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Demand For Plant-Based Meat: Competition with Animal Proteins, Effects of Households' Health Status and Diet Concerns, and Implications for the Environment

Author

Kotsakou, Stamatina

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Demand For Plant-Based Meat: Competition with Animal Proteins, Effects of Households' Health Status and Diet Concerns, and Implications for the Environment

By

STAMATINA KOTSAKOU

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Approved:

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Richard J. Sexton, Chair

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Kristin Kiesel

____

Pierre Mérel

____

Daniel A. Sumner

Committee in Charge

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Abstract

Three promotional branches have supported the second generation of plant-based meat, i.e., of the products that mimic the texture, the appearance, and the flavor of animal meat: protection of animal welfare, of the environment, and of consumers' health through the reduction of animal meat consumption. The goal of this study was to understand whether consumers view plant-based meat as a way to reduce meat consumption and, in turn, benefit their health and the environment.

The present study addresses this question using a dataset that consists of households' protein purchases over time, combined with household demographic and health information. The data contain detailed information on 127,606 U.S. households' meat purchases, along with their demographic and medical information, from 2012 to 2022. Since not every household in the panel responded to the health survey, a separate analysis was conducted for the households which provided this information.

Two econometric approaches are used in this study: a double-hurdle model and an Almost Ideal Demand System for proteins with a censored regression. The first approach breaks a household's decision to consume a product into two processes ("hurdles"): the decision to participate, and, conditional on participating, the decision of how much to consume. The second model sheds light on the substitution patterns between the plant-based meat and the animal proteins.

Results from this study show a clear upward trend on the market availability of plant-based alternatives. However, even in the most recent years, where the sales of these products have reached their peak, their share in stores is less than 5% of the total meat products and their price is consistently the highest of all proteins throughout years. The vast majority of households are nonconsumers of plant-based meat and, although this percentage is decreasing over time, 80% of the panel households did not purchase any plant-based meat product up to 2022.

From the consumption patterns across years it is evident that the adoption of plant-based meat does signify a household's intention to reduce meat consumption overall. The households that permanently adopted plant-based meat over the years reduced meat consumption by 10% and increased seafood consumption by 13%. Overall, the expenditure on proteins (plant-based meat included) increased by 29% which implies that households increased the variety of proteins with plant-based meat but did not fully replace an animal protein with it.

The key results from the double hurdle model estimation suggest that only about one-third of the household panelists considered participation in the plant-based meat market segment. The estimated average share willing to consider plant-based meat varied from 25% to 36% with an average of 29%. The analysis showed that the prices of substitute proteins had a positive effect on the plant-based meat segment participation decision, but the price of plant-based meat itself tended to have little effect on participation. Education of the primary shopper was a strong positive determinant of participation, and consumers who expressed concern about food and pursued an ingredient-conscious diet were significantly more likely to participate in the plant-based meat segment.

In terms of the second hurdle, the expenditure decision, the price of plant-based meat is consistently negatively correlated with expenditure, but the effect is not always statistically significant. The prices of the protein substitutes tend to be more significant determinants of expenditure on plant-based meat. The price of beef in particular is consistently and significantly associated with higher expenditure on plant-based meat. Household income is also significantly associated with higher plant-based meat consumption in the full panel. Demographic variables that play a consistent role in explaining plant-based meat expenditure include having a female primary shopper, having a more highly educated primary shopper, having household members who express concerns about health and who pursue an ingredient-conscious diet. Conversely household size does not tend to have a consistent and significant impact, nor do the politics of the state of residence or the age of the primary shopper. Finally, households experiencing health problems tend to spend less on plant-based meat, other factors constant.

The censored regression model yielded estimation results that complement the results from the double hurdle model. Results of this estimation revealed that all five of the proteins studied in this analysis have near unitary expenditure elasticities, meaning that as household expenditures on proteins increases, expenditures on each protein rise in a nearly proportional manner. Plant-based meat demand was price inelastic in both the main sample and health-survey sample, but the demand was more elastic (indeed, near unit elastic) for the health-survey panel, suggesting some fundamental differences in behavior for the subgroup that chose to provide health information relative to the full panel.

Compensated and uncompensated cross-price elasticities differed considerably due to strong income effects for all proteins in the system except plant-based meat. Estimated cross-price effects for the traditional proteins were consistent with prior meat demand studies. Importantly, results indicated that plant-based meat and beef are net complements based upon the compensated (Hicksian) cross-price elasticities, a finding at odds with the common belief that plant-based meat can become a significant substitute for beef in consumers' diets, thereby leading to reduced methane emissions and other harmful environmental effects associated with cattle production. This finding is consistent with Zhao et al. (2022) and may indicate that plant-based meat products are consumed by some members in the household and beef by others while they are both served at the same meal. An increase in the price of beef reduces the amount of beef consumed by the household and, in turn, this affects the quantity of plant-based meat consumed. This finding casts major doubt on what appears to be an article of faith among those who believe plant-based meats can cause consumers to substitute away from animal meats.

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What a journey! The gratitude I feel for the people who stood by me and cared about my success while I was pursuing my degree cannot accurately be expressed with words, but I will at least try. First, I would like to thank my advisor, Richard Sexton, for his collaboration. He helped me acquire the data for my research, offered me employment which let me focus on my work, offered me feedback on my work in a timely manner, and he encouraged me to teach my own class which turned out to be a pivotal experience that made me discover my passion for teaching.

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Chapter 1

Introduction

Environmental concerns (Reijnders and Soret, 2003; Naylor et al., 2005; McAlpine et al., 2009; De Vries and de Boer, 2010; Mekonnen and Hoekstra, 2012; Tilman and Clark, 2014; Godfray et al., 2018), protection of animal welfare (Grandin, 2010; Pluhar, 2010; Lagerkvist and Hess, 2011; Miranda-de la Lama et al., 2012; Grandin, 2017; Godfray et al., 2018), and diet shifts towards healthier goods (Graça et al., 2015a) are some of the factors that increasingly extend the retail shelf space for the second generation plant-based alternatives to traditional meat products (Ruby, 2012; Kyriakopoulou et al., 2019; He et al., 2020). These are products which mimic the appearance, texture and flavor of animal proteins targeted to consumers who aim to replace in whole or in part meat and seafood in their diet with plant-based products (Wild et al., 2014; Joshi and Kumar, 2015).

The early-stage increasing success of the second generation plant-based meat products, from 2010 to 2020, created the expectation that these products could benefit the environment if consumers were to reduce meat consumption and replace it with plant-based meat. However, the growth of this industry has slowed down since 2021 and this raises concerns about the potential of plant-based meat alternatives to cause a reduction to meat consumption (Caputo et al., 2024; Good Food Institute, 2022). There are several economic questions to be answered at this critical point for this industry. What is the acceptance rate of plant-based meat of consumers and how has it changed over the years? What are the demographic characteristics of the consumers who purchase plant-based meat? To what extend does plant-based meat consumption reduce animal protein intake? Stated differently, is the overarching promotional theme of an environmentally-friendly protein that has the potential to replace meat, and in turn, reduce the adverse environmental effects of livestock production well-founded given actual empirical observations?

The other promotional pillar of plant-based meat alternatives is that it benefits consumers' health through the reduction of animal protein intake. It is, therefore, important to understand the role that consumers' health status and dietary habits play in the consumption of plant-based meat. If plant-based meat appeals to consumers who have already decided to not eat meat (i.e., vegans and vegetarians), then these products merely increase the variety of consumers' protein choice and have no effect on meat consumption or on the health problems that are associated with it. On the other hand, if consumers who eat animal proteins view plant-based meat as a healthy alternative which helps them to moderate their meat consumption, then there is an actual connection between consumers' health status and these products that could lead to tangible reductions of meat consumption.

The present study addresses these questions using a dataset that consists of households' protein purchases over time, combined with household demographic and health information. The access to these data was granted through the U.S. Department of Agriculture, Economic Research Service (ERS) which acquires access to the data from the research company, Circana. They contain detailed information on United States (hereafter U.S.) households' meat purchases along with their demographic and medical information from 2012 to 2022, and they are used to classify households into different consumer segments based on the intensity of their plant-based meat consumption. This detailed dataset makes it feasible to study the differences and similarities of demographic characteristics of each consumer segment and also to estimate own-price and cross-price meat demand elasticities in models that contain the effects of the households' demographic and health information.

The study of the demand for plant-based meat differs from that of other proteins because consumers' adoption of plant-based meat alternatives is still evolving which means that there is a significant mass of households that has never purchased these products, i.e., their expenditure on plant-based meat is zero. There are several reasons that can lead to this pattern. A first potential source is the disinterest of households in consuming a given product. That is, regardless of their income and the market prices, the household is not planning to participate in plant-base meat consumption (this behavior is also known as *abstention*). Second, zeros may indicate a corner solution. In this case, the household is a potential participant in the market (i.e., it considers plant-based meat in its choice set of proteins), but in the current market conditions, its optimal plant-based meat consumption is zero.

This market situation has informed the two econometric approaches that are used in this study. The first, is a two-part or "hurdle" model —a popular model in an array of contexts where many observations are zero (indicatively: meat consumption of single-member households (Burton et al., 1994), loan default (Moffatt, 2005), fertilizer use (Ricker-Gilbert et al., 2011)). This model was first introduced by Cragg (1971), and it is described in detail in Engel and Moffatt (2014). It embodies the fact that an individual's decision to consume a product is the result of two processes ("hurdles"): the decision to participate, and, conditional on participating, the decision of how much to consume. The structure of the double-hurdle model makes it possible to quantify the proportion of households that are interested in consuming plant-based meat products, including households who consider plant-based meat in their choice set, yet their optimal consumption quantity has been zero. The quantification of such a parameter is very useful in understanding the population's actual acceptance rate of plant-based meat products which is different from the proportion of the population who has been observed purchasing them. Further, by breaking down the decision to a "participation" and a "consumption" part, it becomes possible to understand what demographic, market, health, and dietary factors affect each part. This sheds light on the factors which prevent a household from considering to even try the plant-based meat product and the factors which prevent not-abstaining households from increasing their expenditure on plant-based meat.

The second econometric model is an Almost Ideal Demand System for proteins with a censored regression which sheds light upon the substitution patterns between plant-based meat and animal proteins while taking into account the large amount of households with zero plant-based meat consumption with the use of Inverse Mills Ratios. Although the plant-based products analyzed in this research are commonly viewed as substitutes to animal products, there are good reasons to think that there exist complementary relationships between these products as well. For instance, shoppers may buy animal protein for some of the household members, but plant-based protein for others. Another possibility is that plant-based meat products are merely a fad that increases the variety of proteins available to consumers, but does not actually cause a reduction to meat consumption. This analysis responds to this question without ignoring the large number of zero expenditure observations.

The results from the econometric models are then used to discuss the potential environmental benefits from a dietary transition from animal protein to plant-based protein. For example, can plant-based meat play a major role in reducing the greenhouse gas emissions associated with animal production?

The rest of the study unfolds as follows: Chapter 2 provides a brief description of the evolution of the plant-based meat industry, the different types of plant-based proteins and the types of inputs that are used for their production. Chapter 4 contains a detailed description of the data sets that were compiled for this study, of the most important data edits in order to create the final dataset, and of the construction of the key variables of the study. Chapter 5 is focused on the summary statistics and graphs from the data to understand better households' protein purchasing patterns and the effect of the introduction of plant-based meat in the market on the other proteins. The first section reviews the products that are available at the stores and the second is focused on the households that comprise the sample of the study, their protein consumption patterns and how they change depending on the different demographic and health profiles. The next chapter, i.e., chapter 6, describes the empirical approach and the two models used in the study, and chapter 7 discusses the results from the estimation of these models. Finally, chapter 8 uses the empirical results of the study to motivate a discussion about the potential environmental effects of plant-based meat and the study ends with the conclusions in chapter 9.

The findings and conclusions contained herein are those of the author and should not be construed to represent any official USDA or U.S. Government determination or policy. Also, the analysis, findings, and conclusions expressed in this study should not be attributed to Circana.

Chapter 2

The plant-based meat industry

The underlying theme in the promotion and the significant growth that the industry of meat alternatives has experienced over the past years is that they are a healthy alternative to meat proteins, the production of which uses significantly less resources compared to that of traditional meats. I use this chapter to enrich readers' context about the industry of alternative proteins by describing the different types of inputs that are contained in these products as well as the history and the key developments of the industry over time.

2.1 Evolution of the industry

According to Maningat et al. (2022), the first soy-based and wheat-based meat products were produced in 1933, however, the first generation of meat analogs—or textured vegetable protein (TVP)—did not arise until the early 1960s (He et al., 2020; Zhang et al., 2019). These products were described as "fabricated palatable food ingredients processed from an edible protein source including, among others, soy grits, soy protein isolates, and soy protein concentrates with or without suitable option ingredients added for nutritional or technological purposes" (Phillips and Williams, 2011). First-generation analogues aimed to satisfy the specific consumer categories of vegans and vegetarians which were growing at that time. Although soy protein was (and still is) a dominant ingredient in the production of TVP products, other cereal and legume proteins are used too.

From the 1960s through the 2000s, only sparse developments happened in the industry. In 1979, Boca Burger (later acquired by Kraft Heinz (Watrous, 2018)) produced its vegetarian "Sun Burger" (Maningat et al., 2022) and two years later the vegetable-based patty Gardenburger was developed (Lemelson-MIT, 2021). A significant development of that period happened in 1985, where the fungal mycoprotein, Quorn, was introduced in the plant-based meat market (Trinci, 1992). It was around that time (1990s) that consumers' perceptions around meat slowly started changing in the western world. For instance the earliest known use of the term "flexitarian" occurred in a 1992 issue of the Austin American-Statesman daily newspaper (Maningat et al., 2022). Other developments of that era include the debut of Tofurky in 1995 (Tofurky, 2023) and the introduction of veggie burgers in the menus of fast-food chains in 2002, although they did not become a mainstream product.

A key breakthrough happened in 2009 when Beyond Meat launched the pea-protein burger named Beyond Burger. Soon after that, in 2011, the Impossible Foods was founded (Maningat et al., 2022). In the decade of the 2010s the alternative meat industry had several other technological advancements and various alternative sources of protein were introduced. Examples of such advancements are the creation of the first in-vitro (i.e., meat grown outside of the animal body) hamburger from cultured cow cells in 2013 (Post, 2014), and the development of the first insect-based burger in 2014. The first assembly line and distribution in grocery stores of insect burgers occurred in 2018 in Germany (Kornher et al., 2019).

The last technological advancement in the market is the three-dimensional (3D) printing technology for food fabrication that could revolutionize not only the production of animal proteins and their alternatives, but also food manufacturing in general. The technology is based on rapidly building geometrically three-dimensional objects layer-by-layer with the guidance of computational software and with feeding ink cartridges containing semi-solid pastes (Wen et al., 2022). The European company NovaMeat was the first to create a 3D-printed plant-based steak in 2019 (Darrah (2020); Maningat et al. (2022)).

TABLE 2.1 Timeline of key developments in plant-based meat industry

1933	The first soy-based and wheat-based burger are produced.
1960	The first generation of TVP occurs.
1979	The vegetarian "Sun Burger" is produced by Boca Burger.
1981	The vegetable-based patty "Gardenburger" is developed.
1985	Quorn mycoprotein is introduced to the plant-based meat industry.
1992	The term "flexitarian" is used to describe consumers' eating habits with respect to animal protein.
1995	Tofurky is launched by Seth Tibbott.
2009	Beyond Meat is founded by Ethan Brown.
2011	Impossible Meat is founded by Patrick Brown.
2013	The first in-vitro hamburger is created
2018	The first distribution of insect burgers occurs in Germany.
2019	The first 3D-printed plant-based steak is produced.

2.2 Inputs of meat alternative products

A typical recipe of a meat analogue contains 50% to 80% water, 1% to 25% textured vegetable proteins, 4% to 20% nontextured proteins, 3% to 10% flavorings, 0% to 15%

fat, 1% to 5% binding agents, and 0% to 0.5% coloring agents (Kyriakopoulou et al., 2019). In what follows, I describe the possible protein sources that can be used for the production of such products. The use of the adjective "alternatives" instead of "plant-based" here is intentional since this section, for completeness, describes all possible protein sources that can be used to mimic meat, including some that are not vegetable proteins.

2.2.1 Protein types

Over the past twelve years the research for ingredients that can be used for the development of commercial meat alternatives has risen (Singh et al., 2021). Many factors affect the choice of the raw ingredients that go into alternative meat. Some of them are availability, cost, functional and physiological properties, and nutritional value (Phillips and Williams, 2011). The biggest drawback of alternative meat products that contain the vegetable proteins is that they require a lot of processing in order to obtain the meat-like texture and look. As Maningat et al. (2022) explain, native proteins from plants are not conductive in creating this animal muscle-like fibrous structure. The process of texturization of proteins needs to take place in order for the fibers to be built, and the product to gain the gustatory resemblance to animal meat. This is often a concern for consumers, and justifiably so, since these products are classified in the category of ultra-processed foods (Marrón-Ponce et al., 2019).[1] In general, the sources of protein that can be used in the production of alternative meat are the following[2]:

- **Oilseed proteins:** Oilseed crops, soybeans, sunflower, rapeseed, canola etc.

  Soybeans comprise the most widely used oilseed for plant-based meat processing. It is a low-cost oilseed crop which is in abundance in the U.S. Its popularity as an input for plant-based meat lies on its fibrous, anisotropic structure that resembles

[1]Plant-based foods are classified as group 4 in the NOVA classification system that categorizes foods according to the nature and the extent of industrial processing they undergo (Boukid et al., 2023).

[2]Leaf proteins such as alfalfa, tobacco, bushes, grass, etc. are one of the four main sources of vegetable protein, however, they are not used for the production of plant-based meat.

the hardness and chewiness of animal meat (Zhang et al., 2021). The main soy derivatives that are used in plant-based meat manufacturing are defatted soy flour, soy protein concentrates and soy protein isolates with approximate protein content 50%, 70%, and 90% respectively (Webb et al., 2022). An important property of soy proteins is their ability to absorb artificial and natural flavors and to easily be colored with caramel colors (Zhang et al., 2021). Other oilseed proteins that have properties adequate for plant-based meat production are canola and rapeseed. Canola can act as a structuring agent in mixed food systems (Uruakpa and Arntfield, 2004) and rapeseed, when used under high pressure or heat, may enhance meat-like structures (Kyriakopoulou et al., 2019).

- **Cereal protein:** wheat, corn, rice, barley, oats, sorghum, etc.

  Wheat gluten is the most commonly used cereal protein for plant-based meat. Its protein content ranges from 75% to 80% (Webb et al., 2022), and it has the natural capacity to form fibrous proteinacious materials. Its popularity is increasing because it can be used to produce soy-free texturized products (Kyriakopoulou et al., 2019) although it can also be combined with soy-based raw materials (Phillips and Williams, 2011). Textured wheat and its blends provide a clean flavor, a variety of sizes and shapes, ease of formulation and high protein levels without cholesterol (Maningat et al., 2022).

- **Legume and pulse protein:** beans, gram, lentils, lupines, peas, etc.

  The most promising of the legumes that have been tested for their functional properties is pea protein. The common pea (Pisum savitum L.) contains high protein and fiber compared to cereal grains and other pulses (Webb et al., 2022), although beans and peas in general are more variable raw materials, harder to texturize (Phillips and Williams, 2011), and they have a softer structure compared to soy (Kyriakopoulou et al., 2019).

- **Mycoprotein:** Another protein source is the one derived from the mycelium of the microorganism *Fussarium venenatum.* This fungi is capable of turning starch into protein, and, with the use of the fermentation process, it can be used for the production of plant-based meat (Finnigan, 2011). Its texture is quite versatile, making it an appropriate input not only for whole-muscle textured products such as fillets, but also for products which require the texture of minced meat such as plant-based sausages and burgers. Mycoprotein is of high quality, rich in fiber, low in saturated fat, and its protein contains all the essential amino acids (Finnigan, 2011).

  The creation of plant-based meat through fermentation experienced a boom from 2013 to 2022, and reached a peak in 2021. This market has attracted the interest of the industry, with 138 companies developing plant-based meat products and 32 companies developing seafood products (Boukid et al., 2023). The first company that used this technology is Quorn™ (Finnigan, 2011). Fermented plant-based products can be differentiated from other plant-based meats as "less processed foods with minimal additives"—product attributes that, as it was mentioned earlier, frequently concern consumers (Baune et al., 2022). An example of the finished product of mycoprotein-based meat is presented in figure 2.1

Figure 2.1: Plant-based meat produced with Rhiza mycoprotein

Source: The Better Meat Co (The Better Meat Co, 2023)

2.2.2 Other inputs

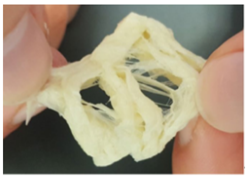
- **Fats and Oils:** sunflower oil, rapeseed oil, canola oil, coconut oil, ad soy oil, palm oil, corn oil.

  The use of fat and/or oils in plant-based meat production has its advantages because it enhances flavor and tenderness (Egbert and Borders, 2006), but, if used excessively during processing, it can impede the formation of fibrous structures (Kyriakopoulou et al., 2019). The meat analogues that are currently available have a low fat/oil content.

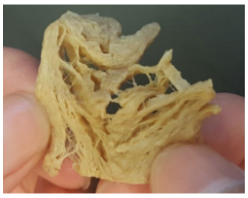
- **Taste enhancers:** savory spicing, meat and savory aromas, iron complexes etc. The successful imitation of a meat-like taste is probably the most crucial objective in order for these products to be accepted and adopted by the consumer. The same plant-based material can result in a different meat-like aroma (e.g., chicken or beef) in a flavoring process depending on the temperature, the pH, and other environmental parameters (Wu et al., 2000). The optimization of the flavor is a challenging task that it is greatly affected by the quality of the raw materials and the monitoring of aroma formation (Kyriakopoulou et al., 2019).

- **Coloring agents:** coloring ingredients such as caramel colors, beet root extracts, malt, annatto, turmin, cumin, carotene and reducing sugars such as dectrose, maltose, xylose, mannose, and arabinose etc. (Rolan et al., 2008).

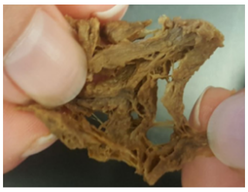
  Examples of how the color changes the appearance of the plant protein are shown in figure 2.2. Plant-based meat products should mimic not only the color of raw meat, but also the color change that meat goes through while being cooked. The addition of coloring agents is crucial, since the raw inputs, such as soy, have a bright beige or brown color that differs substantially both from cooked and uncooked meat (Kyriakopoulou et al., 2019).



((a)) Uncolored textured wheat protein that resembles chicken.



((b)) Caramel colored textured wheat protein that resembles pork.



((c)) Dark caramel colored textured wheat protein that resembles beef.

Figure 2.2: Fibrous structure of hydrated colored and uncolored textured wheat protein. Source: Maningat et al. (2022).

2.3 Summary

The industry of the second generation of meat alternatives has been developed rapidly over the past 20 years in order to respond to consumers desire to adjust their food consumption in ways that align with their concerns for the environment, animal welfare, and their own health. The possible inputs vary from vegetal proteins to mycoprotein and in-vitro animal proteins.

An important and concerning characteristic of their production is the heavy processing of the vegetal proteins and the use of many additives in order to achieve the taste, the texture and the look of real meat. Extensive processing, remaining differences in taste and appearance, as well as potentially significant price differences between plant-based meat and conventionally produced, can be deterrents for at least some consumer segments. The extend to which these factors limit the potential growth of plant-based meat alternatives is something that is explored empirically in following chapters.

