.99, 1.05	0.180	Vegan sales were not significantly affected by ambient temperature.
Tuesday	0.05	1.05	0.84, 1.32	0.662	Tuesdays, Thursdays and Fridays did not have significantly different vegan sales compared to Mondays. Wednesdays and Saturdays had significantly lower vegan sales than Mondays.
Wednesday	-0.45	0.64	0.50, 0.82	0.001	
Thursday	-0.22	0.80	0.63, 1.02	0.075	
Friday	-0.09	0.91	0.72, 1.15	0.423	
Saturday	-3.11	0.04	0.02, 0.10	<0.001	

Table C13: GLMM output for likelihood (%) of individuals selecting a fish meal. Effect size calculated by taking the exponential of the model estimate. MostVeg and Monday are the reference categories for diner quartile and day of the week respectively. This model should be interpreted cautiously as the variance inflation factors (VIFs) for price change and the interaction between price change and quartiles are between 10 and 15. The VIFs were still between 10 and 15 in a model with only price change, quartiles and interaction, so this model cannot be improved by removing variables.

Variable	**Model estimate**	**Effect size**	**Effect size 95% CIs**	**p-value**	**Narrative**
Price change (Ref=Baseline)	-0.62	0.54	0.27, 1.05	0.070	Likelihood of selecting a fish meal did not change after the price change for the MostVeg quartile.
Quartile- More Veg	0.10	1.11	0.55, 2.23	0.771	The likelihood of the MostVeg quartile selecting a fish meal was not significantly different than that of MoreVeg, LeastVeg or LessVeg.
Quartile- Less Veg	0.57	1.77	0.88, 3.56	0.109	
Quartile- Least Veg	0.36	1.43	0.74, 2.75	0.284	
Days Since Baseline	0.00	1.00	0.98, 1.02	0.855	Likelihood of selecting a fish meal did not change with time during the baseline period.
Days Since Intervention	0.01	1.01	0.99, 1.02	0.474	Likelihood of selecting a fish meal did not change with time during the intervention period.
Mealtime (Ref=Lunch)	-0.73	0.48	0.37, 0.64	<0.001	Lower likelihood of selecting a fish meal at dinnertimes than lunchtimes.
Mean temperature (°C)	0.02	1.02	0.98, 1.05	0.357	Likelihood of selecting a fish meal did not change with ambient temperature.
Tuesday	-0.10	0.91	0.61, 1.36	0.635	Likelihood of selecting a fish meal was not significantly different on Tuesdays, Wednesdays, Thursdays or Saturdays compared to Mondays. Fridays had significantly higher likelihood of fish selection than Mondays.
Wednesday	0.23	1.26	0.85, 1.85	0.246	
Thursday	-0.15	0.86	0.57, 1.30	0.480	
Friday	2.34	10.33	7.33, 14.56	<0.001	
Saturday	0.35	1.42	0.87, 2.32	0.158	
Price change: More Veg	0.59	1.81	0.89, 3.65	0.099	MoreVeg, LessVeg and LeastVeg did not respond significantly differently to the price change compared to the MostVeg quartile.
Price change: Less Veg	0.47	1.60	0.80, 3.20	0.184	
Price change: Least Veg	0.40	1.49	0.77, 2.90	0.234	

Table C14: GLMM output for likelihood (%) of individuals selecting a vegan meal. Effect size calculated by taking the exponential of the model estimate. MostVeg and Monday are the reference categories for diner quartile and day of the week respectively.

Variable	Model estimate	Effect size	Effect size 95% CIs	p-value	Narrative
Price change (Ref=Baseline)	-0.38	0.68	0.31, 1.50	0.342	Likelihood of selecting a vegan meal did not increase after the price change for the MostVeg quartile.
Quartile- More Veg	-1.33	0.26	0.11, 0.65	0.004	The likelihood of the MostVeg quartile selecting a vegan meal > MoreVeg > LessVeg = LeastVeg.
Quartile- Less Veg	-2.23	0.11	0.04, 0.32	<0.001	
Quartile- Least Veg	-2.16	0.12	0.04, 0.30	<0.001	
Days Since Baseline	0.02	1.02	0.98, 1.06	0.272	Likelihood of selecting a vegan meal did not change with time during the baseline period.
Days Since Intervention	0.02	1.02	1.00, 1.04	0.077	Likelihood of selecting a vegan meal did not change with time during the intervention period.
Mealtime (Ref=Lunch)	-0.57	0.56	0.35, 0.90	0.016	Lower likelihood of selecting a vegan meal at dinnertimes than lunchtimes.
Mean temperature (°C)	-0.06	0.94	0.88, 1.00	0.041	Lower likelihood of selecting a vegan meal with warmer ambient temperature.
Tuesday	-0.25	0.78	0.47, 1.31	0.352	Likelihood of selecting a vegan meal was not significantly different on Tuesdays, Thursdays, Fridays or Saturdays compared to Mondays. Wednesdays had significantly lower likelihood of vegan selection than Mondays.
Wednesday	-0.69	0.50	0.28, 0.89	0.019	
Thursday	0.21	1.23	0.75, 2.01	0.406	
Friday	-0.21	0.81	0.47, 1.39	0.448	
Saturday	-12.42	0.00	0.00, 0.00	0.915	
Price change: More Veg	-0.76	0.47	0.18, 1.19	0.111	MoreVeg, LessVeg and LeastVeg did not respond significantly differently to the price change compared to the MostVeg quartile.
Price change: Less Veg	0.18	1.20	0.42, 3.41	0.736	
Price change: Least Veg	-0.14	0.87	0.33, 2.29	0.773	

Table C15: GLMM output for likelihood (%) of individuals selecting a vegetarian&vegan meal. Effect size calculated by taking the exponential of the model estimate. MostVeg and Monday are the reference categories for diner quartile and day of the week respectively.