Chapter 3

Previous research on consumers' perspectives and demand for plant-based meat

3.1 Consumption drivers, barriers, and demographics

What are consumers' drivers and barriers when it comes to purchasing plant-based meat? The main drivers to switch from meat to non-meat alternatives stated by consumers are concerns related to environment, health, and animal welfare, as well as consumers' social environment. Vlaeminck et al. (2014) suggest that information about a product's environmental impact affects consumers' choices on meat. Specifically, when given the information, consumers exhibit more eco-friendly behavior. In the survey of Clark and Bogdan (2019) health concerns and animal welfare concerns were listed as motives to reduce meat consumption and try meat alternatives, although health was ranked higher relative to animal welfare as a motive to reduce meat consumption.

Lentz et al.'s (2018) also find that different consumer groups are heterogeneous with respect to their motives to consume plant-based meat and reduce meat consumption. The authors found that typical omnivore consumers prioritize price and health, while reducers[1] prioritize environment and animal welfare. The latter can be a motive to adopt even stricter dietary changes that exclude meat completely from a diet and not merely reduce the quantity of meat that they consume Hoek et al. (2011); Lentz et al. (2018).

Further, the purchase of plant-based meat products seems to be affected positively by social norms (Onwezen et al., 2021). For instance, Curtain and Grafenauer (2019) characterize plant-based meat as a social facilitator that allows consumers who avoid meat to engage in group meals that include meat. Similarly, consumers who engage with a partner or a housemate who is positive about plant-based meat products are more likely to choose them (Hoek et al., 2011).

The extent to which these motives are sufficient to induce a shift in consumers' dietary habits, however, is unclear. Perino and Schwirplies (2021) highlight that for each of these factors there is a discrepancy between a stated intention to reduce meat consumption and the actual reduction of meat consumption. Consumers' *intention* to reduce meat consumption increased after reading arguments about climate change and animal welfare, but only the animal welfare considerations induced an *actual reduction* of red meat consumption. The same study also found that, on average, health arguments reduced neither the intention to consume nor the meat consumption itself.

It is intriguing that health concerns and social environment have been identified as arguments in favor of meat consumption too. de Boer et al. (2017) found that consumers use health benefits to argue both for and against meat consumption. Also, the social value that meat carries for some consumers (Godfray et al., 2018) and peer pressure (Perino and Schwirplies, 2021) affect negatively the demand for plant-based meat. Indicative of this behavior is the study Michel et al. (2021) in which consumers stated that they are more willing to consume meat alternatives when peer pressure was low, e.g., when eating alone.

[1]The term reducers refers to the segment of consumers who have reduced, but not completely eliminated meat from their diet.

Beyond the aforementioned factors that impede the expansion of plant-based demand, the literature has identified price, neophobia (i.e., the fear or dislike of anything new) (Carlsson et al., 2021; Hoek et al., 2011) and low sensory attractiveness of plant-based meat (Hoek et al., 2011) as additional reasons for consumer skepticism regarding these products.[2] In general, the acceptance of plant-based meat is higher compared to other alternative proteins such as insect or cultured meat, but, nonetheless, the evidence suggests that people prefer things that they are familiar with (Onwezen et al., 2021). Consumers associate meat with mostly positive terms and feelings such as "delicious" or "pleasure," but associate meat alternatives with negative terms such as "disgust" (Graça et al., 2015a; Michel et al., 2021). Also, in most cases, they associate the prospect of not eating meat with negative feelings (Michel et al., 2021).

Regarding the demographic characteristics of the consumers who drive the demand for plant-based meat, education and age have been identified as significant demand factors. On average consumers with higher education have a higher demand for non-meat alternatives and younger people are more willing to try plant-based meat (Carlsson et al., 2021; Van Loo et al., 2020).

Although it has been identified that males have different perceptions about meat than females (Michel et al., 2021), the effect of gender on demand for plant-based meat remains unclear. Some studies support that plant-based alternatives are more preferred by men (Van Loo et al., 2020), while others indicate women as the heavier user (Carlsson et al., 2021), and some do not report any effects on demand of socio-demographic characteristics (e.g., Caputo et al. (2022)). Furthermore, there is, to date, little information on the effects of income on demand. Ethnicity and culture also affect the demand for

[2]The factors that prevent plant-based meat consumption listed here refer only to the ones found in literature related to consumers' intentions to reduce meat consumption and/or to partially substitute it with plant-based meat products. Barriers that go beyond consumers' influence and preferences such as political factors (powerful interest groups, advertisement efforts, etc.), or food environment (e.g., infrastructure, food access) are not reviewed here.

plant-based meat. Bryant et al. (2019) report that the acceptance rate of cultured and plant-based meat in India and in China is much higher compared to the U.S., with the likelihood of urban, well-educated and high income consumers purchasing cultured or plant-based meat being significantly higher in the eastern countries.

3.2 Consumer awareness and information about plant-based meat

As mentioned in the beginning of the chapter, food choices and preferences are affected by non-sensory characteristics such as information. As this industry is still new, a question that arises naturally is what information do consumers have about plant-based meat? Lentz et al. (2018) found that consumers' awareness about the effects of meat consumption on sustainability was low. When participants were asked to rank food behaviors that contribute to sustainability, they ranked first behaviors such as eating seasonally and using less packaging, while they ranked eating less meat last. This is in accordance with Onwezen et al. (2021) who found that consumers do not know or underestimate the potential benefits of alternative proteins.[3]

Would more information about the ingredients and the social benefits of plant-based meat expand its demand? Martin et al. (2021) assessed consumers' purchase preferences, i.e., whether or not they will buy plant-based meat, and their willingness to pay for plant-based meat. They tested consumers under blind tasting, with exposure to packaging information only and with exposure to additional information about health or environment that was revealed in two stages. Results showed that consumers preferred the meat product under most treatments. The revelation of additional information in-

[3]An alternative explanation of this behavior, not stated by the authors, could be that it is much more costly for consumers to reduce meat rather than change other behaviors of theirs.

creased consumers' willingness to purchase plant-based meat, but only to the extent that it became equal to that of meat and never managed to surpass it.

Similarly, Katare et al. (2023) studied consumers' willingness to pay a premium for sustainably produced meat and plant-based substitutes using information nudges. The results indicate that the information intervention did not motivate consumers to pay more for the sustainable animal meat or the plant-based meat.

Besides the direct forms of information that a consumer may receive from packaging or from a statement, there are also indirect sources of information stemming from product placement or presentation order. Kurz (2018) found that the presentation of dishes in the restaurants play a role in whether people would choose a meat dish. The author found that making plant-based products more visible, or changing the order that they are presented caused persistent changes in consumers' dish choice. Finally, the extent to which consumers are receptive to information seems to vary with their attachment to meat. Graça et al. (2015b) suggest that information is likely to trigger defensive or loss-aversion mechanisms that will lead to opposite results for consumers who show attachment to meat.

3.3 Research methods

The primary approach is through surveys and hypothetical or field experiments that identify consumers' willingness to pay (WTP). Slade (2018) provided consumers with a variety of hypothetical burger options that included conventional and plant-based meat and asked them their willingness to pay. With equal prices, 65% of the participants would purchase a beef burger, 21% would purchase plant-based meat, and the remainder would purchase cultured meat or not purchase any product. Among health, animal welfare and environmental considerations, the results identified only environmental concerns as a driver of plant-based purchase decisions.

Van Loo et al. (2020) conducted an online choice experiment where 1,800 U.S. shoppers stated their valuation for conventional beef, lab-grown patty and plant-based patties. They found that, holding prices constant and conditional on purchasing a food product, 72% preferred conventional beef, 23% plant-based meat and 5% lab-grown meat. The same study found that consumers' WTP for plant-based products increased when information about the environmental benefits of plant-based meat was provided to them. The results of Van Loo et al. (2020) are quite interesting because, as will be shown in chapter 5, although the actual expenditure share of households on plant-based meat is much lower than 23% (in fact, it was found to be less than 5%), yet, the p-tobit model estimated in chapter 7 showed that indeed, 26% of consumers are willing to buy plant-based meat if the protein prices and their income permit.

Continuing with the hypothetical experiments, an online survey with hypothetical choices was used to elicit the WTP of 1,096 Swedish meat-eaters by Carlsson et al. (2021), who found that at the same price 90% of surveyed consumers would choose traditional meat instead of a substitute. Profeta et al. (2020) conducted an online hypothetical experiment that studied consumers' choice between meat, plant-based meat and a hybrid product that contained both. Even in this hypothetical scenario, meat products ranked first in consumers' choices, followed by the mixed product and then the plant-based meat product. The results suggest that hybrid products could facilitate a transition of meat-eaters towards a more sustainable diet.

Hypothetical choice experiments have been found to not predict retail sales well (Chang et al., 2009). Even if they achieve the external validity for goods well-known to consumers, one important limitation that they suffer from when it comes to novel products like plant-based meat is that consumers are unfamiliar with the taste and the smell of plant-based meat (Slade, 2018). Recognizing the importance of tasting on the demand for plant-based products, a few studies have included sensory tests including Caputo et al. (2022) and Tonsor et al. (2023).

Caputo et al. (2022) designed a sensory and discrete-choice experiment where consumers tasted a number of burgers made with beef, plant-based proteins, and a 70%-30% beef-mushroom blend. Tasting was blind for half of the participants and informed for the other half. The results showed strong consumer heterogeneity in their preference for plant-based meat. Interestingly, although product information increased the demand for a plant-based burger over a blended burger, the WTP for a beef burger was greater under both treatments.

The only study that uses purchase data to estimate consumers' demand for plant-based meat is Zhao et al. (2022), to my knowledge. It focuses specifically on the impact that COVID-19 had on demand. The study uses market scanner data from 2017-2020 on fresh meat expenditure across the U.S. Using an AIDS model, the study finds that plant-based meat is the most price elastic (-1.48) compared to beef, pork, chicken, turkey, and fish. Also, the results indicate that the pandemic affected the demand for plant-based meat positively, with the consumers increasingly adopting plant-based meat as part of their diet.

3.4 Evidence on replacement of meat with alternative proteins

The potential benefits of plant-based meat for the environment, consumers' health, and animal welfare hinge upon the perception that meat alternatives will cause a decrease in meat consumption and production. That is, consumers will treat plant-based meat as a substitute for animal products. It is, therefore, crucial to review the substitution patterns between traditional meat and plant-based meat.

The relationship of animal protein and alternative proteins is unclear in the literature and the possibility that these products may be complements cannot be rejected. For instance, the demand estimation of Zhao et al. (2022) suggests that plant-based meat serves as a complement for beef and pork and as a substitute for chicken, turkey, and fish. Finally, Tonsor et al. (2023) report cross-price and own-price elasticities of demand from two experimental studies. The elasticities of one study suggest that plant-based meat is more price-elastic compared to animal proteins and it is a complement for beef and chicken. However, the other study suggests that the plant-based meat is a substitute of chicken and beef.

Another factor that affects greatly the extent to which plant-based products can cause a significant reduction in the demand for animal protein is whether consumers will first initiate and then maintain a shift towards plant-based meat and away from animal meat. It is, therefore, critical to know the persistence of purchase over time, i.e., if individuals consume repeatedly over time or if they try plant-based meat once and then drop out.

Hoek et al. (2013) conducted an experiment where participants ate repeatedly one type of protein among chicken, tofu, and Quorn.[4] At the beginning, the two meat alternatives were liked less than chicken, but after the repeated exposure, the difference in preference was not significant. The study concludes that liking can be increased over time for products that are new. However, as the authors point out, since the initial liking was low, it is unclear if the repeated purchase and increased liking could occur.

[4]Recall that Quorn is a fungal mycoprotein that was introduced in the plant-based meat market in 1985 (Trinci, 1992).

3.5 Benefits of alternative proteins and policy suggestions

First, the magnitude of the benefits of alternative proteins on environment and on health are still unclear. For instance, Van der Weele et al. (2019) explain that meat alternatives require high levels of energy for transformation and processing which limits their sustainability benefits. Similarly, Ye et al. (2022) point out that it is unclear how resource-intensive the production method of each alternative protein is, and that the strategies for the comprehensive utilization of resources require further investigation.

Regarding the health benefits of these products, there is little actual evidence either in favor or against their healthfulness since they have not been included yet in dietary assessments (Aschemann-Witzel et al., 2021). From the existing evidence, plant-based products seem to lack the necessary nutrients to compete with the nutritional value of animal protein. Curtain and Grafenauer (2019) conducted an audit of plant-based products and conventional meat and compared them in terms of their nutritional profile. The results showed that less than a quarter of these products were fortified of vitamin B12, iron, and zinc at levels comparable to meat. Also, 96% of the products were higher in sodium, sugars, and carbohydrates. More recently, Aschemann-Witzel et al. (2021) emphasized that there is no consensus so far as to whether it is possible to produce a sufficient amount of plant proteins with a nutritional value equivalent to animal protein. Hence, the "health halo" surrounding these products may not be entirely justified.

The point of this discussion is to encourage the reader to assess and question whether alternative proteins are—or will be—able to deliver the environmental and health benefits that people perceive them to have and to what extend they are a solution to these issues. Examples of other potential avenues are to make pulses more appealing without transforming them into "meat alternatives", improve animal production such that it is friendlier for the environment, work on improving the mal-distribution of animal protein consumption (i.e., global meat overconsumption and underconsumption).

Current literature provides some, yet limited, evidence regarding the aforementioned alternative paths. For instance, Lemken et al. (2019) support that many consumers would rather use unprocessed pulses instead of plant-based meat, some are willing to try, but are not planning to reduce meat consumption and some are not willing to consider consuming meat alternatives. Martin et al. (2021) propose that there might be greater acceptance if these products are viewed as plant-based and not as meat substitutes where consumers would prefer to replace meat with legumes rather than with a processed product. de Boer et al. (2014) explore the possibility of "less but better" meat as well as the introduction of meatless meals over the week. Their results indicate that these strategies could appeal to certain consumer segments and combined could facilitate a gradual reduction in the amount and the type of protein consumed.

Questioning and putting the potential benefits of alternative proteins into perspective is particularly important before jumping into any policy recommendations that could have a tremendous impact on consumer welfare. Michel et al. (2021) identified that the high price of plant-based meat compared to conventional meat is a purchase barrier for consumers and proposed an increase of the price of meat as a way to make meat alternatives more attractive. Other policy measures that have been proposed to encourage substitution of meat with plant-based alternatives are information campaigns, product labeling, taxing meat consumption, subsidising production of plant based products, or using personal subsidies such as stamps to promote substitution (Apostolidis and McLeay, 2016).

Alternative proteins will require a high level of societal, institutional and technological coordination compared to meat in order to be viable in a large scale (Van der Weele et al., 2019). This implies that a great amount of resources need to be further invested in this industry in order to achieve a production scale that can satisfy an increased demand. This argument needs to be paired with the fact that these resources are withdrawn from the exploration of alternative solutions for the crucial objective of producing a sustainable type and sufficient amount of protein.

3.6 Contribution to the literature

The current literature reveals gaps concerning the potential impact of this emerging industry on meat demand and on the environment. So far, consumers' perceptions towards plant-based meat have been investigated mostly through experiments and not with actual household purchase data. Also, no consensus has been reached on whether consumers perceive plant-based meat as a substitute or as a complement to animal meat, nor on whether consumers' stated arguments about better health, environmentally cleaner food, and animal welfare drive an actual and persistent decrease in meat consumption. In addition, the extent to which plant-based alternatives to animal products can mitigate the adverse environmental effects of animal production has not been quantified in the literature yet.

This study extends the previous work on this topic in many ways. First, it uses actual household protein purchase where some of the households are traced across multiple years. Hence, it does not rely on stated preferences about meat and plant-based meat which, as was discussed above, are often different from the actual purchasing behavior. Further, the data spans from 2012 to 2022; this is a broad time window that essentially captures the expansion of this industry from its beginning up to its peak. In terms of the empirical component of this study, it extends previous work in two frontiers. First, both methods used in the econometric analysis, take into account the large amount of zero-expenditure observations. In addition, the double-hurdle model used here breaks down the purchasing decision into two stages (i.e., (i) the decision to consume plant-based meat and (ii) the decision of how much to consume), which gives the ability to understand how the market and demographic variables affect each decision. Also, it provides an opportunity to quantify the share of potential consumers of plant-based meat even if they haven't currently bought the product.

This study also aims to quantify the two major promotional narratives of plant-based meat, i.e., to assess whether consumers perceive plant-based meat as a healthy alternative to meat and whether this product could benefit the environment. For the former, I use household responses to a survey about their health and dietary habits to study how different health levels or dietary preferences relate to plant-based meat consumption. The last contribution of this study is the use of the estimates from the econometric models to inform a discussion about the potential environmental benefits of plant-based meat.

Chapter 4

Data

4.1 Description of the datasets

One of the main advantages of this work is the richness of the datasets used for the empirical analysis. The access to these data was granted through the U.S. Department of Agriculture, Economic Research Service (ERS) which acquires access them from the research company, Circana.[1, 2] The data contain detailed information on U.S. households' meat purchases along with their demographic and medical information from 2012 to 2022 and they are used to classify households into different consumer segments based on the intensity of their plant-based meat consumption. Such detailed dataset makes it possible to study the differences and similarities of demographic characteristics of each consumer segment and also, to estimate own-price and cross-price meat demand elasticities that contain the effects of the households' demographics and health information.

[1]This vendor is widely known as "IRI" which is its previous name. It receives consumer data from the National Consumer Panel (NCP) which is a joint venture equally owned by Circana and the Nielsen Company (Muth et al., 2016).

[2]As stated in chapter 1, the findings and conclusions contained herein are those of the author and should not be construed to represent any official USDA or U.S. Government determination or policy. The analysis, findings, and conclusions expressed in this report should not be attributed to Circana.

In this chapter, I first define some terms that are associated with the data and will be used repeatedly throughout this and the following chapters. Then, I list and describe all the datasets that were compiled in order to carry out the empirical analysis and finally, I report the data editing employed before arriving at a final dataset used in my estimations.

The products that consumers purchase from retail stores can be divided into **uniform-weight** and **random-weight**. Random-weight are perishable products that are typically sold in bulk or by unit. Goods such as fresh meat, seafood, fruits, vegetables, bakery, cheese, lunch meat, coffee, nuts, etc. belong to this category. On the other hand, uniform-weight are typically packaged products such as plant-based meat packs or canned fish.

An important distinction between the random-weight and the fixed-weight products is the fact that the latter have a Universal Product Code (hereafter **UPC**) associated with them. This is "a barcode symbology widely used in the U.S. and other countries to track trade items in stores" (Muth et al., 2016). Any product with a UPC can be scanned by a standard **point-of-sale** checkout or by the payment system that retailers have.

4.1.1 Household-based scanner data or Consumer Network data

The Consumer Network dataset is the most fundamental data source for the current study, and it contains information on all shopping trips of thousands of households in the U.S. These households are recruited and incentivized to record the transactions from each shopping trip they make by using a handheld in-home device.[3] The dataset contains quantities purchased, total dollar amount paid per product per trip (i.e., not unit prices), discounts, and coupons used.

[3]For more information on the recruiting process of the households to the consumer panel the interested reader should refer to Muth et al. (2016).

The total dollar amount paid for each product is not always reported by the households. In fact, more often than not households are not the ones reporting this value. More specifically, when households scan their purchases they enter the store where the purchase occurred. If the store is included in the network of stores from which Circana receives retail data, then the household does not enter an amount and Circana assigns a value based on the average purchase price of the specific store chain and market area.

If such information is not available, then Circana assigns a value based on the average price for this type of store (i.e., grocery store, mass merchandiser etc.) in the specific market area. If neither such information is available, then the household is asked to insert the amount paid. Finally, if the household does not enter a value, Circana assigns a value based on price dictionary; a long-term average price for each UPC, by outlet type and at the national level. Although such process reduces the participation costs for the households, it inevitably reduces the variation of prices actually faced by the consumers. The composition of the various sources of the total dollar amount paid in the sample of this study is shown in table 4.1:

Table 4.1: Data sources of the dollar amount assigned to each observation in the sample

Price source	Number of observations	Percent
Household	18,255,558	51.14
Retailer (actual or similar)	16,976,692	47.56
Dictionary	461,304	1.29
No price	3,209	0.01
Total	35,696,763	

In this study I observe reported household shopping trips between 2012 and 2022. Some households appear in the dataset only in one year and some households appear in multiple years. Households are distinguished by a unique ID and each product they purchase can be identified and linked to its product information through the UPC. Regarding the geographic location of the shopping trip, it is important to note that households record the retail chain and not the specific store that they visited. Therefore, the shopping trips can be geographically linked to a broadly defined market and not to a specific location.

Consumer Network panel tied to product dictionaries

For each product that is available in the collaborating retail stores, Circana provides product dictionaries with information about various product attributes and descriptors. These product dictionaries can be linked via UPC to any product purchased by the households and provide information on the weight of the product, on nutritional claims, and on whether the product is random-weight or fixed-weight. For the majority of the UPCs, dictionaries also contain information on the store aisle they belong to, the product category and provide a brief description of the product.

This is one of the most critical pieces of information for the present work, since the cleaning and the classification of the data under different protein types were based on a combination of multiple variables from these dictionaries. Also, the information on the quantity of the product is used to derive the per-unit price of each item. A detailed description of the data editing is provided later in this chapter in section 4.2.

Consumer Network panel tied to household demographics

Each household can be tied to its demographic profile via its household ID. Demographic variables relevant for this study include the household size, household income (in a scale with multiple thousand-dollar increments), age, gender, and education of the primary shopper, as well as the state of residence and the shopping market area (as defined by Circana).

It is estimated that about 75% of all participated households update annually their demographic information and it is unknown whether this percentage is higher for the households who report their purchases more consistently (Muth et al., 2016).

Consumer Network panel tied to household members' medical conditions

Every household in the Consumer Network panel is asked once per year to participate in an opt-in survey regarding members' health concerns, medical conditions, diet, and lifestyle. In contrast with the demographic and shopping information, which are recorded at the household level, this survey is conducted at the household member level. That is, each household member can provide an individual response. I use this dataset to create a household's "health index" and explore whether health concerns and illnesses affect the likelihood of shifting towards plant-based meat products.

Relevant variables used from this survey are members' self-assessment of their health-state (e.g., poor, very good, excellent), any health problems they may suffer from that can be linked to food consumption, whether they pay attention to food ingredients, whether they are concerned about health factors such as weight, stress level, cholesterol, diabetes, etc., and whether they follow a low-carbohydrates/calorie/fat/sugar diet. In 2022 only, participants were also asked if they are vegan or vegetarian, and if they follow a low-meat diet. Each year about one third or less of the households in the entire panel have at least one member who has responded to this survey.

4.2 Notes on the construction of the master dataset

4.2.1 Exclusion of households that did not report consistently

From the total number of households who commit to participate to the Consumer Network, only half or less report their transactions consistently enough. For this reason, Circana divides the Consumer Network dataset into a "static" and a "not-static" panel. The static panel, includes only the households which pass the following reporting-consistency thresholds:

1. Households that have reported purchases at least once every four weeks for 80% of the weeks of the year.

2. Households that have reported a minimum average spending of $25 per week if 1-person households, $35 per week if 2-person households and $45 per week for 3-or-more person households.[4]

The analysis of this study is narrowed down to the static panel. This improves the overall quality of the data without harming significantly the amount of information used since the static panel accounts for the majority of the transaction records in the dataset (indicatively, in 2012 the static panel accounted for 82% of the total number of transaction records).

4.2.2 Inclusion of random-weight items

In this study both fixed-weight and random-weight products are taken into account, although, it is important to note that random-weight meat products do not have a unit of measurement for the quantities purchased which makes it impossible to know if a quantity refers to pounds or to pieces. For instance if an observation for chicken breasts lists a quantity of 5, it is unclear if this corresponds to 5 pounds or 5 pieces. This, in turn, makes it impossible to obtain unit prices for these products, since the only way to derive the unit prices from the dataset is to divide the expenditure by the quantity purchased (for a detailed description on prices see section 4.2.6).

[4]This information comes from Muth et al. (2016) which covered the period 2008 to 2012. Although there is not more recent explicit information available on these criteria, it can be inferred from more recent data manuals that the minimum spending cutoff has not increased in recent years.

Nonetheless, because the expenditure share on random-weight meat items is high for the households that report such purchases, it is necessary to be included in the economic analysis. In table 4.2, I present the expenditure share on random-weight items of each protein type for the year 2022, which was the year with the most households reporting such items. I also list the average share on random-weight items for the entire period 2012-2022. Note that there are no random-weight plant-based meat products available (at least up to 2022). Also, although 2022 had the largest percentage of households that reported random-weight items, the average share across all years is slightly higher than the share of 2022 alone. This is because the reporters in earlier years (e.g., 2012 and 2013) had a random-weight expenditure share of around 60%.

Table 4.2: Expenditure share of random-weight products by each protein type

Protein	**Share in 2022**	**Average share 2012-2022**
Beef	0.21	0.25
Pork	0.09	0.11
Poultry	0.14	0.15
Seafood	0.06	0.06
Plant-based	-	-

4.2.3 Population weights or projection factors

As explained in sections 4.1.1 and 4.2.2, the ultimate dataset includes data on households that reported consistently both random-weight and fixed-weight meat products and have completed the survey about their medical profile. An important issue that arises with the restriction of the sample to the static panel is the potential effect that it may have on the demographic representativeness of the sample with respect to the U.S population demographics. That is, whether the share of each demographic group in the sample is the same as its respective share in the U.S. population. For this reason, Circana provides weights associated with each household in the static panel, called projection factors, that weight the data to match the demographics of the U.S. Census and the American Community Survey. The projection weights are specific to the static panel and aim to balance the differences between the static panel and the general population.

Since not all households in the static panel report random-weight purchases[5] or complete the survey about their health profile,[6] Circana provides different sets of projection factors for each of these subsets of households. I use the two sets of factors to create two samples. One includes households who reported consistently both random-weight and fixed-weight items; let us call this "main sample" since it is the primary dataset of the study. The other, let us call it "health survey sample", includes households which reported consistently both random- and fixed-weight items and completed the health survey. Figure 4.1 is a visual representation of the main and the health survey sample. The numbers of each subset in the graph represent the total number of households across the 11 years.

[5]On average 77% of the households static panel have reported random-weight items.

[6]On average 51% of the households in the static panel have completed the health profile survey.

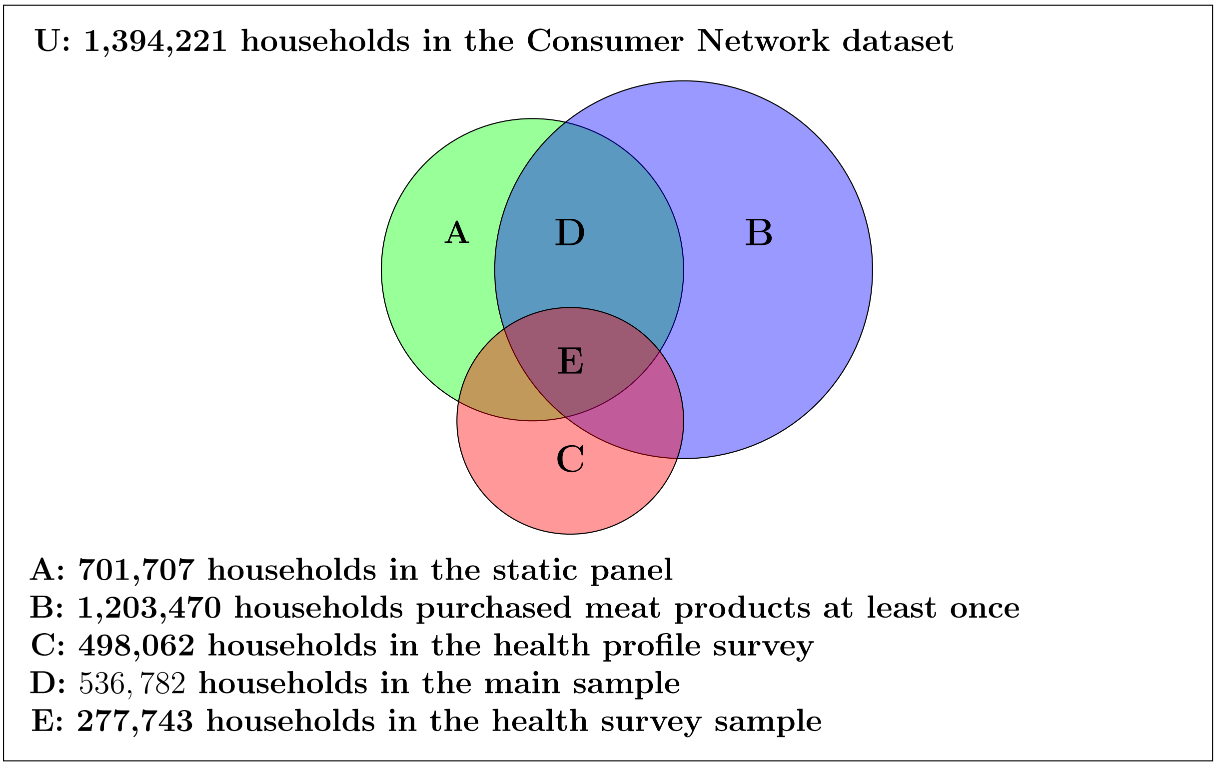


Figure 4.1: Households included in each sample

Although projection factors are not used in the econometric analysis that happens at the household level, they are useful to obtain an approximation of national total expenditures on proteins. To estimate this, I multiply each household's quantities purchased and expenditures by its respective projection factor. It is important to note that the projection factors provided by Circana are similar, but not identical to the demographic proportions found in Census. These differences are the result both of the self-selection of the households in the panel in general and of the behavioral qualities of the households who report consistently. In section 9.1, I discuss the potential adverse effects of these weight discrepancies on the conclusions of this study.

4.2.4 Selection process of UPCs

There are many types of products that the households purchase and that contain meat (e.g., cooked meals, kits, products with fresh uncooked meat). An important decision to be made is which of these products will be included in the sample. In this section, I describe what products I defined as "meat products."

I focus only on uncooked animal-protein products of all kinds (e.g., pork, chicken, beef, fish) and some processed meats such as ham, bacon, patties, sausages, shelf-stable meat chunks, and jerkies. I have excluded from the sample processed meats (frozen or fresh) in the form of pre-cooked meals, meatballs, loaves, breakfast kits, and salad kits.

The work of narrowing down the dataset to the desired products started by excluding unrelated products based on the most aggregated product category provided by Circana, i.e., the grocery store department that the products belong. Then, the remaining unrelated products were excluded by using more disaggregated categories such as the "aisle" which is the second most aggregate product classification variable of Circana and contains the grocery aisle that each product belongs to (e.g., baking aisle, baby food aisle, produce aisle). Before excluding an aisle, other, less aggregated variables such as product type and product category were studied to ensure that no relevant products were eliminated. This process was repeated for the relevant aisles too. For instance, the aisle that contained deli was kept, and then the product type and category variables were used to eliminate deli cheese and keep only deli meat.[7] Ultimately, the products that remained unclassified were kept or excluded based on their individual UPC description.

Once this process was completed, a second refinement was initiated in order to remove undesirable processed products. At this phase, any meat that was contained in meals, entrees, meatballs, loaves, seafood cakes, or contained a combination of meats

[7]For the years 2012-2018 products were split into "perishable" and "not perishable" datasets. The process described above was repeated in both datasets in order to ensure that all the relevant items were included. In later years, there was only one dataset that included both types of products.

(e.g., sausage with beef and pork), was excluded. The decision to remove these products was based on the fact that, first, very frequently they contain a mix of proteins and they cannot be classified as "beef," "pork," "poultry," "seafood," or "meat substitutes" and second, the presence of meat substitute products in grocery stores deli departments was minuscule for the majority of the years that are included in the sample.

Once this step was completed, the retained products were classified as "beef," "pork," "poultry," "seafood," or "meat substitutes." This classification happened at the UPC level, with the use of key words from the product description. Key words could be the type of meat such as "beef," or a brand. Products where the description and/or brand did not indicate a specific meat type such as "chorizo," "bacon," "ham," "braunschweiger," "frankfurter," etc., were classified after searching the type of meat typically contained in these products.

The final step was to study all the available information, including description, brand, aisle, product type, etc., of each product that remained unclassified. In most cases these were sausages that had no indication of the type of meat that was contained. These products were excluded too. Circana has introduced a series of changes in the way that it delivers the data to ERS, and as a result each year's dataset structure is similar, but not identical. Because of this reason, and in order to avoid mistakes due to changes in aisle names, product categories, etc., the refinement and classification were repeated separately for each year.

The refined dataset with the classified meat products was then tied through the UPC to the households that purchased each product. From a total of 701,707 households in the static panel across the 11 years, 1,952 households had never purchased an unprocessed meat or plant-based meat product included in my analayis. That is, 99.72% of the static panel was matched with at least one of the identified meat products or meat alternatives. Only these households were kept in the sample. Finally, the households that remained in the sample were tied to their demographic information and health profile via their ID number. Figure 4.2 depicts how the different datasets were merged.

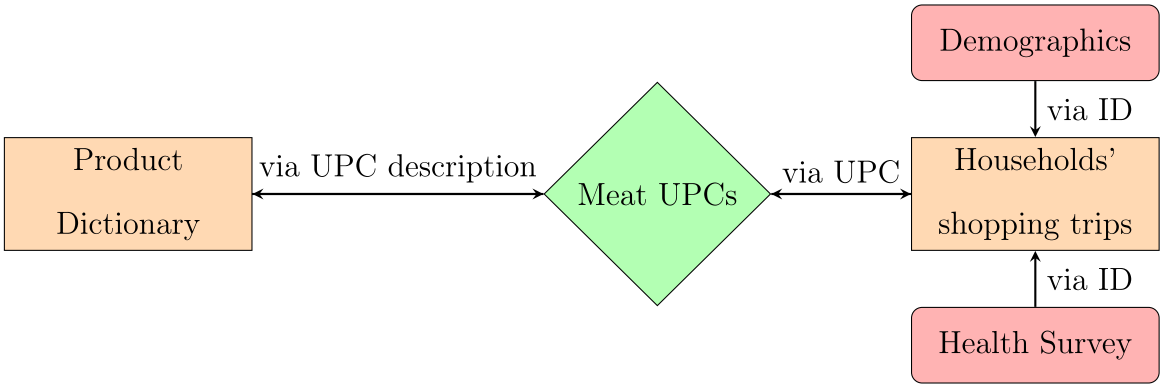


Figure 4.2: Merging of the different datasets

Quality test

A significant challenge when working with household- and retail-level data is that one can never be certain that no observations have been unintentionally excluded or misplaced. The volume of these data is so large that the inspection of mistakes is an exercise of its own. To address this concern, I performed a quality test to ensure that: (i) the master dataset includes all the items of interest, and (ii) that each product is classified under the correct meat category (e.g., plant-based meat products are classified as "meat substitutes" and not as "pork" or "chicken.").[8]

The general approach to doing quality control was to examine how well the most prominent plant-based meat alternative products were captured. Of course the alternative meat market, with thousands of items, is much broader than the products included in the quality test, but as long as the products that are most common to consumers are correctly captured, then the cost of false positives or false negatives is likely to be small.

[8] I am grateful to one of my ERS collaborators, Patrick W. McLaughlin, for his idea to carry out such test and for setting up a prototype model which I then used and developed further in order to cover the entire dataset.

To identify the prominent brands that are exclusively plant-based alternatives to animal products, I used the report of Good Food Institute (2022). With the top brands in mind, my first step was to see how many top brand items (i.e., UPCs) show up in my curated set of product dictionary records and compare it with the number of UPCs in the raw Circana dataset. I repeated this process separately for each of the years since the products change over time.

By comparing the numbers from the raw data and the clean dataset, I can assess whether there were mistakes made in the process. Table 4.3 lists the missing plant-based products per year.

Year	Number of Top Brands in Raw Data	Number of Top Brands Missing
2012	307	17
2013	225	9
2014	257	11
2015	415	20
2016	439	20
2017	428	16
2018	419	15
2019	502	60
2020	502	22
2021	557	24
2022	840	234

Table 4.3: Quality test

I used the description of the UPC of each of the missing products per year, along with any other information available for the type of the product to check why the product was not included in the curated dataset. The results of this process showed that these products were excluded because they were either prepared meals or processed products in the form of meatballs, or loaves which are not part of the dataset. Notably the total number of products as well as the number of excluded products in 2022 is much larger than any of the previous years. This is because the number of ready meals that contain plant-based meat offered in grocery stores has increased—notice that the total number of top-brand products is inflated too in 2022. However, after reviewing the description of each missed product, none of these items were falsely excluded from the sample.

Moving to misclassifications and focusing now solely on the observations that were classified as meat substitutes, the cleaning process was repeated until no false positives were found. That is, until there was no product that had mistakenly been classified as plant-based meat. The vast majority of these records have the word "substitute" in their product description, which made it obvious that they are meat substitutes. For the remaining items also, the descriptions tended to include the words that made it clear that it was a plant-based protein. Similarly, I tested whether there were meat-substitute products included in the sample that were not classified as plant-based products. No false negatives were found in the test.

In conclusion, the process undertaken for identification of plant-based meat alternatives appears to have been successful, especially in terms of identifying items that have the potential to be most prominent, i.e., those of the top brands. Some items belonging to the top brands were excluded on the basis that they were part of prepared meals or processed products.

4.2.5 Exclusion of outliers and erroneous observations

Once the protein UPCs were matched with the households that purchased them, the data were checked for outliers or obvious data-insertion errors. The first observations that were dropped were the ones where the actual dollar value paid was likely to be erroneous. More specifically, for each transaction I calculated the actual dollar amount paid after subtracting any coupon value. I removed any observations where the actual price paid was negative, zero, or very low for the item in question (e.g., \$0.01 for 32oz of shrimp, or 24oz of chicken). Table 4.4 shows the percentage of observations dropped.

Table 4.4: Number of observations dropped because of their net price paid

Actual dollars paid	**Percentage out of total obs.**
Negative	0.24%
Zero	0.09%
$\$0 < x < \$0.5$	0.21 %

Another group of dropped observations comes from 20 households which participated multiple years in the panel, but their yearly protein expenditure for some of these years is zero. Although these households are included in the summary statistics, the years that their protein expenditure was zero had to be dropped from the econometric estimation of the demand system because the model requires a positive total expenditure for each observation. Each of these households reported zero expenditures only in one year out of all the years that they stayed in the panel.

Further, products with "count" as their unit of measurement were dropped as well because there was no reliable way provided by Circana to convert this unit into pounds. These observations comprised 0.84% of the total number of UPCs accounted in this sample and 0.08%[9] of the total number of observations (see table 4.5).

[9]This figure is a percentage out of the fixed-weight observations since the random-weight items do not have a unit of measurement for quantity. If I include the random-weight observations in the total, then the percentage of observations tied to "count" unit of measurement is 0.0005%.

Table 4.5: Number of UPCs reported under each unit of measurement

Unit of measurement	**Number of UPCs**	**Panel obs. tied to this unit**
oz	283,747 (53.87)	15,097,955 (62.87%)
Pound	238,569 (45.29 %)	8,898,447 (37.5%)
Count	4,407 (0.84%)	18,555 (0.08%)
Total	526,723	24,014,957

The final set of outliers and possibly erroneous records was related to the age of the primary shoppers. Around 2% of households reported their demographics for multiple years and the difference in their age in two consecutive years was more than 1. These households are kept in the sample, but their age is dropped. Also, in households where two primary shoppers were included (a male and a female) and the age of one was above 97 years old, only the age of the younger primary shopper was kept.

4.2.6 Calculation of unit prices

As mentioned in section 4.1.1, unit prices for each UPC are not available in the dataset. However, they can be derived by the reported total dollar amount paid and the per-unit quantity of each item.[10] To find the price of each item, I first calculated the total quantity purchased (e.g., if a household bought two units of a specific UPC, I multiplied the quantity of the unit by two to find the total quantity purchased) and then I divided the total dollar amount paid by the total quantity of pounds purchased. The weight of the products was reported in different units of measurement (see table 4.5) so, before calculating the prices, I converted all product quantities into pounds.

Two more issues arise with the use of prices: the inflation of prices over time and the use of prices of in the econometric analysis that happens at the year level. For the former, I converted the prices to real terms, by using the annual average Consumer Price

[10]This process is relevant only for fixed-weight items since there is no reliable quantity for random-weight items.

Index (CPI) reported by the Bureau of Labor Statistics (2023) (see appendix A). For the latter, I computed the average price per protein that each household faced each year. If such price was not available, e.g., a household did not consume pork, I computed the average yearly price for pork at the zip code level. If neither such price was available, I calculated the average yearly price at the level of the specific market area.

4.2.7 Aggregation of quantities consumed at the year level for the empirical analysis

The estimation of the demand system happens at the year level for several reasons. First, as it will be shown in chapter 5, households purchase very few plant-based meat items per year, with the majority buying one or two times throughout an entire year. This means that an analysis at the monthly level, let alone at the weekly level, would intensify the already existing issue of many zero expenditures on plant-based meat. Further, considering that the sample consists of $536,782$ households, the computational burden of the estimation of a demand system with more than 8,000,000 observations makes it very challenging to work with purchases aggregated at the month level. Finally, the focus of the demand estimation is to reveal the underlying relationship between plant-based proteins and animal proteins over the years and whether plant-based meat consumption has lead to significant decreases of animal protein consumption. An aggregation at the year level is sufficient to achieve this goal.

Note that, as mentioned in section 4.2.6, the aggregation of quantities at the year level implies that the prices of each protein, for each household have been averaged at the year level too. More specifically, the price of each protein faced by a household in a given year is the average price of all items of this protein type purchased by the household, weighted by the quantity purchased. In other words, the protein prices for each household are imputed by dividing total expenditure on a protein over total quantity.

4.2.8 Construction of health variables

The household health profile survey described in section 4.1.1 contains interesting and relevant information on respondents' health status and dietary habits that can help to explore how consumers with various health conditions and dietary preferences perceive plant-based meat as well as conventional meat consumption.

There are two important notes regarding the construction of the health variables. First, since this survey is completed at the individual level and not at the household level while the econometric analysis happens at the household level, I aggregate these variables at the household level too. Second, I group a number of these questions under a common theme, such as questions about food ingredients or questions about suffering from diseases that are connected to food consumption. The reason for grouping these questions into a common-themed variable is because I am not interested in the effect of a specific disease or ingredient on plant-based meat demand, but rather on testing the hypothesis that consumers consider plant-based meat as a healthier alternative to meat. More specifically, whether the purchasing behavior of the households that are more intentional about food consumption due, for instance, to a food-related health disease or a concern about food ingredients differs from those who do not place such constraints in their food consumption. To incorporate this information to the analysis, I create an index. Below I describe the health themes that I use in this study and how I create a single index for each theme:

- **Household's self-assessment of health:** This variable represents the score of the household on three questions:
  1. "I don't feel I do enough to stay healthy" (1=Agree 2=Neutral 3=Disagree).
  2. "I am much healthier than most people my age" (1=Disagree 2=Neutral 3=Agree).
  3. My health is (1=Poor 2=Fair 3=Very good 4=Excellent).

To aggregate at the household level, I take the average response of the household to each question and then I add the three averages to create an index. The higher the total score, the better the health status of the household according to their self-assessments.

- **Household's concerns about diet-related health issues**: This variable shows whether the members of the household are concerned about a health issue related to dietary intake and how much. Note that these members do not necessarily suffer from this health issue but, they are merely concerned about it. The variable contains responses of the members on five questions:

  1. "I am concerned about becoming diabetic" (1=Not at all concerned 2=Somewhat concerned 3=Very concerned).
  2. "I am concerned about my weight" (1=Not at all concerned 2=Somewhat concerned 3=Very concerned).
  3. "I am concerned about my cholesterol levels" (1=Not at all concerned 2=Somewhat concerned 3=Very concerned).
  4. "I am concerned about heart problems" (1=Not at all concerned 2=Somewhat concerned 3=Very concerned).
  5. "I am concerned about my digestive health" (1=Not at all concerned 2=Somewhat concerned 3=Very concerned).

  In this case, the higher the score the more concerned the members of the household are.

- **Household's experienced health issues**: With this variable I aim to capture the purchase behavior of households which face health issues that can be linked to food habits. This variable contains answers of household members to the following questions:

1. "I suffer from high cholesterol" (0=No 1=Rx only 2=Over the counter only 3=Dual 4=Sufferer do not treat).
2. "I suffer from type I diabetes" (0=No 1=Rx only 2=Over the counter only 3=Dual 4=Sufferer do not treat).
3. "I suffer from type II diabetes" (0=No 1=Rx only 2=Over the counter only 3=Dual 4=Sufferer do not treat).
4. "I have experienced a heart attack" (0=No 1=Rx only 2=Over the counter only 3=Dual 4=Sufferer do not treat).
5. "I suffer from heart problems" (0=No 1=Rx only 2=Over the counter only 3=Dual 4=Sufferer do not treat).
6. "I suffer from high blood pressure" (0=No 1=Rx only 2=Over the counter only 3=Dual 4=Sufferer do not treat).
7. "I suffer from obesity" (0=No 1=Rx only 2=Over the counter only 3=Dual 4=Sufferer do not treat).
8. "I suffer from cancer" (0=No 1=Rx only 2=Over the counter only 3=Dual 4=Sufferer do not treat).

I define a member as a "sufferer" if they use prescribed medication, over-the-counter medication, or both for their problem, or if they state that they have it, but they do not treat it. To obtain each individual's health issues, I sum across these variables. Then, I sum across all household members who completed the survey. The higher the value of this variable, the more health issues a household is facing.

- **Ingredient-conscious household**: Any concerns of the households regarding the ingredients of the food are included in this variable. It contains information on whether the family consumes organic, high fiber or high protein products, whether it does not consume gluten, and whether it follows a low-carbohydrate, or low-fat, or low-salt, or low-sugar diet. Although ingredients such as sugar are not included or are contained in a low concentration in meat products, they still signal a household that is careful and intentional about food consumption. The questions that are grouped in this variable are the following:

1. "I follow an organic/Non-GMO diet" (0=No 1=Yes).
2. "I follow a gluten-free diet" (0=No 1=Yes).
3. "I follow a high-fiber diet" (0=No 1=Yes).
4. "I follow a high-protein diet" (0=No 1=Yes).
5. "I follow a low-calorie diet" (0=No 1=Yes).
6. "I follow a low-carbohydrates diet" (0=No 1=Yes).
7. "I follow a low-fat diet" (0=No 1=Yes).
8. "I follow a low-salt diet" (0=No 1=Yes).
9. "I follow a low-sugar diet" (0=No 1=Yes).