Variable	Model estimate	Effect size	Effect size 95% CIs	p-value	Narrative
Price change (Ref=Baseline)	0.49	1.64	1.03, 2.59	0.035	Likelihood of selecting a vegetarian&vegan meal increased after the price change for the MostVeg quartile.
Quartile- MoreVeg	-1.90	0.15	0.08, 0.28	<0.001	The likelihood of the MostVeg quartile selecting a vegetarian&vegan meal > MoreVeg > LessVeg > LeastVeg.
Quartile- LessVeg	-2.70	0.07	0.03, 0.13	<0.001	
Quartile- LeastVeg	-3.07	0.05	0.02, 0.09	<0.001	
Days Since Baseline	-0.02	0.98	0.97, 1.00	0.050	Likelihood of selecting a vegetarian&vegan meal decreased with time during the baseline period.
Days Since Intervention	-0.01	0.99	0.98, 1.01	0.308	Likelihood of selecting a vegetarian&vegan meal did not change with time during the intervention period.
Mealtime (Ref=Lunch)	0.30	1.35	1.07, 1.70	0.012	Higher likelihood of selecting a vegetarian&vegan meal at dinnertimes than lunchtimes.
Mean temperature (°C)	-0.04	0.96	0.93, 0.99	0.020	Lower likelihood of selecting a vegetarian&vegan meal with warmer ambient temperatures.
Tuesday	-0.54	0.58	0.43, 0.79	<0.001	Likelihood of selecting a vegetarian&vegan meal was not significantly different on Thursdays or Fridays compared to Mondays. Tuesdays, Wednesdays and Saturdays had significantly lower likelihood of vegetarian&vegan selection than Mondays.
Wednesday	-0.43	0.65	0.48, 0.87	0.005	
Thursday	-0.01	0.99	0.74, 1.33	0.963	
Friday	0.00	1.00	0.74, 1.34	0.987	
Saturday	-0.64	0.53	0.35, 0.79	0.002	
Price change: MoreVeg	-0.54	0.58	0.36, 0.94	0.026	LessVeg and LeastVeg did not respond significantly differently to the price change compared to the MostVeg quartile. MoreVeg had a significantly different response to the price intervention than MostVeg.
Price change: LessVeg	-0.36	0.70	0.41, 1.18	0.180	
Price change: LeastVeg	-0.41	0.66	0.40, 1.1	0.110	

Table C16: GLMM output for likelihood (%) of individuals selecting a meat&fish meal. Effect size calculated by taking the exponential of the model estimate. MostVeg and Monday are the reference categories for diner quartile and day of the week respectively.

Variable	Model estimate	Effect size	Effect size 95% CIs	p-value	Narrative
Price change (Ref=Baseline)	-0.55	0.58	0.37, 0.92	0.020	Likelihood of selecting a meat&fish meal decreased after the price change for the MostVeg quartile.
Quartile- MoreVeg	1.87	6.48	3.47, 12.10	<0.001	The likelihood of the MostVeg quartile selecting a meat&fish meal < MoreVeg < LessVeg < LeastVeg.
Quartile- LessVeg	2.68	14.6	7.42, 28.73	<0.001	
Quartile- LeastVeg	3.06	21.39	11.41, 40.08	<0.001	
Days Since Baseline	0.02	1.02	1.00, 1.04	0.023	Likelihood of selecting a meat&fish meal increased with time during the baseline period.
Days Since Intervention	0.01	1.01	0.99, 1.02	0.244	Likelihood of selecting a meat&fish meal did not change with time during the intervention period.
Mealtime (Ref=Lunch)	-0.29	0.75	0.59, 0.94	0.014	Lower likelihood of selecting a meat&fish meal at dinnertimes than lunchtimes.
Mean temperature (°C)	0.04	1.04	1.01, 1.08	0.010	Higher likelihood of selecting a meat&fish meal with warmer ambient temperatures.
Tuesday	0.55	1.74	1.29, 2.35	<0.001	Likelihood of selecting a meat&fish meal was not significantly different on Thursdays or Fridays compared to Mondays. Tuesdays, Wednesdays and Saturdays had significantly higher likelihood of meat&fish selection than Mondays.
Wednesday	0.46	1.58	1.17, 2.14	0.003	
Thursday	0.02	1.02	0.76, 1.36	0.917	
Friday	0.00	1.00	0.74, 1.35	0.991	
Saturday	0.65	1.92	1.28, 2.88	0.002	
Price change: More Veg	0.56	1.76	1.09, 2.84	0.021	LessVeg and LeastVeg did not respond significantly differently to the price change compared to the MostVeg quartile. MoreVeg had a significantly different response to the price intervention than MostVeg.
Price change: Less Veg	0.40	1.49	0.88, 2.53	0.134	
Price change: Least Veg	0.45	1.56	0.94, 2.60	0.086	

Table C17: Customer price, ingredients costs, margin and mark up for the meat and vegetarian meal options. Estimates supplied by college catering manager. The margin is the difference between the customer price and the ingredients costs; the mark up is the margin divided by the ingredients cost, and multiplied by 100 to obtain the percentage.

	Control period		Intervention period	
Meal option	Vegetarian	Meat	Vegetarian	Meat
Customer price (£)	2.05	2.52	1.85	2.72
Ingredients cost (£)	~1.05	~1.90	~1.05	~1.90
Margin (£)	~1.00	~0.62	~0.80	~0.82
Mark up (%)	~100	~33	~76	~43
ce change	NA	NA	-9.8%	+7.0%