- **Household concerned about food**: In this variable, I have incorporated information on households' concerns regarding antibiotics in meat production, growth hormones/rBST in dairy, trans fat/hydrogenated oil, artificial flavors and genetically modified organisms. As it can be understood from the descriptions of the questions below, the higher the value of this variable, the more concerned the household is.

    1. "I am concerned about growth hormones/rBST in dairy products" (1=Not at all 2=Somewhat 3=Very concerned).
    2. "I am concerned about fat/hydrogenated oil in food" (1=Not at all 2=Somewhat 3=Very concerned).

3. "I am concerned about antibiotics used in meat production" (1=Not at all 2=Somewhat 3=Very concerned).
4. "I am concerned about artificial flavors in food" (1=Not at all 2=Somewhat 3=Very concerned).
5. "I am concerned about GMO in food" (1=Not at all 2=Somewhat 3=Very concerned).

The following variables represent individual questions and they are are not indexes. I singled these variables out because each of them represents a different level of low-meat diet and they are very relevant to plant-based meat demand. Unfortunately, these variables are available only for 2022, but I still incorporate them in the summary statistics and in a cross-sectional empirical model.

- **Flexitarian diet**: "I follow a flexitarian diet" (0=No 1=Yes). The higher the number, the more household members are following this diet.
- **Vegan diet**: "I follow a vegan diet" (0=No 1=Yes). The higher the number, the more members are following this diet.
- **Vegetarian diet**: "I follow a vegetarian diet" (0=No 1=Yes). The higher the number, the more members are following this diet.

Chapter 5

Summary statistics

This chapter presents summary statistics and graphs from the data to understand better households' protein purchasing patterns and the effect of the introduction of plant-based meat on the other proteins in the market. The first section reviews the products that are available at the stores in general, regardless if they were purchased by the household panelists in the sample or not. The second section focuses on the households that comprise the sample of the study. It reviews their protein consumption patterns and how they change depending on the different demographic and health profiles. To ease visual comparisons, each protein is consistently depicted with the same color throughout the chapter. Beef is depicted with red, pork with purple, poultry with yellow, seafood with blue, and plant-based meat with green.

5.1 The market for proteins

One question that is worth exploring is how the distribution of meat products available in the market has changed over time with the increased presence of plant-based meat. Figure 5.1 shows the available UPCs in the market per year for each protein, and figure 5.2 shows the number of available plant-based meat products per year. These UPCs represent all the meat products of the sample[1] (for details on the selection process see section 4.2.4), before they were merged with the households. Some of these products were not purchased by households in the static panel. However, they are meat products available in the market (and probably have been purchased by households in the non-static panel) and so, they are included in graphs 5.1 and 5.2.[2]

It is clear that there is an upward trend on the market availability of plant-based alternatives. However, even in the most recent years, where the popularity of these products has reached its peak, their share in stores is less that 5% of the total meat products (as a reference, the absolute number of plant-based meat products over time is shown in figure 5.2). Seafood products comprise the highest percentage, i.e., over 30% of UPC presence in stores, followed by pork products. This is not surprising since seafood is the only protein that, beyond the frozen and fresh sections of the stores, has as an extensive presence in the shelf-stable section too (e.g. canned fish and caviar). One thing to note in figure 5.1 is that the availability of each animal protein relative to the other does not change over time. Examining the availability of each protein individually, seafood is the only one of the animal proteins that has an increasing UPC presence over time, while pork and beef show a slight decrease. Finally, the graph verifies the fact that plant-based meat is a niche product with limited availability and that the scales of the traditional meat market and the plant-based meat market are totally different.

[1]Random-weight products are included too, although their presence does not have a significant effect on this graph because random-weight proteins have only a handful of generic UPCs per protein.

[2]This analysis does not distinguish the UPCs according to the year that they were introduced neither tracks for how many years a product appeared in the stores after its first introduction. It is known however that a large number of new products fail within a year from their introduction and future research on the topic could explore this issue for the plant-based meat products.

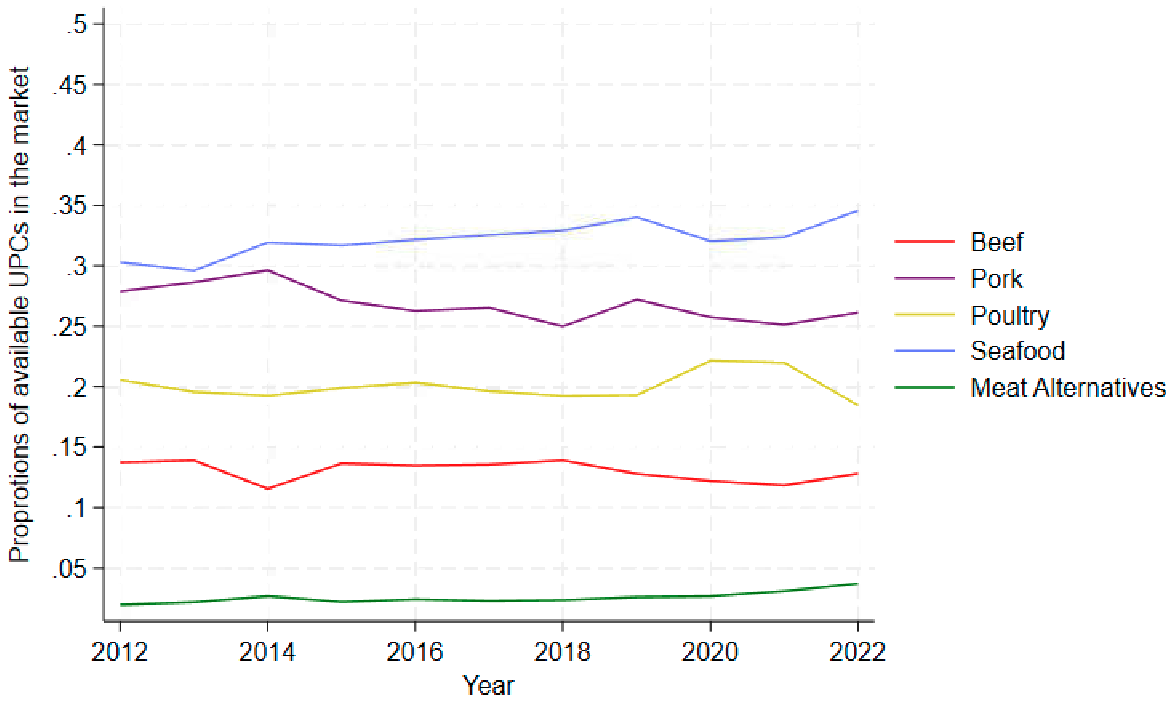


Figure 5.1: Proportion of available UPCs in the market per protein

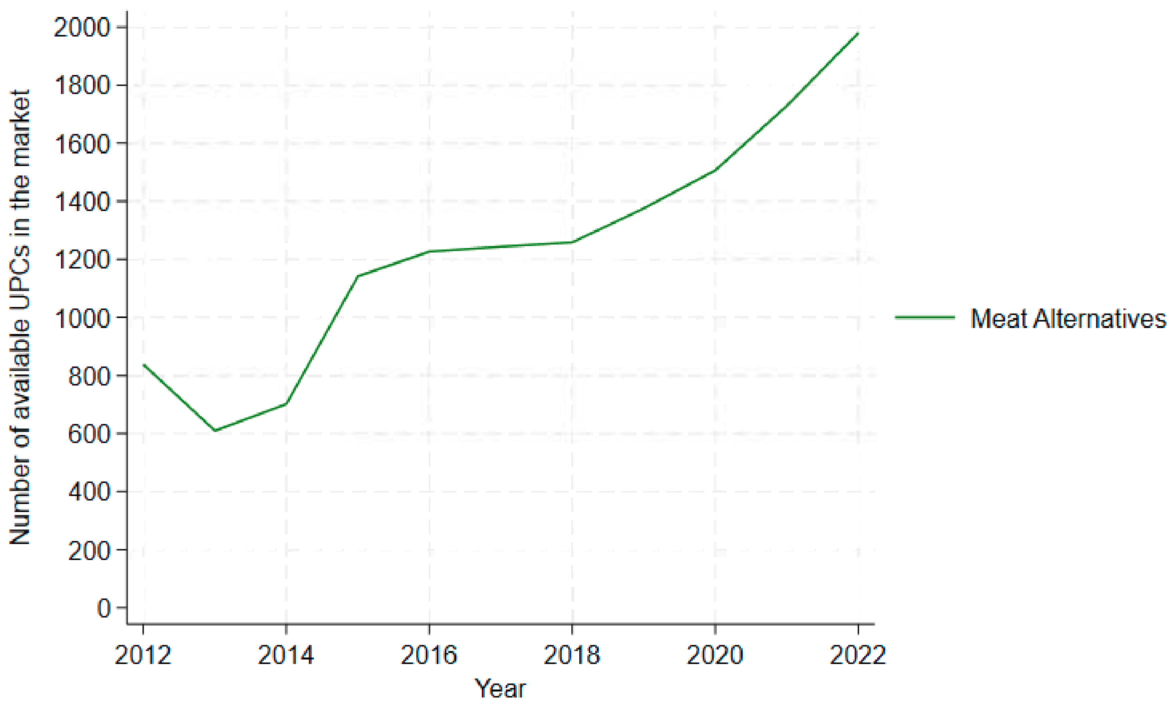


Figure 5.2: Number of meat-alternative products in the market

Another important question regarding the market of proteins is related to their cost and whether prices of proteins have been decreasing as plant-based meat is becoming more popular among consumers. Figure 5.3 shows the pricing patterns in nominal from 2012 to 2022. The prices are monthly averages of the per-pound price of each protein, in U.S. dollars.

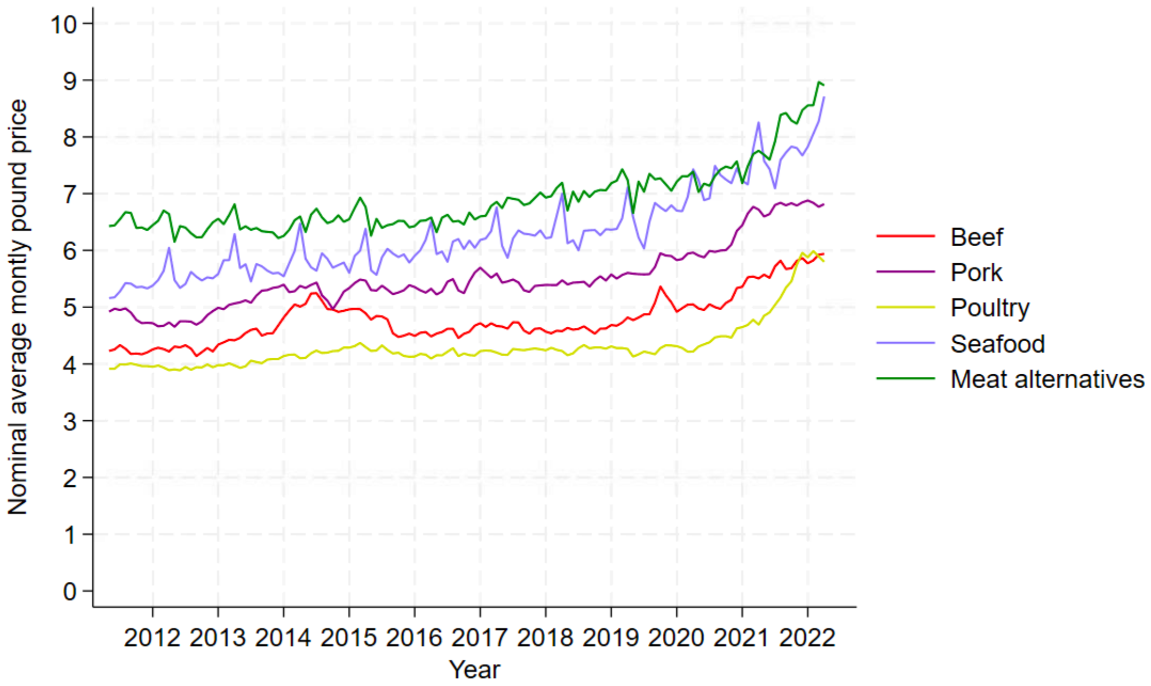


Figure 5.3: Per-pound protein prices in nominal terms (in U.S. dollars)

Plant-based meat is consistently the most expensive category throughout years, with an average price gap of around \$3 relative to poultry—a protein not as burdensome for the environment or consumers' health as the proteins from ruminants, and one that is widely available in a less-processed form compared to plant-based meat. Further, using 2018 as a reference point, which, according to figures 5.1 and 5.2, is the starting point of a steep increase in the availability of plant-based meat in the market, and comparing it with the price levels of plant-based meat since then, one can infer that promotions and other contributors to consumer preferences shifts have indeed expanded the demand for these differentiated products, since their price did not decrease despite the increased supply.

5.2 Protein purchases of households

This section is based on the main sample, i.e., on the households which belong to the static panel and which purchased at least one type of protein, in a fixed-weight or random-weight form, at least once for the given year that they were observed.[3] The sample includes 127,606 unique households across 11 years—from 2012 through 2022. The term "unique" implies that this number does not account for the fact that some households participate in the panel for more than one year.

Many of the 127,606 households have been traced throughout multiple years. More specifically, as table 5.1 shows, 7% of the households have reported their purchases for all 11 years and around 31% of the households are in the sample for 5 years or more. Regarding the number of households observed per year, on average 48,798 households report their purchases (see table 5.2) and each year comprises around 9% of the total sample. There is a significant increase in the households from 2015 and on and this is because every year more and more households report their random-weight purchases. The number of households per year presented in table 5.2 is pretty consistent with the number of static households reporting random-weight groceries provided by Circana, which is an indication that the data have been cleaned properly.[4] Overall, the sample includes $536,782$ observations (i.e., household-year combinations) across all years.

[3]For a detailed description of the criteria for static panel classification see section 4.2.

[4]The average number of households per year in the random-weight panel reported by Circana is 49,002.

Table 5.1: Number of households traced in multiple years

Years in the panel	Number of HH	Percentage	Cum. Percentage
1	35,635	27.93	27.93
2	19,167	15.02	42.95
3	13,837	10.84	53.79
4	10,450	8.19	61.98
5	8,739	6.85	68.83
6	8,375	6.56	75.39
7	6,299	4.94	80.33
8	6,788	5.32	85.65
9	4,966	3.89	89.54
10	4,384	3.44	92.97
11	8,966	7.03	100
Total	127,606		

Table 5.2: Number of observed households per year

. Year	Number of HH	Percentage	Cum. Percentage
2012	33,780	6.29	6.29
2013	36,437	6.79	13.08
2014	40,603	7.56	20.65
2015	46,686	8.70	29.34
2016	51,110	9.52	38.86
2017	55,365	10.31	49.18
2018	55,603	10.36	59.54
2019	55,980	10.43	69.97
2020	55,210	10.29	80.25
2021	53,674	10.00	90.25
2022	52,334	9.75	100
Total	536,782		

Table 5.3: Average annual number of shopping trips

	Mean[a]	**Std. dev.**[a]	**Min**[a]	**Max**[a]
All trips	78.75	42.78	1	359.63
Trips involving a protein purchase	28.40	18.27	0	258.63

a: This is the average value of the statistic produced for each year.

Table 5.4: Gender composition of the primary shopper of U.S. households

Gender	**Percentage**
Female	78.80
Male	21.20

As per tables 5.3 and 5.4, households do on average 1.5 shopping trips per week (79 trips per year), and one third of the trips involves a protein purchase (on average 28 trips per year).[5] Female household members are primarily responsible for making these shopping trips (i.e. the primary shopper for 79% of the households is female).

Regarding the percentage of households per year that consume each protein type, both in a random- or fixed-weight form, figure 5.4 shows that, as expected, the percentage of households that consume animal proteins is much higher than the percentage that consumes plant-based proteins, with each animal protein being consumed by at least 84% of American households.[6] Notably, the relative proportions of households consuming each animal protein are very stable over time with poultry being the most popular followed closely by pork and beef. All animal proteins show a small and steady decrease of the percentage of households that consume them. Beef has the largest attrition of households,

[5]The annual number of shopping trips was very consistent across years, therefore only the average is reported here.

[6]These percentages are calculated with the use of projection factors in order to approximate the actual national percentages of consumption.

moving from 94% of U.S. households consuming beef in 2012 to 90% in 2022. During the same time period, households consuming pork have been dropped from 95% to 91%, poultry from 97% to 94%, and seafood from 87% to 84%. Although one should use caution to not over interpret this graph since it does not reflect quantities consumed or expenditures, this graph may provide support to the idea that households have started shifting their dietary habits away from animal proteins.

When it comes to households that consume plant-based meat specifically, their percentage was fluctuating between 13% and 14% in the early years, but it has notably increased by 6 percentage points from 2018 to 2020, although, the rate of increase diminishes after 2020. Overall, the percentage of households purchasing plant-based meat in recent years is higher than in the past, but the total percentages of households purchasing these products remain small. Despite a significant increase in the availability of these products in recent years, only two out of ten households have purchased any of these products so far. In contrast, nine out of ten households continue to purchase beef at retail.

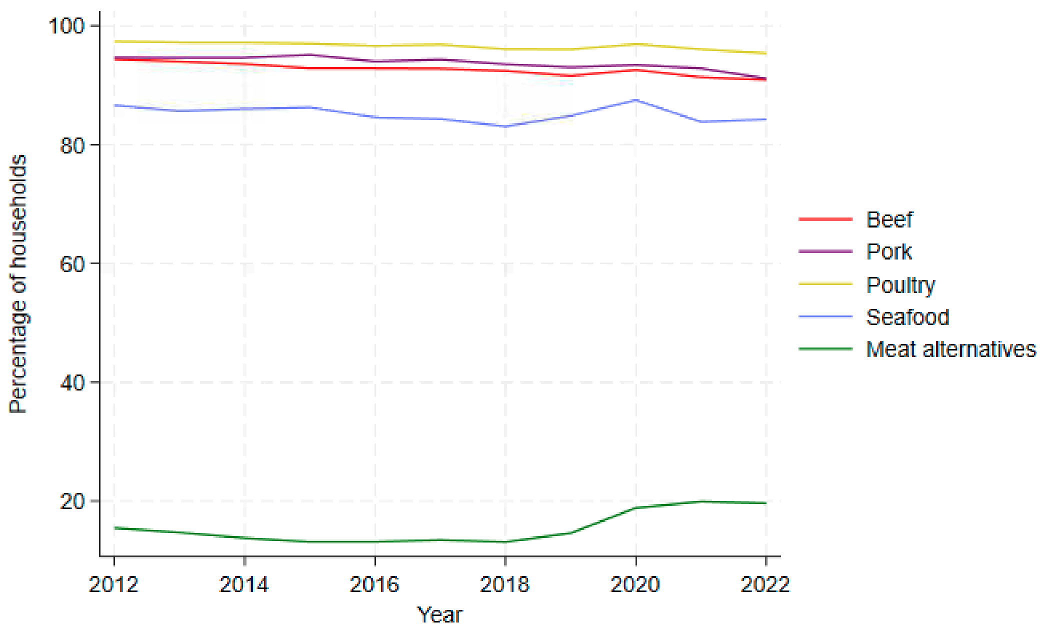


Figure 5.4: Proportion of U.S. households purchasing each protein by year

To better understand if households are substituting plant-based meats for animal proteins, I use the plant-based UPCs purchased by the households across the years and classify them according to their description in one of the four animal protein categories. When such classification is not possible from the description of the products, I classify them as "unknown." According to figure 5.5, most consumers are buying imitation of beef (40%). A significant role for this result plays the fact that, as discussed in chapter 2, alternatives to beef are the most widely available and the ones with the longest presence in the market[7] since the second generation of plant-based meat emerged. The alternatives of other proteins are still actively being developed and may also become more popular in the future, as consumers familiarize themselves with the idea of an plant-based alternative to animal products.

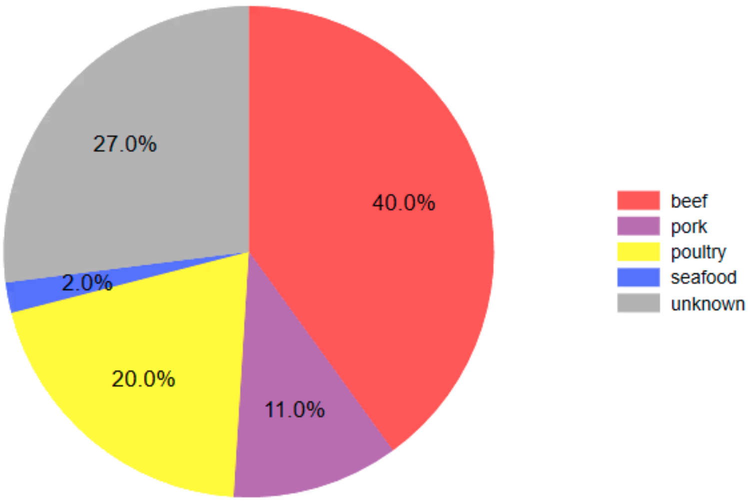


Figure 5.5: Type of animal protein that U.S. households aim to mimic with plant-based items

When looking at how the spending of U.S. households on proteins has evolved over time, figure 5.6 suggests that beef is the protein with the highest expenditure share, although it is also the only animal protein for which I observe a declining trend over

[7]The only exception is the Tofurky which was launched in 1995 and it is an imitation to turkey.

time.[8] More specifically, the average expenditure share of beef in 2012 was 0.32 and it has been constantly declining every year reaching a share of 0.29 in 2021 and 2022 (10% decrease). The two proteins with increasing share over time are seafood and plant-based meat. Households' expenditure on seafood has risen from 0.12 in 2012 to 0.16 in 2022 (25% change). Although the share of plant-based meats has increased by 66%, expenditure shares remain minuscule (0.025 in 2022). The increase in plant-based spending is so substantial not because households spend a lot of their protein budget on plant-based meat, but because the spending in the earlier years was even more minuscule. Furthermore, as will be discussed in section 5.2.1, much of the observed increase represents a one-time try of plant-based products rather than a permanent replacement of animal proteins.

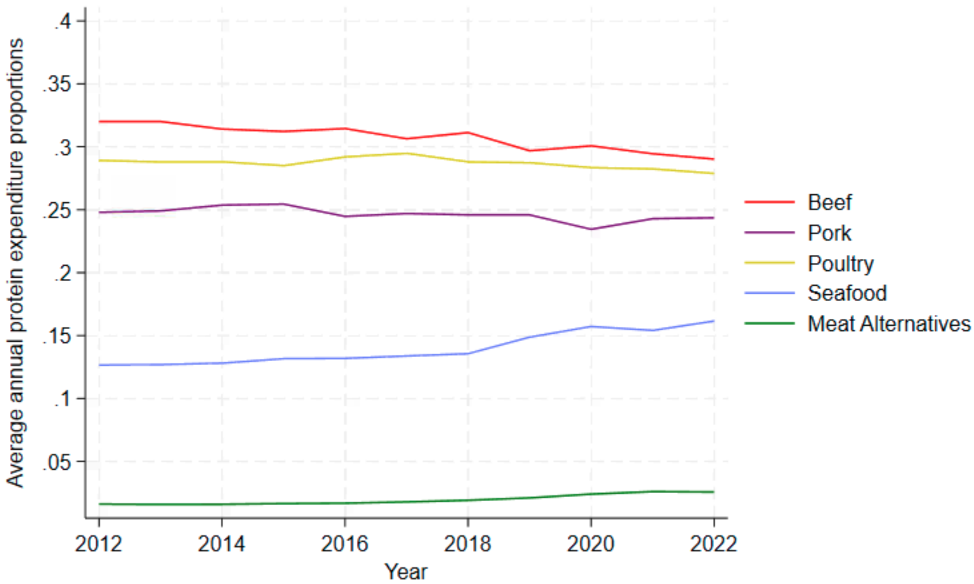


Figure 5.6: Expenditure share of U.S. households on each protein per year

To put household expenditure shares on proteins in perspective, table 5.5 shows the average annual spending on each protein of the households in the sample and figure 5.7

[8]The estimates of the expenditure shares are calculated with the use of projection factors to be representative of the U.S. population.

shows an approximation of the total spending of the U.S. households on plant-based meat over time. Households spend on average $10 annually on plant-based meat substitutes—an amount eleven times lower than the next smallest annual expenditure which is the one on seafood. Nonetheless, the plant-based meat consumption generates on average around 1 billion U.S. dollars annually with the total spending reaching a peak of 1.33 billion U.S. dollars in 2020.

Table 5.5: Average annual spending on each protein in U.S. dollars

	Mean[a]	**Std. dev.**[a]	**Min**[a]	**Max**[a]
Beef	287.60	265.71	0	3569.68
Pork	207.43	174.82	0	3636.42
Poultry	234.13	212.74	0	4805.72
Seafood	113.84	165.35	0	4633.78
Meat Alternatives	9.95	64.47	0	2819.23

a: This is the average value of the statistic estimated for each year.

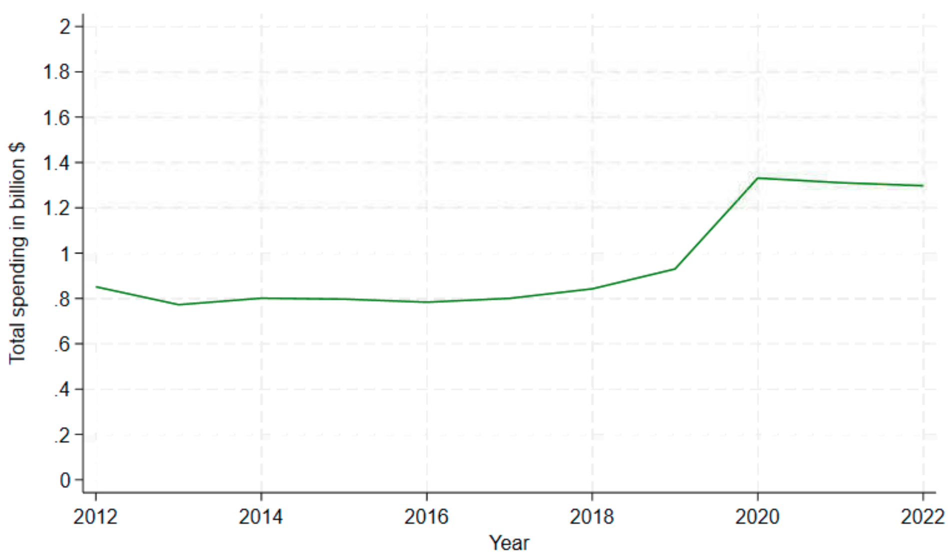


Figure 5.7: U.S. total household spending on plant-based meat

By combining the information on prices and expenditures presented above, plant-based meat was the most expensive protein up to 2022 and the protein that households consume the least. However, the unit price is not the only reason for the low consumption of plant-based meat since the average spending on seafood is much higher than that of plant-based meat despite the fact that seafood is the second most expensive protein after plant-based meat and the gap between the price levels of the two proteins is in fact very small.

5.2.1 Purchasing patterns and demographics

For the substitution of meat with plant-based proteins to be effective in terms of benefiting the environment, a persistent consumer adoption is required. That is, consumers will need to implement a permanent reduction of animal proteins which they replace with repeated consumption of plant-based meat, in order for these products to have a positive net effect on the environment. For this reason, the subject of this section is the purchasing patterns of households within and across years and the links between plant-based meat consumption and demographic characteristics such as gender, education, income, etc.

5.2.2 Consuming patterns within a year of observation

For each household in the main sample each year, I create a "monthly return ratio" that shows how many months of the year the household purchased a plant-based item. I classify as "nonconsumers" the households that did not purchase plant-based meat in any of the 12 months. I classify as "infrequent consumers" the households that purchased plant-based meat less than every other month (i.e., with ratio $< 6/12 = 0.5$). Finally, I classify as "frequent consumers" the households that purchased plant-based meat 6 or more months of the year.

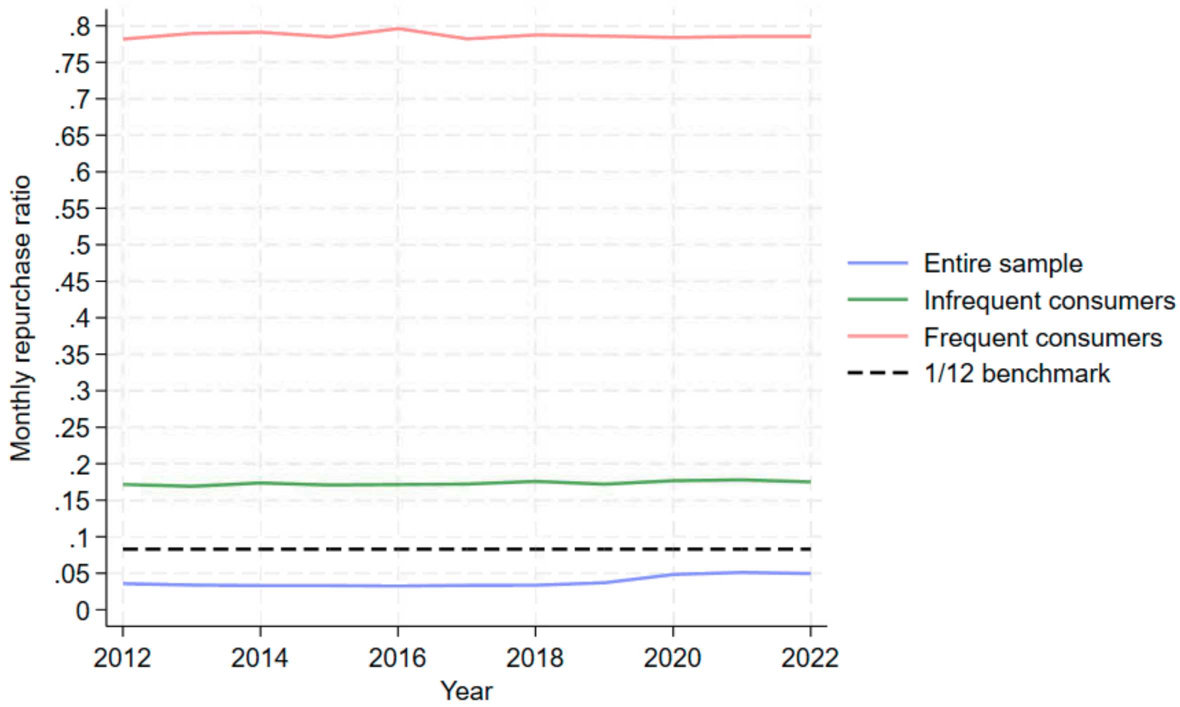


Figure 5.8: Household monthly repurchase ratio of plant-based meat

According to figure 5.8, the average household purchases plant-based meat less than once per year. The infrequent consumers purchase plant-based meat twice per year on average and the frequent consumers close to 12 times a year or once every month. Figure 5.9 shows the percentage of U.S. households in each category.

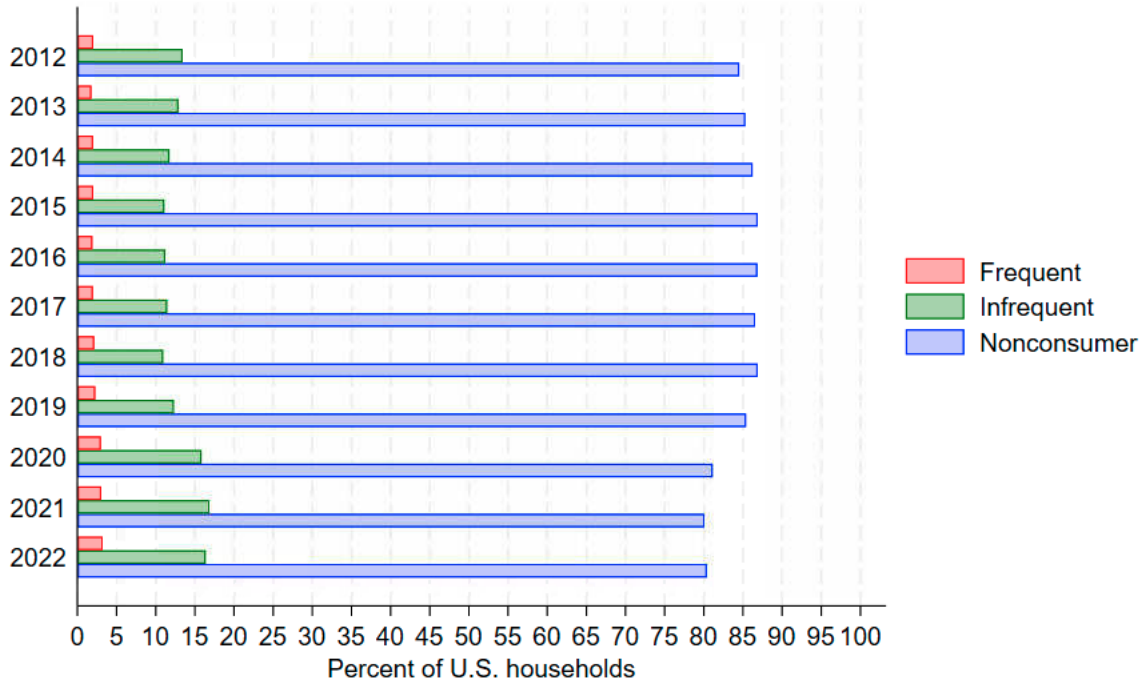


Figure 5.9: Percentage of households that consume plant-based meat frequently, infrequently, or never, by year

The vast majority of households are nonconsumers of plant-based meat and, although this percentage is decreasing over time, 80% of the U.S households in 2022 did not purchase a plant-based meat product even once. The percentage of frequent and infrequent consuming households is increasing over time, reaching a little over 3% and 16% respectively in 2022 (for a graph scale focused on just these two categories see figure 5.10).

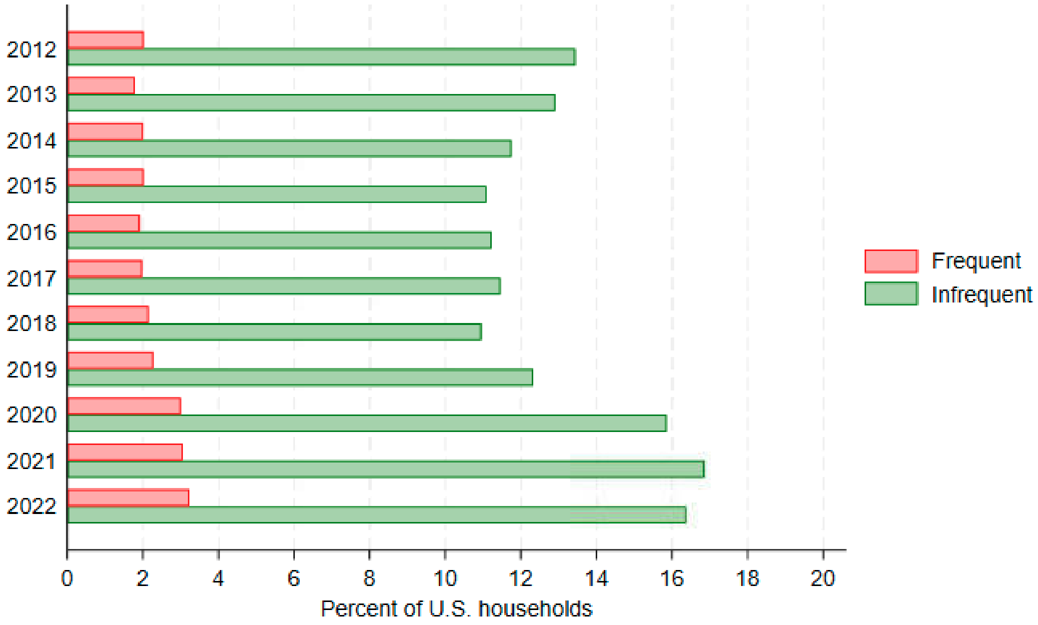


Figure 5.10: Percentage of households that consume plant-based meat frequently and infrequently, by year

Since the frequency of consumption does not necessarily translate to high expenditure share (i.e., one can consume frequently, but very little), it is useful to complement figure 5.9 with spending patterns. To study the plant-based meat spending patterns of U.S. households, I classify the sample in the following annual spending categories:

- Nonconsumer ($0 dollars spent)
- Low spenders ($0<dollars spent ≤$50)
- Medium spenders ($50<dollars spent≤$100)
- High spenders (dollars spent>$100)

Figures 5.11 and 5.12 show the percentage of U.S. households in each spending category. An increasing number of households spend more than a $100 per year on plant-based food, but, even at its peak, this percentage does not exceed 2.6% of the U.S. population. By analysing the correlation between intensive and extensive margin of plant-based meat consumption (i.e., between frequency of purchase and spending) with an OLS regression, one almost perfectly explains the other ($R^2 = 0.91$), meaning that the high spenders are also frequent consumers and vice versa.

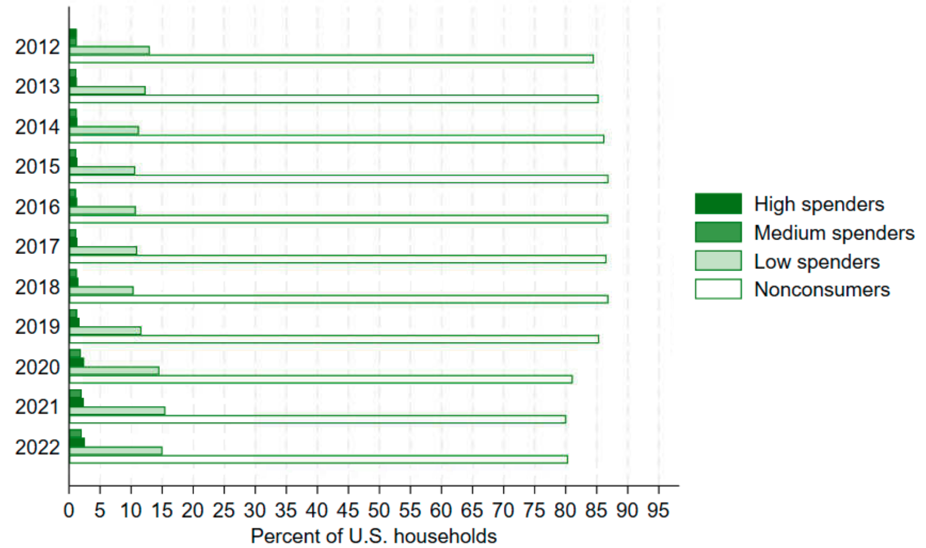


Figure 5.11: Plant-based meat spending patterns of U.S. households

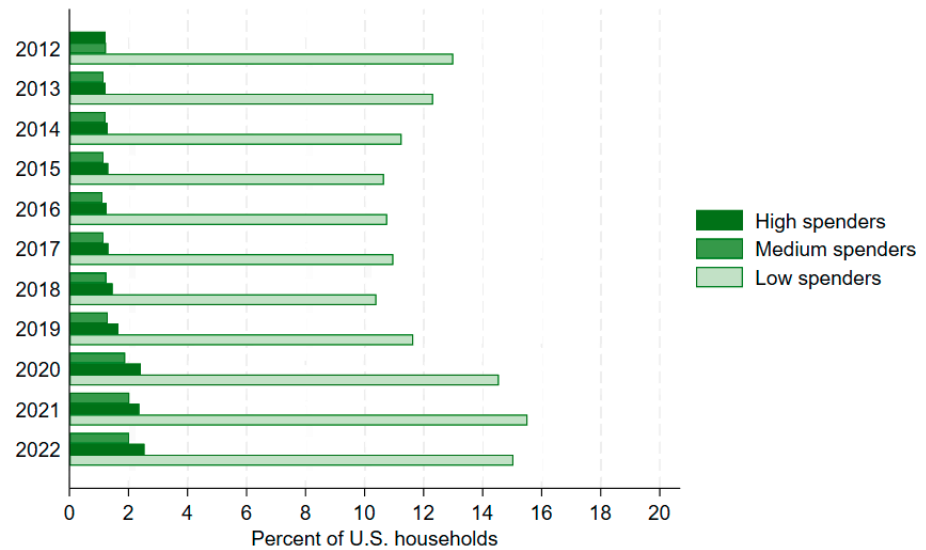


Figure 5.12: Plant-based meat spending patterns of U.S. households (consumers only)

To understand better the relationship between household spending on plant-based meat and spending on animal proteins, I analyse the average spending on other proteins for each of the four household types. This will shed light to the question of whether households that spend more on plant-based meat, spend less than the average population on animal proteins. Table 5.6 shows the average spending per protein per household type.

Table 5.6: Average annual protein spending per household type

	Nonconsumers	**Low**	**Medium**	**High**
Beef	200.96	163.02	122.93	90.02
	(211.50)	(191.74)	(176.00)	(162.70)
Pork	145.94	119.13	86.82	60.94
	(139.26)	(125.40)	(113.32)	(110.68)
Poultry	155.74	189.07	178.33	136.95
	(156.73)	(179.47)	(201.18)	(213.71)
Seafood	75.02	101.05	114.46	111.70
	(118.56)	(140.04)	(167.17)	(219.01)
Meat Alternatives	0.00	16.01	82.83	285.68
	(-)	(13.52)	(16.61)	(235.40)

The standard deviation is in parenthesis.

Indeed, the total expenditure on animal proteins is inversely proportional to plant-based meat expenditure. Out of all consumer categories, nonconsumers spend the most on beef, pork, and poultry together and high spenders the least. Interestingly, seafood spending increases along with plant-based meat spending, but the difference in seafood spending among the consuming categories of plant-based meat is very small. Pork and beef are the two protein types that have the biggest expenditure reductions as a household's consumption of plant-based meat intensifies.

When looking at the lower bound of the average quantity consumed for each protein in table 5.7, the same consumption pattern as with the expenditures emerges. Nonconsumers eat at least twice as much beef as high spenders and the same holds for pork. The total consumption of poultry presents an interesting pattern that holds both for the expenditure and the quantity consumed: as consumers reduce the consumption of beef and pork, the spending on poultry initially increases up to the point that consumers are less willing to consume meat overall (i.e., up to high spenders) where all meat proteins, including poultry, are consumed modestly. Finally, seafood consumption is 30% higher in households with high plant-based meat spending compared to nonconsumers. An interesting observation to note is that high spenders on plant-based meat still consume meat overall. This implies that these consumers do not merely dislike meat consumption, but they intentionally try to reduce it and replace it with a meat alternative. If this were not the case, then the reduced meat expenditure should not have been accompanied by such an increased expenditure on meat alternatives.

Table 5.7: Average annual protein consumption (in pounds) per household type

	Nonconsumers[a]	**Low**[a]	**Medium**[a]	**High**[a]
Beef	10.47	8.45	6.75	5.28
	(16.76)	(13.74)	(12.58)	(11.89)
Pork	14.95	12.20	9.02	6.49
	(16.80)	(14.78)	(13.13)	(13.34)
Poultry	19.39	23.33	22.07	16.35
	(29.31)	(30.18)	(32.03)	(30.67)
Seafood	7.21	9.05	9.98	10.00
	(10.86)	(12.69)	(13.86)	(18.14)
Meat Alternatives	0	2.33	11.39	36.97
	(-)	(2.06)	(3.27)	(27.97)

[a] Estimates based on fixed-weight items. The standard deviation is in parenthesis.

The next step is to analyze the demographic profile of the different consumer categories. For this part I do not divide consumers in low, medium, and high spenders, because the differences in demographic effects were very small among these groups. Instead, I split the households into consumers and nonconsumers.

The vast majority of households that consume plant-based meat have a female primary shopper (75%) (see figure 5.13). Of course, this does not imply that females are more inclined to consume plant-based meat than males, since this information does not necessarily reveal the gender of the household member who consumes the product and since most households have a female primary shopper anyway. However, this is the only available approximation of the gender composition of consuming households. Moving on to the age of the primary shopper, as figure 5.14 shows, the most-consuming households have primary shoppers below 30 years old (18.3%) and 30 to 40 years old (17.5%). In the remaining age groups, although there are more shoppers overall, the consuming households do not exceed 11% and 14% respectively.

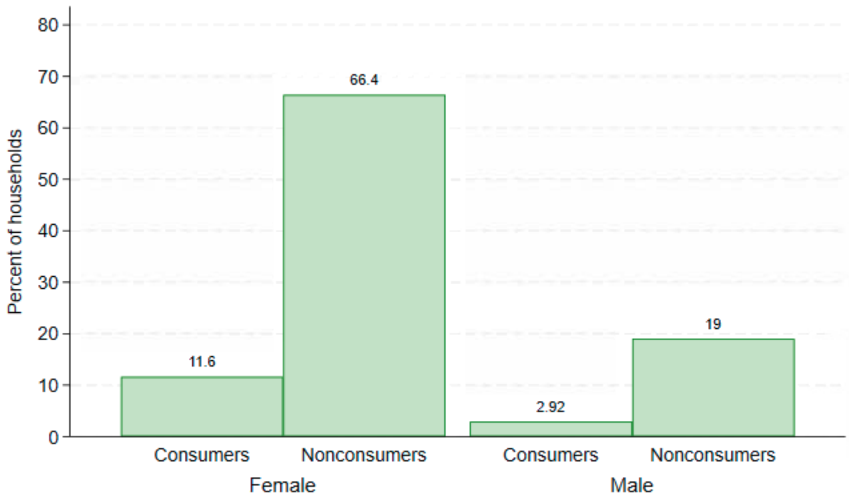


Figure 5.13: Gender composition of consuming vs nonconsuming households

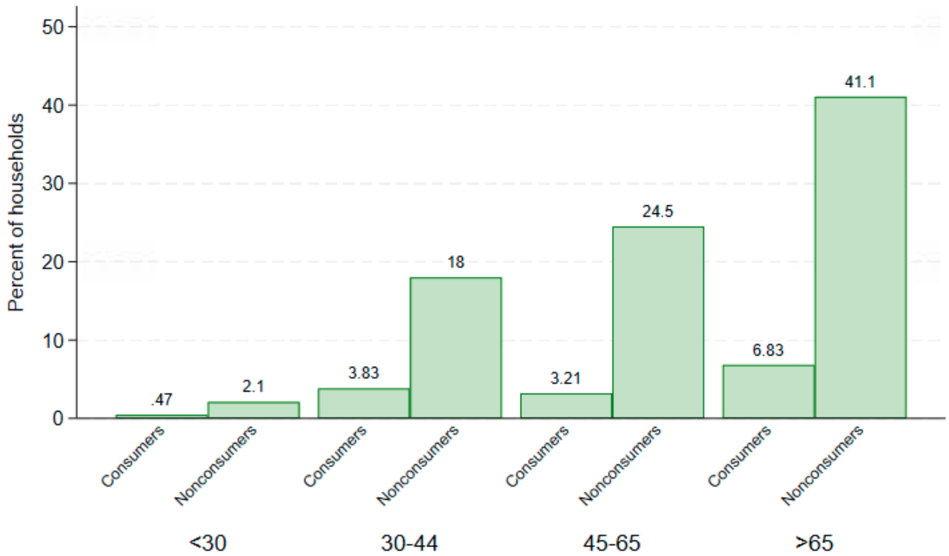


Figure 5.14: Age distribution of consuming vs nonconsuming households

Figure 5.15, shows the education level of the primary shopper in consuming and nonconsuming households. Households where the primary shopper has college or post graduate studies have higher percentages of consuming households, i.e., 20% and 16.7% respectively. On the other hand, households with primary shoppers who have graduated high school tend to have a lower percentage of plant-based consumers (11%).

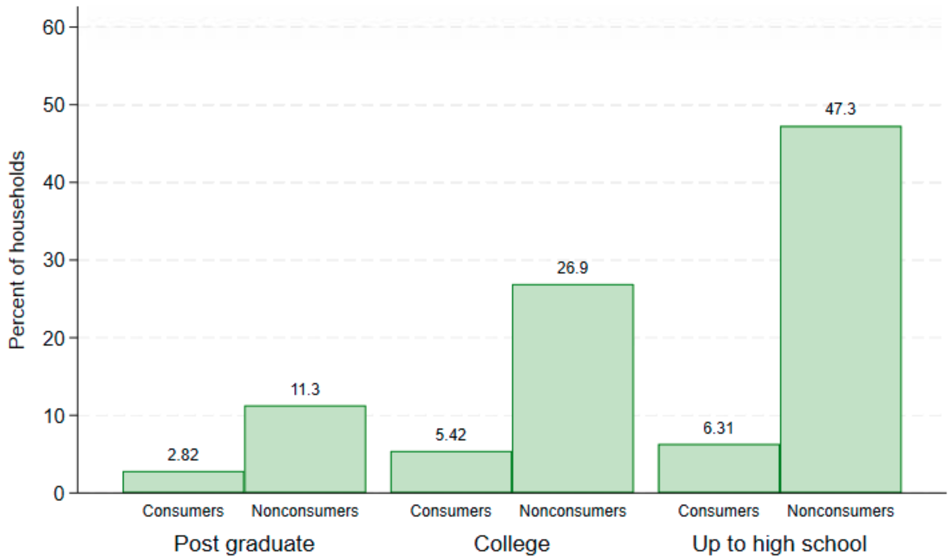


Figure 5.15: Education distribution of consuming vs nonconsuming households

Regarding the income level that has the highest percentage of consumers, 19% of households with income higher than $60,000 consume plant-based meat. In the rest of the income brackets, consuming households vary between 11% and 13% (see figure 5.16).

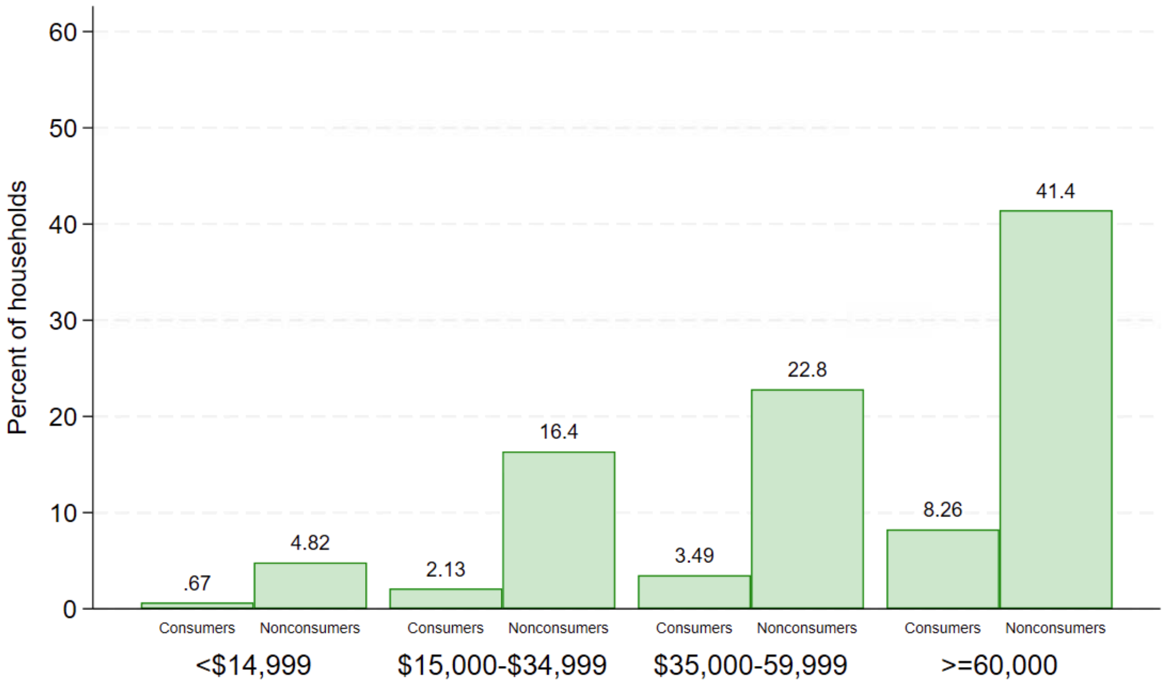


Figure 5.16: Income distribution of consuming vs nonconsuming households

As per figure 5.17, the percentage of consuming households varies also with the size of the household, but not as much as with household's income or education of the primary shopper. The highest percentage of consuming households is in 3-member (16%) and 4-member families (16.5%), while in the remaining household sizes, the consuming cases are 14%.

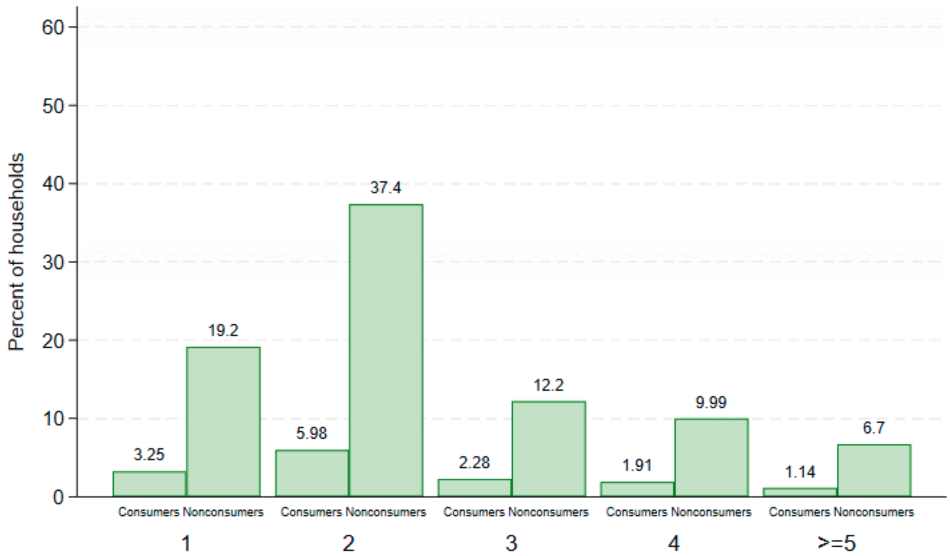


Figure 5.17: Household size of consuming vs. nonconsuming households

A final demographic that I explore is that of the political affiliations of a household's state of residence. As mentioned in the literature review, for some consumers the level of meat consumption is a means of showing their moral values in the sense that it shows their concerns about the environment and animal welfare. For this reason, it is worth exploring whether states where specific political views dominate have different perceptions towards plant-based meat. To study this question I use the results of the past three Presidential elections in the U.S. A state where the majority of its residents voted for the Democratic party, is characterized as "Democratic," a state where the majority of its residents voted for the Republican party, is characterized as "Republican," and as state that majority switched between the two parties across the past three elections, is characterized as "mixed."

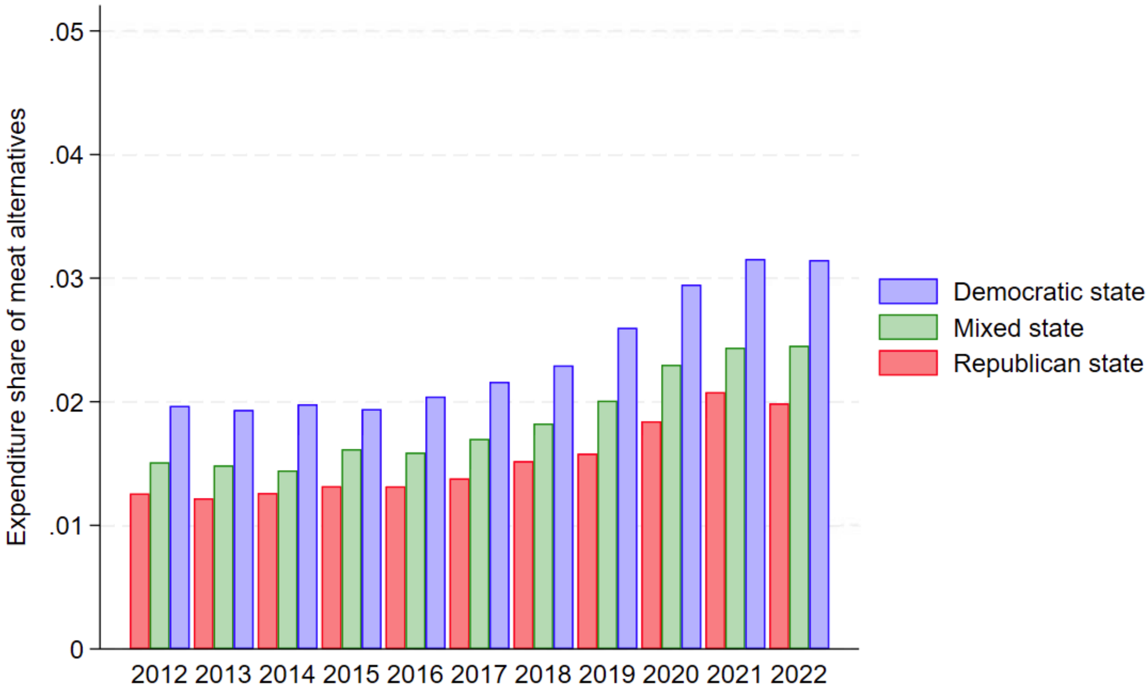


Figure 5.18: Plant-based expenditure share by political inclination of the state of residence

Figure 5.19 shows the percentage of consuming households in each state category. Over the entire sample, 20% of consuming households in Democratic states consume plant-based meat, compared to 14% in mixed and 11% in Republican states. This result suggests that the political culture around meat consumption affects the extent to which households will consume plant-based meat.

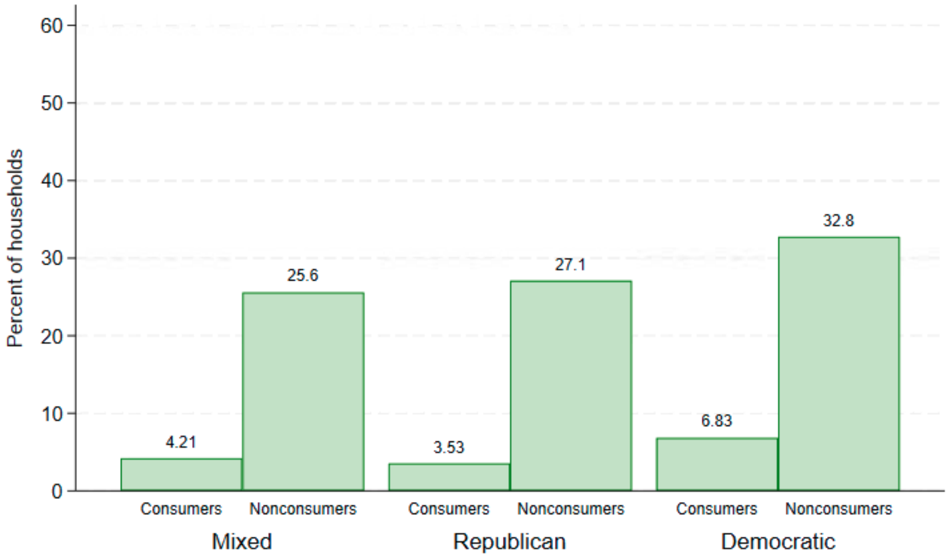


Figure 5.19: Political inclination of consuming vs nonconsuming households' state of residence

5.2.3 Consuming patterns across multiple years of observation

The fact that I observe a generous number of households across multiple years, provides the opportunity to explore how the consuming behavior of these households changes throughout the years. That is, whether consumers that are observed over multiple years, keep purchasing plant-based meat after the year they first bought it.

To be able to study this I first remove the group of households that I cannot make inference about their purchasing pattern over time. First, I remove the households which purchased plant-based meat at their last year in the panel only. For instance, a household that is in the panel for three years, but only purchased plant-based meat in its third year, will not contribute to the question of whether a habit is formed after the first purchase. There is a total of 8,798 such households and most of them were in the panel for up to two years as shown in table 5.8. Another special group of households are those that either never purchased or purchased every single year that they stayed in the panel. According to table 5.9, 73% of the households have never purchased plant-based meat and 7.72% have been always purchasing. I drop the two extreme groups and I study how many households kept purchasing continuously throughout the remaining years that they stayed in the panel after the first year of purchase.

Table 5.8: Households that purchased plant-based meat in their last year in the panel only

Years in the panel	**Number of households**	**Sample percentage**[a]
1	5,175	4.05
2	1,161	0.90
3	656	0.51
4	403	0.31
5	303	0.23
6	283	0.22
7	174	0.16
8	205	0.14
9	142	0.13
10	105	0.11
11	191	0.08
Total	8,798	6.89

a: Percentage out of 127,606 unique households observed across 11 years.

Table 5.9: Households that have never consumed or have always consumed plant-based meat throughout their years in the panel

	Number of households	**Sample percentage**[a]
Never purchasers	92,984	72.87
Always purchasers	9,848	7.72
Total	102,832	76.52

a: Percentage out of 127,606 unique households observed across 11 years.

The remaining households form three distinct groups: (i) households that continued purchasing plant-based meat for the rest of the years they stayed in the panel, (ii) households who never purchased again after their first purchase, and (iii) households that had an on-and-off consumption pattern over the years. As table 5.10 shows, only 1.64% of the panel households kept purchasing after their first try, 7.5% of the households stopped purchasing plant-based meat after the first purchase, and another 7.5% returned to the market sporadically over the years.

Table 5.10: Consumption patterns after the first purchase of plant-based meat

	Number of households	**Sample percentage**[a]
Continued after first purchase	2,098	1.64
On-and-off	9,540	7.48
Dropped after first purchase	9,513	7.45
Total	21,151	16.58

a: Percentage out of 127,606 unique households observed across 11 years.

In table 5.11, I analyze the average meat consumption of the household segment that stayed after the first purchase and the household segment that ceased purchasing after the first time. More specifically, I observe the average annual expenditure before and after the first purchase to understand whether the plant-based purchase coincided with an overall change in protein consumption.

Table 5.11: Household average meat expenditure before and after the introduction of plant-based meat into household's diet

	Continued after first purchase		Dropped after first purchase	
	Before	**After**	**Before**	**After**
Beef	169.56	148.94	195.66	193.72
	(186.75)	(177.62)	(190.95)	(179.99)
Pork	123.87	110.65	142.02	142.58
	(125.15)	(115.32)	(121.76)	(117.06)
Poultry	203.80	187.06	172.76	172.38
	(221.74)	(178.90)	(150.08)	(142.13)
Seafood	91.77	104.09	86.97	89.07
	(124.26)	(127.15)	(129.79)	(114.70)
Plant-based meat	0.00	45.58	0.00	2.64
	(-)	(70.35)	(-)	(4.74)

According to the average expenditures reported in table 5.11, the introduction and adoption of plant-based meat signifies a reduction in meat consumption overall. The households that permanently adopted plant-based meat over the years reduced meat consumption by 10% (specifically, beef by 11%, pork by 10%, and poultry by 8%) and increased seafood consumption by 13%. Overall, the expenditure on proteins (plant-based meat included) increased by 29% which implies that households increased the variety of proteins with plant-based meat but did not fully replace an animal protein with it.

Regarding the consumer segment that dropped after the first purchase, the expenditure on meat is identical before and after this incident. The reason for looking more into the meat expenditure of this group was to see if there are consumers who explore different ways to reduce meat consumption, and the introduction of plant-based meat was one of these ways. The estimates of the average meat expenditure of this group show that there was not a noticeable change in the purchasing behavior of this group before and after the plant-based meat purchase.

For the remainder of this section I focus on the demographic profile of each consumer segment. As expected, the gender of the primary shopper in all consuming categories is female. Particularly on the households that have always been plant-based meat consumers, 83% off the primary shoppers are females. For all the other consuming patterns this percentage is 80%.

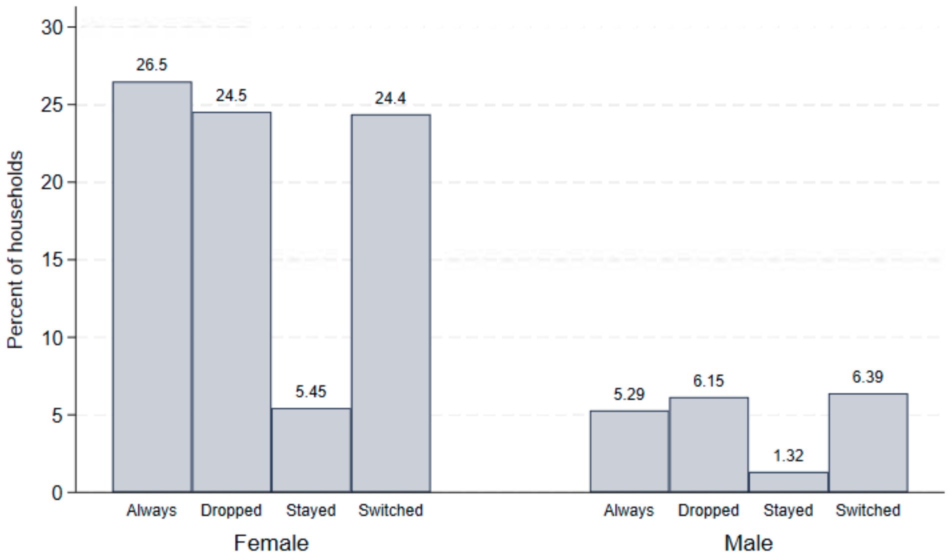


Figure 5.20: Gender composition of consumer segments across years

Regarding the age composition of the households in the different consumer segments, 46% of the households who engage in some type of plant-based meat consumption have a primary shopper between 45 and 65 years old. Within the specific segments now, 43% the "always consuming" households have a primary shopper between 30-44. Further, half of households who stopped their consumption after the first purchase has a primary shopper between 45 and 65 years old. 47% of the households that stay after their first purchase have a primary shopper between 45 and 65 years old and 55% of the households that return sporadically after their first try also have a primary shopper between 45 to 65 years old.

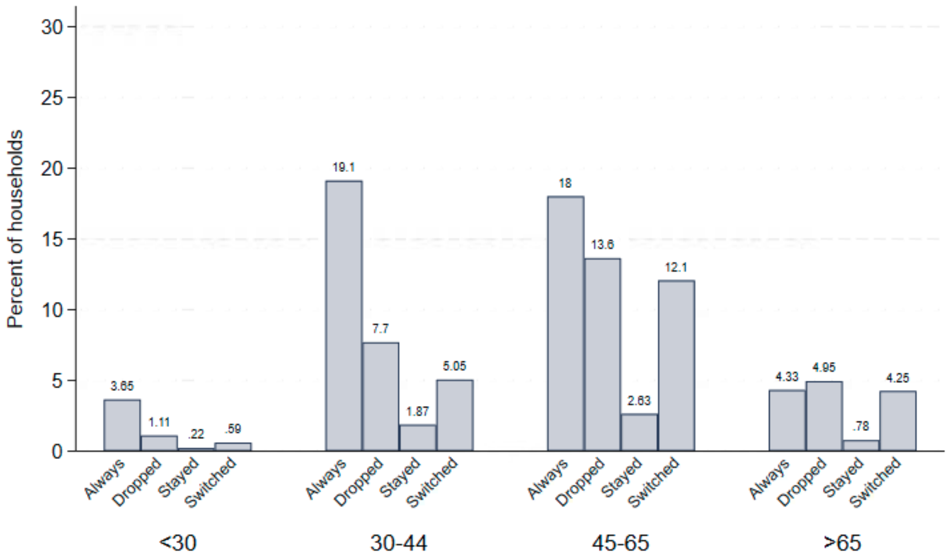


Figure 5.21: Age distribution of purchasing categories across years

As for the education level of the primary shopper within the different consuming segments, 80% of the households that have been always consuming plant-based meat have a primary shopper who has graduated high school or college. 50% of the households that drop have a primary shopper with high school education. The lowest percentage of households that stay in the market after the first try has a primary shopper with a post-graduate degree and the same holds for the households that switch consumption across years.

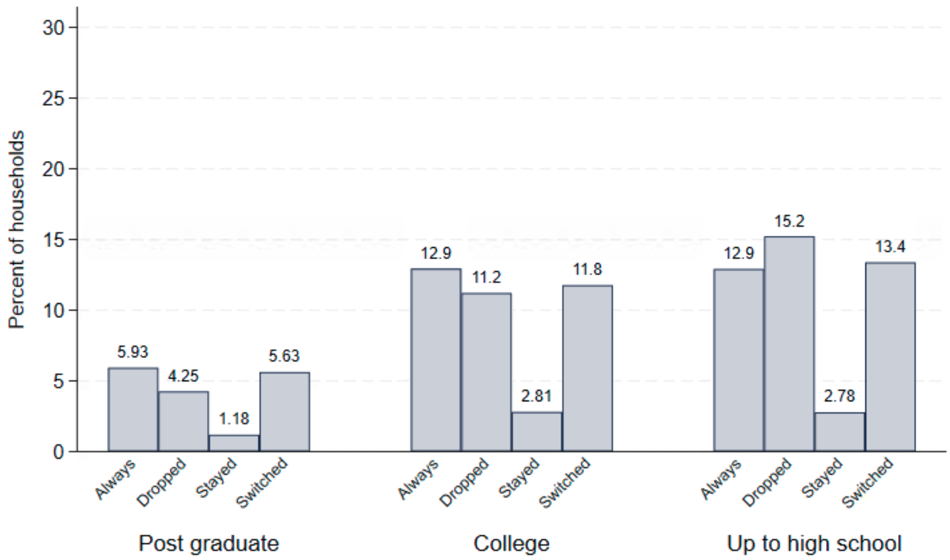


Figure 5.22: Education of household head across different purchasing categories and years

There a few interesting observations regarding the role of income on purchasing patterns. First, it is not that low-income households tend to drop plant-based meat consumption more. In fact, according to figure 5.23, 50% of the households who stop consuming after the first try earn $60,000 or more and also, within each income bracket a constant percentage of around 6% decides to drop. Also, the percentage of households that were always consumers of plant-based meat is not increasing with income. In fact, the income bracket of $14,999 or less has the highest percentage of households that always consumed plant-based meat (37%) and in all other income levels this consuming segment constitutes around 31%. Regarding the households that stay after their first year of purchase, the percentage increases as income increases, but only slightly and by an amount that hardly justifies that income plays a role in such decision. Starting from the lowest to the highest income bracket, the percentages of such households are respectively 6%, 6.5%, 6.7%, and 6.9%. Finally, the percentage of the consumer segment that alternates its plant-based consumption throughout the years increases slightly as income levels increase. It is 25% in the lowest income category, 30% in the next two, and 31% in the highest income bracket.

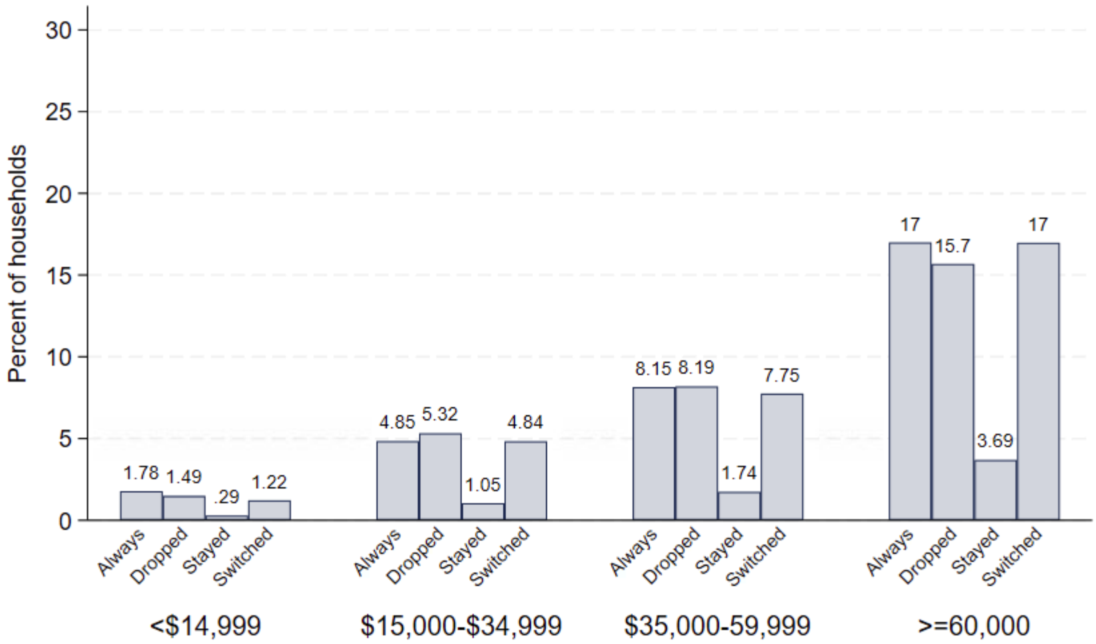


Figure 5.23: Household income across different purchasing categories and years

When looking at the household size and the different consuming patterns, it seems that smaller households have more consumers that tried plant-based meat in any extent compared to larger households. Interestingly, the household size does not determine whether a household will keep consuming after the first year. More specifically, the percentage of such households ranges between 6% and 7% in each household size. The same observation is true for the "always consumers," the ones who dropped after the first year, and the ones that stayed. The only consumer segment that seems to be more affected by the household size is the one of switching consumers. As the size of the household increases, the percentage of such consumers decreases starting from 35% for the one-person households, and continuing to 32% for two-person households, to 29% for 3-person households, to 26% for four, and finally being 25% in 5-person households or more.

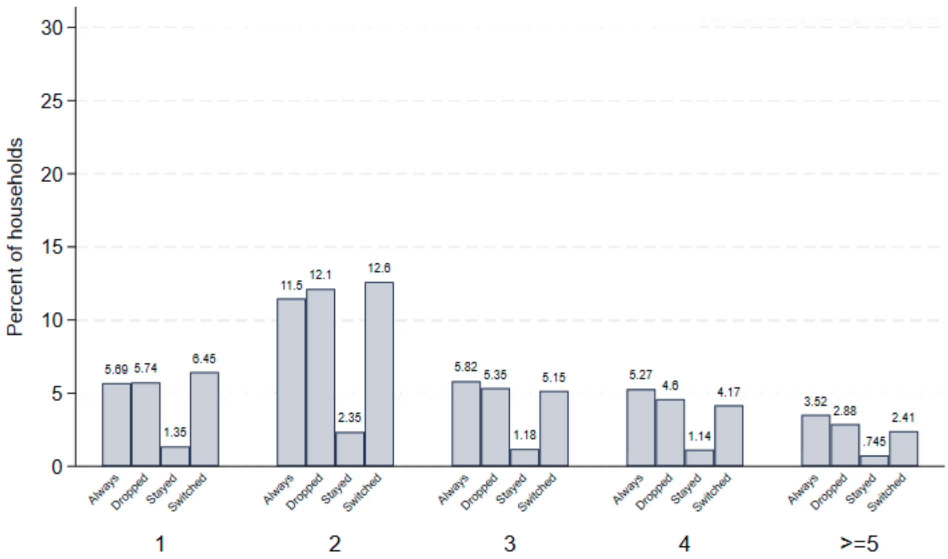


Figure 5.24: Household size across different purchasing patterns

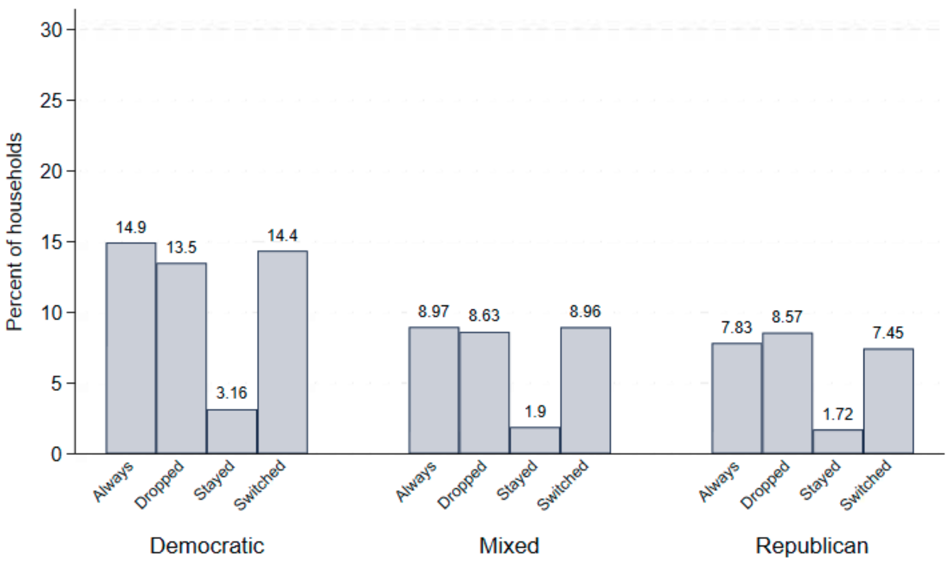


Figure 5.25: Political inclination of the state of residence

Finally, as observed in the consumption patterns presented in section 5.2.1, Democratic states have overall more households that are willing to engage with plant-based meat consumption at any level. They also have higher percentages of consumers who were "always consumers" with 32% versus 31% in the mixed states and 30% in the Republican states. The political inclination of the state of residence does not seem to affect the percentage of consumers who decide to stay after the first year of consumption. This household percentage is 6% for all political orientations. In contrast, the decision to cease consumption after the first year changes depending on the political inclination of the state with Republican states having the larger share of such households (33%), while the same consumer segment comprises 30% in mixed states and 29% in Democratic states. Finally, Republican states have the lowest share of households who alternate their consumption of plant-based meat throughout the years with 29%, while the percentage of such households in mixed and Democratic states is 31%.

5.3 Plant-based meat consumption given a household's health status and dietary habits

The final section of this chapter is devoted to consumption patterns of households that have completed the health survey, and it analyzes their purchasing behavior from the perspective of their dietary habits and health condition. Since this section uses the health survey sample, which is different that the main sample used in previous sections, I first present its summary statistics and then discuss the consumption patterns.

There is a total of 84,864 unique households in this sample and, as shown in table 5.12, many of them are traced across multiple years, with 20% of the households being observed for 5 years or more. An average of 25,249 households are observed each year.

Table 5.12: Number of households traced in multiple years

Years in the panel	**Number of HH**	**Percentage**	**Cum. Percentage**
1	32,415	38.20	38.20
2	15,032	17.71	55.91
3	9,143	10.77	66.68
4	6,159	7.26	73.94
5	4,964	5.85	79.79
6	4,250	5.01	84.80
7	3,286	3,87	88.67
8	2,981	3.51	92.18
9	2,353	2.77	94.96
10	2,239	2.64	97.59
11	2,042	2.41	100
Total	84,864		

Table 5.13: Number of observed households per year

. **Year**	**Number of HH**	**Percentage**	**Cum. Percentage**
2012	17,029	6,13	6.13
2013	21,737	7.83	13.96
2014	21,634	7.79	21.75
2015	25,768	9.28	31.02
2016	27,604	9.94	40.96
2017	30,654	11.04	52.00
2018	28,876	10.40	62.40
2019	24,192	8.71	71.11
2020	26,663	9.60	80.71
2021	26,831	9.66	90.37
2022	26,755	9.63	100
Total	277,743		

According to the average self-health-assessment score presented in table 5.14, most households in the survey consider themselves in good health,[9] however, given the minimum value of the variable and the standard deviation, there are individuals in the sample who consider themselves in poor health. Similarly, most households do not face many health problems that can be linked to food consumption, although, on average, they are moderately concerned about possibility of facing such health issues in the future.

Table 5.14: Households' health status overview

Health index/variable	**Mean**	**Std. dev.**	**Min**	**Max**
Self health assessment	6.59	0.91	1	10
Health concerns	8.62	2.40	1	15
Health issue	2.07	2.04	0	35

Regarding households' dietary concerns presented in table 5.15, most households in the sample do not follow a diet with minimal content of certain ingredients or attributes such as sugar, gluten, carbohydrates, GMOs, fats, salt, etc., or additional content of other attributes such as fiber and protein, although they are somewhat concerned about growth hormones, antibiotics in meat production, artificial flavors etc.[10] Further on dietary habits, table 5.16 shows that, as expected, the average household does not have a member that follows a low-meat diet, either vegan, vegetarian, flexitarian, or pescatarian diet. From the four types of low-meat diets, the one that is more likely to occur in a household is the flexitarian diet which includes some meat, but in reduced amounts. According to table 5.16, one out of ten households have a member that follows such diet.[11]

[9] Recall that the higher the score, the better the health condition of the individuals of the household according to their own assessment

[10] For a complete list of the survey questions included in each variable refer to section 4.2.8.

[11] Note that the table 5.16 has observations from 2022 only since this information was not available in previous years. The total number of households that answered these questions is 8,929.

Table 5.15: Households' dietary concerns

Health index/variable	**Mean**	**Std. dev.**	**Min**	**Max**
Ingredient-conscious	2.31	3.32	0	65
Concerned about food	13.06	9.74	0	72

Table 5.16: Households following low-meat diets

Diet	**Mean**	**Std. dev.**	**Min**	**Max**
Vegetarian	0.034	0.24	0	5
Vegan	0.04	0.25	0	5
Flexitarian	0.12	0.47	0	7
Pescatarian	0.02	0.17	0	4

To explore the effects of a household's health status and dietary habits on plant-based meat consumption, I use each of the variables presented in tables 5.14 and 5.15 and divide households into groups based on their score in the specific variable. Households with scores higher than one standard deviation from the mean comprise one group, households with a score lower than one standard deviation from the mean comprise the second group, and the remaining households the third group. If a given variable, such as the health issue variable listed in table 5.14, does not have observations below one standard deviation from the mean, I divide the sample in two groups only. I present how I classified households in good, average, and poor health as an example. A household is classified to be in good health if its score is one standard deviation or more higher than the means of the self-health-assessment variable and the health concerns variable presented 5.14 in table. Similarly, a household is considered to have members in poor health if its score is lower than one standard deviation or more from the means of these variables. Table 5.17, shows the percentage of households under each category.

Table 5.17: Households' health concerns

Health index/variable	Number of households	Percentage	Cum. Percentage
Good health status	100,980	36.35	36.35
Average health status	126,784	45.64	81.99
Poor health status	49,979	17.99	100
Total	277,743	100	

Based on figure 5.26, the expenditure share on each protein is fairly similar across the different health classifications of the households. The only difference is that households in good health spend 2% less than the average on beef, 1% less on pork, and 1% more on seafood and poultry. Also, there are no significant differences in plant-based meat spending among the different groups.

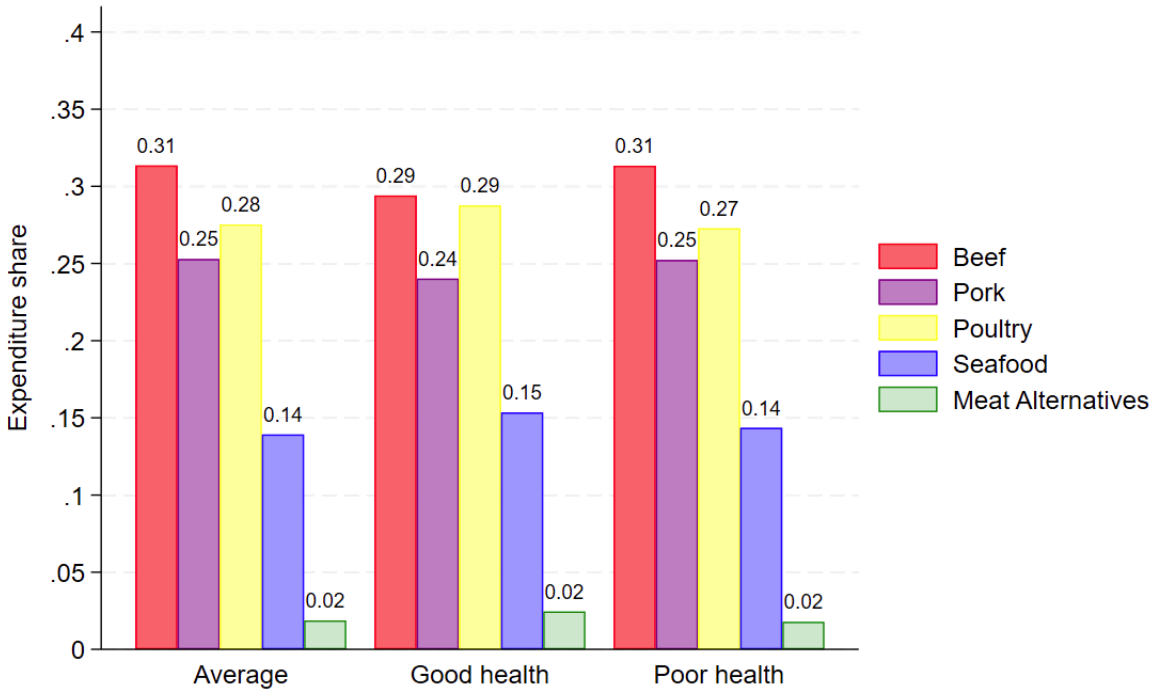


Figure 5.26: Expenditure share on proteins of households with different health statuses

I explore the same question, but from the angle of households who actually suffer greatly from diseases related to food consumption. More specifically, I split the sample into households with many health problems (5 or more) and households with zero or a few health problems. As per table 5.18, 12% of the sample has members that suffer from 5 or more health problems that could be tied to food consumption.

Table 5.18: Households' health problems

Health index/variable	**Number of households**	**Percentage**	**Cum. Percentage**
Many health problems	34,324	12.36	12.36
No/few health problems	243,419	87.64	100
Total	277,743		

Figure 5.28 reveals that households with health problems have different meat purchasing behavior. More specifically, households with none or a few health problems, spend 0.01% more on plant-based meat, 5% more on poultry, and 2% more on seafood. They also spend 5% less on beef and 4% less on pork. It is important to note though, that although there is a difference on plant-based meat spending between the two groups, none of them exceeds the national average expenditure share. What is interesting about this finding is that consumers likely approach meat consumption as a preventative measure against poor health and not as a treatment once the health problems have arisen. Of course, this is merely an assumption as it is not clear whether there is a causal relationship between of increased meat consumption and health problems.

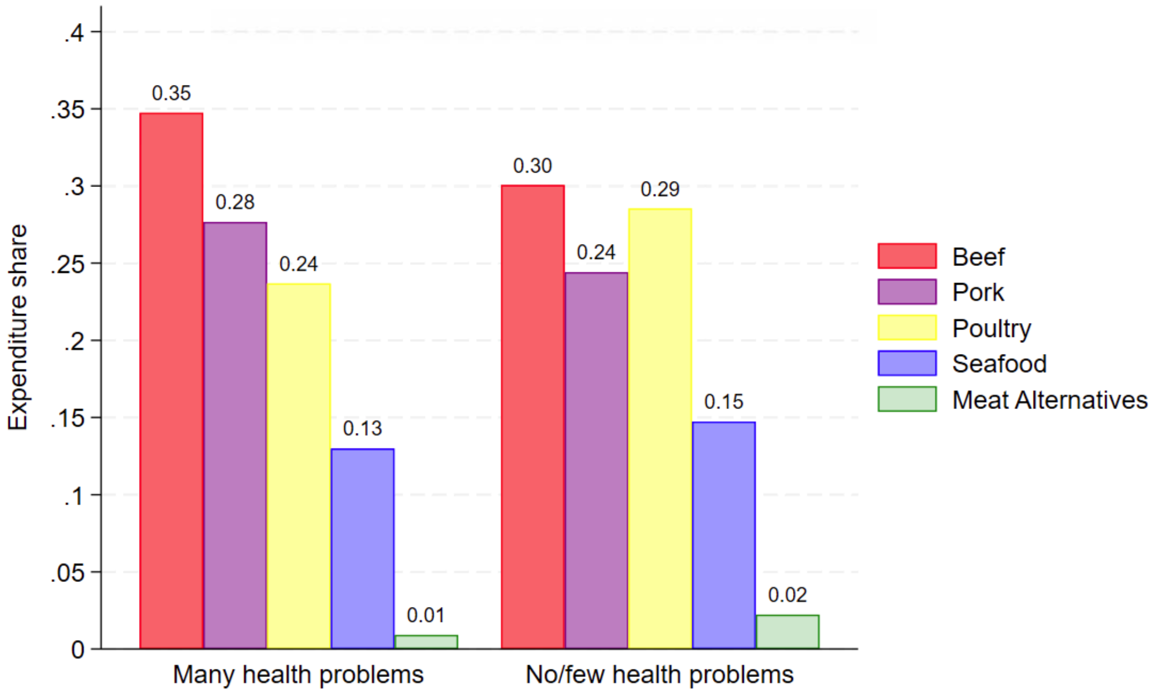


Figure 5.27: Expenditure share on proteins of households with health problems

The next question to be studied is how dietary habits and concerns about food consumption affect households' meat spending overall and plant-based meat spending specifically. I use two classifications to study this: one based on the ingredient-conscious variable and one based on the concerned-about-food variable. In the first, I classify households as ingredient-conscious and not ingredient-conscious. In the second, I use three groups since the range of scores is much broader. I classify households as not concerned, relatively concerned, and very concerned.

According to tables 5.19 and 5.20, only 10% of the households are very ingredient-conscious, and only 4% are very concerned about antibiotics and hormones. The majority of the households is not ingredient-conscious, yet it is relatively concerned about antibiotics, hormones, and artificial flavors.

It appears that households with members who are very conscious about the food ingredients spend 2% less on beef and pork and 2% more on poultry and seafood. The two groups have no difference between them when it comes to the expenditure share given to plant-based meat, and they are both at the levels of the national average. It is likely that the differences on meat consumption between these two groups are small because, as explained earlier, this variable includes some ingredients that are not directly tied to meat consumption such as gluten and carbohydrates.

Interestingly, according to figure 5.29, households that have the most concerned members about antibiotics, spend only slightly less on beef (1%), pork (4%), and seafood (1%). Also, they do not differ in their plant-based meat spending from the other groups. This result indicates that members' increased concerns about food quality do not necessarily translate to a drastic reduction of household's spending on meat.

Table 5.19: Ingredient-conscious households

	Number of households	**Percentage**	**Cum. Percentage**
Not/a little conscious	249,278	89.75	89.75
Very conscious	28,465	10.25	100
Total	277,743	100	

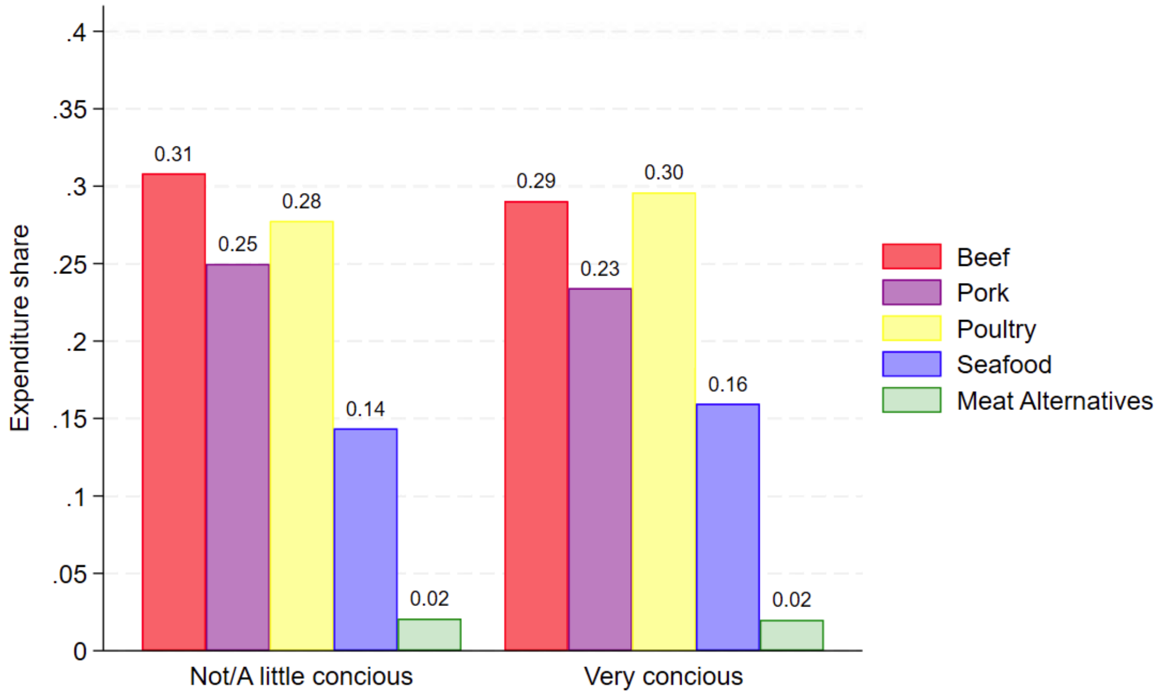


Figure 5.28: Expenditure share on proteins of ingredient-conscious households

Table 5.20: Households with concerns about food

	Number of households	Percentage	Cum. Percentage
Not/a little concerned	58,803	21.17	21.17
Very concerned	11,552	4.16	25.33
Relatively concerned	207,388	74.67	100
Total	277,743	100	

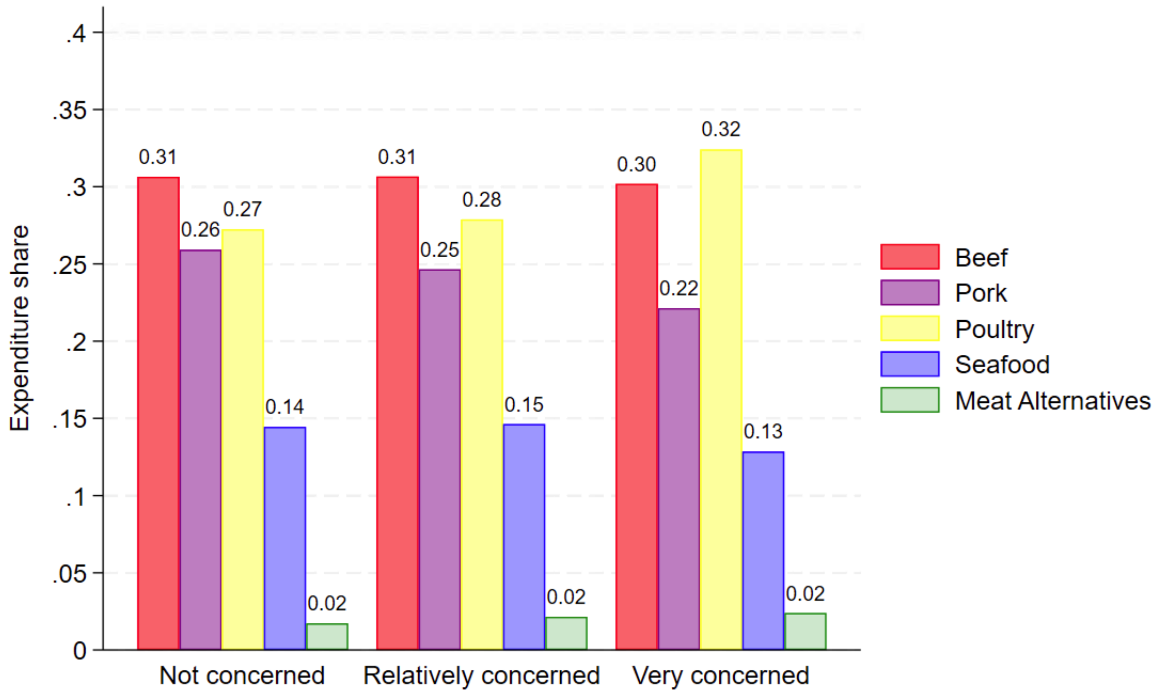


Figure 5.29: Expenditure share on proteins of households concerned about food

The last set of figures is focused on households with members who follow a specific low-meat diet. As expected, the more vegan members a household has, the lower the expenditure share on animal proteins. An interesting observation to note is that the protein most reduced as the number of vegans increases is pork and not beef. The expenditure share of beef varies mostly between vegan and non vegan households and not as much with the number of vegans within a household. The picture is fairly similar in the households that have vegetarian members. Note that households with vegans and vegetarians are the only ones so far having expenditure shares on plant-based meat that exceed the national average of 2.6% and reach up to 70%. This means that plant-based meat satisfies the needs mostly of individuals who eat very little or zero animal meat. Satisfying the needs of this group of households with plant-based meat causes no benefit for the environment since it does not reduce meat consumption. In fact, it may even have a net negative effect because of the additional resources used for its production.

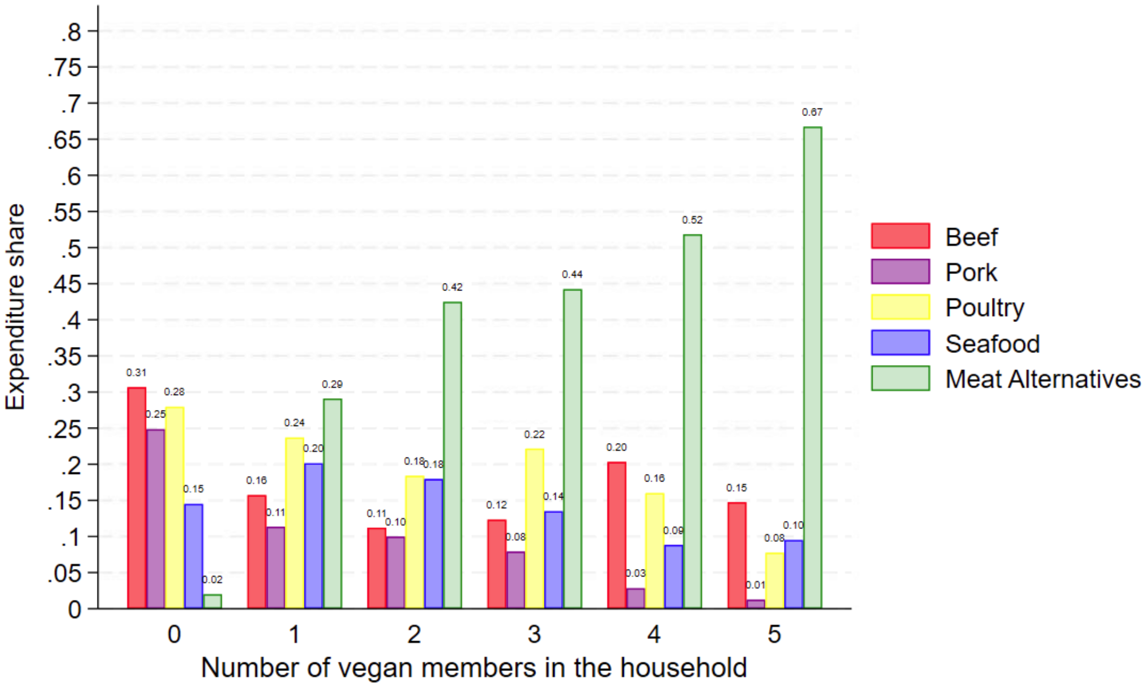


Figure 5.30: Expenditure share on proteins of households with vegan individuals

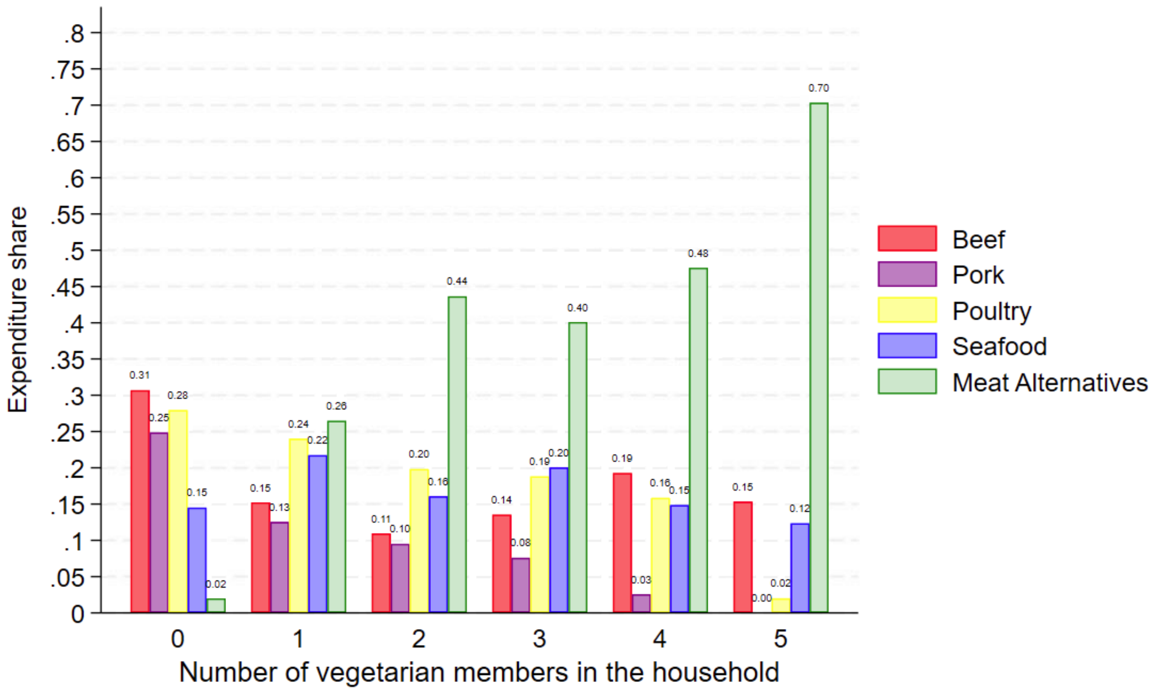


Figure 5.31: Expenditure share on proteins of households with vegetarian individuals

The meat consumption in households with flexitarian members is, as expected, higher compared to households with vegans or vegetarians. Pork is the protein that decreases constantly and steadily as the number of flexitarian members increases while the expenditure share of beef remains relatively unaffected by the number of members that follow such diet and only drops by 12% when moving from zero members to a positive number of members. Interestingly poultry expenditure increases as flexitarian members increase and so does the expenditure on seafood. This observation indicates that flexiatrians focus more on reducing red meats rather than meat in general. In fact, the average increase in the expenditure share of plant-based meat (7%), plus of seafood (12%) and poultry (3.5%), is exactly equal to the average decrease in the expenditure on pork (10%) and beef (13%). Notably, this also means that plant-based meat replaces some of the red meat proteins, but not the entire quantity. That is, other, less processed sources of animal proteins are considered a viable alternative by the households who aim to reduce red meat consumption.

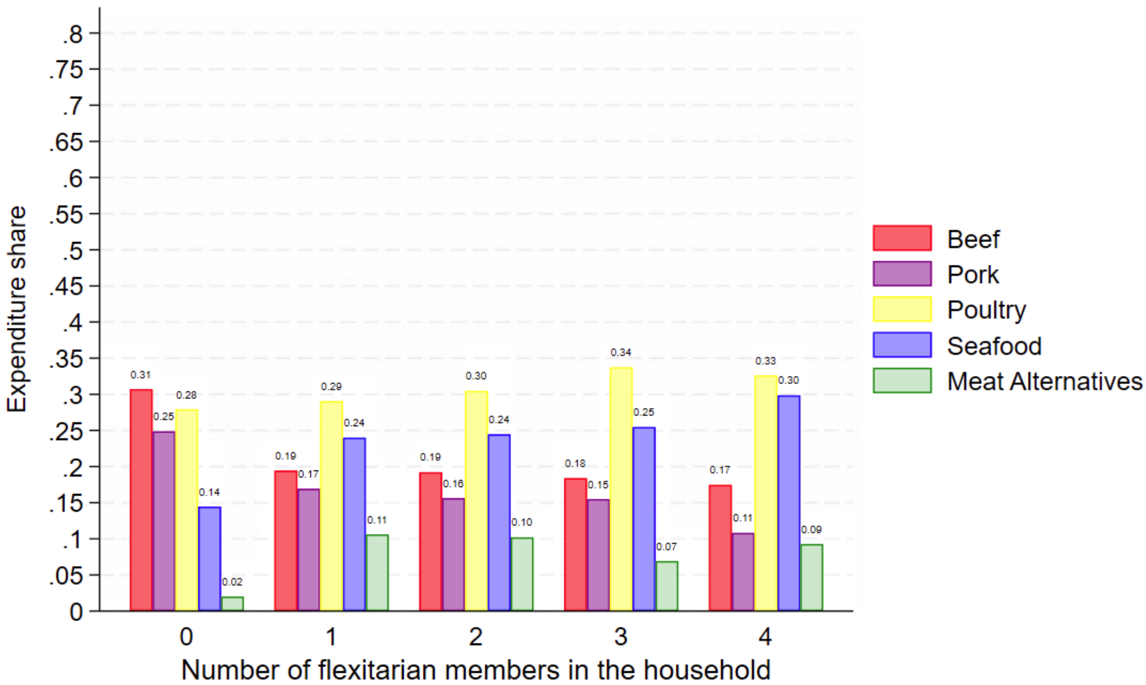


Figure 5.32: Expenditure share on proteins of households with flexitarian individuals

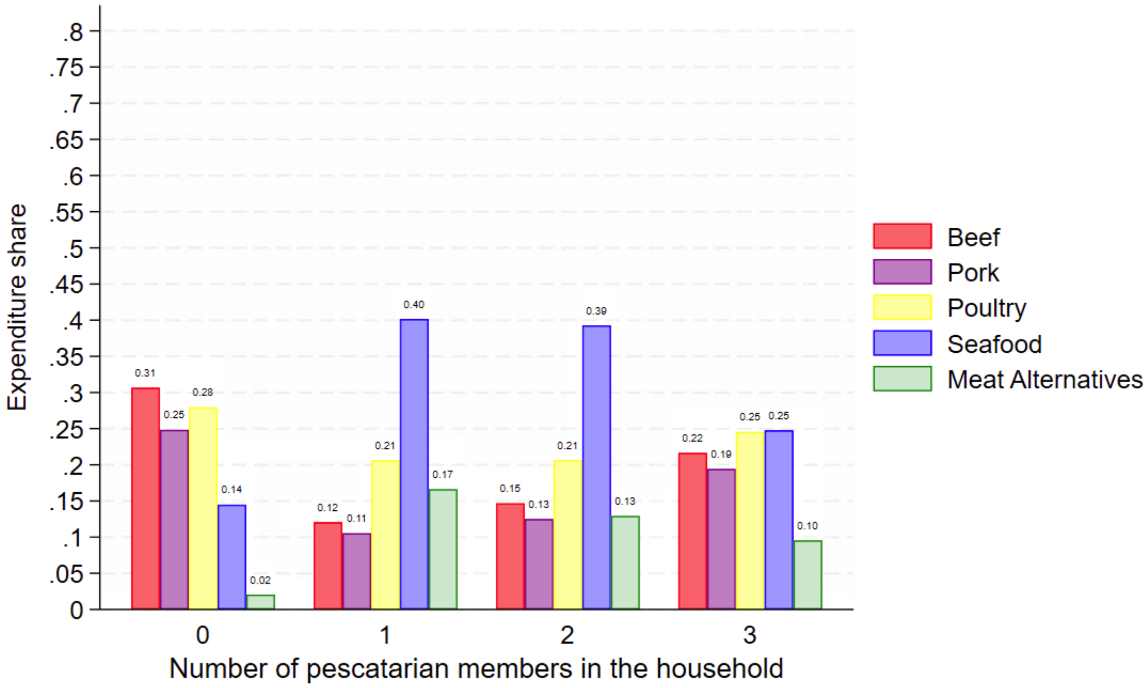


Figure 5.33: Expenditure share on proteins of households with pescatarian individuals

The last type of special diet presented here is the one of pescaterians, individuals who limit animal proteins to seafood. Of course, the presence of a pescaterian member in the household increases the expenditure share on seafood. It also decreases the amount of beef and pork and increases the share of plant-based meat. However, interestingly, the number of members that follow such diet does not have a negative effect on the meat expenditure shares. The results of the analysis presented here is also tested through the econometric analysis presented in chapter 7 since these demographic variables are included in the econometric models too.

Chapter 6

Empirical approach

6.1 The double-hurdle consumption model

As has been established in previous chapters, plant-based meat alternatives are fairly new and more expensive than animal proteins on a per-pound basis. For these reasons, there is a significant mass of households that has never purchased these products, i.e., their expenditure of plant-based meat is zero.

It is not rare that consumption data of certain goods include a lot of zeros (e.g., consumption of health services (Deb and Norton, 2018), cigarettes (Koffarnus et al., 2015), dairy (Wu et al., 2021)). There are several reasons that can lead to this pattern and Deaton and Irish (1984) were the first ones to explore the different sources of observed zeros in household expenditure data. A first potential source is the disinterest of households in consuming a given product. That is, regardless of their income and the market prices, the household is not planning to participate in this market (this behavior is also known as *abstention*). Second, zeros may indicate a corner solution. In this case, the household is a potential contributor to the market (for instance, in this study, it considers plant-based meat in its choice set of proteins), but in the current market circumstances, its optimal plant-based meat consumption is zero. Third, the household consumes the product infrequently and hence, many shopping trips do not involve any purchase of it (indicative bibliography regarding this distinction: Deb and Norton (2018); Garcia and Labeaga (1996); Humphreys (2013)).[1]

The third reason is not a source of zero expenditures in this study, since protein expenditures are aggregated at the year level (see section 4.2.7) which means that even the most infrequent consumers are captured within this time span. However, the other two reasons are valid sources of zeros for this study and have informed the model specification since these zeros represent a *genuine* optimal consumption quantity for the consumer. Two issues are raised due to the nature of the data: one related to the substance of the study and one technical. The latter is the difficulty to produce reliable estimates of the substitution patterns among the different proteins when the distribution of plant-based meat consumption is substantially skewed and has a large mass at zero. The former is the need to understand the characteristics that make some households want to participate in this market and others not.

To address both of these issues, I use a two-part or "hurdle" model —a popular model in an array of contexts where many observations are zero (indicatively: meat consumption of single-member households (Burton et al., 1994), loan default (Moffatt, 2005), fertilizer use (Ricker-Gilbert et al., 2011)). This model was first introduced by Cragg (1971), and it is described in detail in Engel and Moffatt (2014). It embodies the fact that an individual's decision to consume a product is the result of two processes ("hurdles"): the decision to participate (equation 6.1), and, conditional on participating, the decision of how much they will consume (equation 6.2). Namely, the probability of

[1] An additional reason of observing zeros, rarely discussed in studies using micro data, is that consumers might not buy a plant-based item because it is out of stock. Especially for newer items that might fluctuate in demand, that can be an issue. To the best of my knowledge, there is not an empirical approach to address this. Future research could assess the severity of this issue on plant-based meat purchases by matching retail data with household trips and control for plant-based meat availability at the date and store where the trips occurred.

observing a positive expenditure on plant-based meat is estimated through a tobit-like model, and in the second stage, the factors that affect the level of expenditure on plant-based meat are being estimated through a probit estimator run on the subsample with positive expenditure.

$$d_i^* = \boldsymbol{z_i'\alpha} + \epsilon_{1,i} \tag{6.1}$$

$$y_i^{**} = \boldsymbol{x_i'\beta} + \epsilon_{2,i} \tag{6.2}$$

$$\begin{pmatrix} \epsilon_{1,i} \\ \epsilon_{2,i} \end{pmatrix} \sim N \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & 0 \\ 0 & \sigma^2 \end{pmatrix} \right]$$

d_i^* represents the outcome of the first hurdle. $d_i = 1$ if $d_i^* > 0$ and $d_i = 0$ if $d_i^* \leq 0$. Stated in words, when a household's purchase of plant-based meat is observed ($d_i = 1$), then this implies that this household wants to participate in the market ($d_i^* > 0$). Note that d_i^* is a latent variable, i.e., I cannot directly observe a household's willingness to consume plant-based meat. This becomes particularly important in the case where $d_i^* = 0$ since I do not know if the observed zero represents a corner solution or abstention from plant-based meat. $\boldsymbol{z_i}$ is a vector of variables that predict the likelihood of a household being willing to consume plant-based meat. The second hurdle, i.e., the intensive margin of plant-based meat consumption is given by the following function:

$$y_i^* = max(y_i^{**}, 0) \tag{6.3}$$

Note that y_i^* is not observable either. The only thing that is observable is:

$$y_i = d_i y_i^* \tag{6.4}$$

Equation 6.4 essentially shows that a household might be willing to consume plant-based meat ($d_i = 1$), yet, its consumption is zero because of the current market circumstances ($y_i^* = 0$). Note that y_i is a continuous variable, i.e., it is the observed yearly expenditure. $\boldsymbol{x_i}$ is the vector of variables that predict the plant-based meat quantity demanded. The errors of the two equations 6.2 and 6.1 are assumed to be independent.

The log-likelihood function for this model is:

$$LogL = \underbrace{\sum_{0} \ln\{1 - \Phi(\boldsymbol{z_i'\alpha})\Phi(\frac{\boldsymbol{x_i'\beta}}{\sigma})\}}_{\text{Abstention}} + \underbrace{\sum_{>0} \ln\{\Phi(\boldsymbol{z_i'\alpha})\frac{1}{\sigma}\phi(\frac{y_i - \boldsymbol{x_i'\beta}}{\sigma})\}}_{\text{Consumption}} \tag{6.5}$$

A sub-case of the model described above, leads to the p-tobit model of Deaton and Irish (1984) that has particular interest in the context of plant-based meat consumption since it distinguishes a zero corner solution from abstention. Consider equations 6.1 and 6.2, where the first-hurdle equation has no explanatory variables. Then the log-likelihood function becomes as shown in 6.6 where the term $p = \Phi(\alpha_0)$ is now a scalar and represents the percentage of potential consumers of the plant-based meat and, respectively, the term $(1 - \Phi(\alpha_0))$ represents the percentage that is not interested in consuming plant-based meat.

Being able to obtain an estimate of the expected percentage of *potential consumers* is quite important in my setting since it will inform the discussion about the capability of plant-based meat products to replace meat consumption and in turn to have a positive effect on the environment. If the estimated percentage of households who could potentially consume plant-based meat is predicted to be very small, then the hope to reap environmental benefits from such products vanishes since many consumers do not even consider buying them.

$$LogL = \sum_{0} \ln\{\underbrace{1-\Phi(\alpha_0)}_{\text{nonconsumers}} \Phi(\frac{\boldsymbol{x_i'\beta}}{\sigma})\} + \sum_{>0} \ln\{\underbrace{\Phi(\alpha_0)}_{\text{consumers}} \frac{1}{\sigma}\phi(\frac{y_i - \boldsymbol{x_i'\beta}}{\sigma})\} \tag{6.6}$$

Models 6.5 and 6.6 do not incorporate the panel structure of the data which will add a lot of information in the estimations because many households are tracked over multiple years. Following the panel double-hurdle model that was introduced by Dong and Kaiser (2008) and the notation of Engel and Moffatt (2014), I describe below the panel double-hurdle model for the plant-based meat consumption.

Let n be the number of households and T be the total number of years in the panel. Then, y_{it}, is the total expenditure on plant-based meat of household i in year t. Then the first hurdle is as before:

$$d_i^* = \boldsymbol{z_i'\alpha_i} + \epsilon_{1,i} \tag{6.7}$$
$$d_i = 1 \text{ if } d_i^* > 0;\ d_i = 0 \text{ otherwise}$$

Note that equation 6.7 specifies one outcome per household and this is essential in order for the households that do not want to participate in the plant-based market to be correctly defined. That is, a household that does not want to consume plant-based meat should have zero consumption in every observation. However, such assumption creates another problem: households that are occasional consumers of plant-based meat (i.e, that switch between zero and positive consumption over time) are not accommodated. The issue is tackled by constructing a likelihood function for each household that is weighted by the probabilities of $P(d_i = 1)$ and $P(d_i = 0)$. The amount consumed of a household that participates in the plant-based meat market is allowed to change over time. Hence the second hurdle becomes:

$$y_{it}^{**} = \boldsymbol{x'_{it}}\boldsymbol{\beta} + u_i + \epsilon_{2,it} \tag{6.8}$$
$$y_{it}^{*} = max(y_{it}^{**}, 0)$$

$$\begin{pmatrix} \epsilon_{1,i} \\ u_i \\ \epsilon_{2,it} \end{pmatrix} \sim N \left[\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho\sigma_u & 0 \\ \rho\sigma_u & \sigma_u^2 & 0 \\ 0 & 0 & \sigma^2 \end{pmatrix} \right]$$

Finally, the observed component in this case is:

$$y_{it} = d_i y_{it}^{*} \tag{6.9}$$

There are two important observations regarding equation 6.8. The first is that there is a random-effects term u_i for each household that allows for within-subject dependence. The second is that the model allows for a correlation, $\rho = cor(\epsilon_1, u)$, between the two hurdles. This term means that some unobserved factors that affect the decision of a household to participate to the plant-based market, also affect the quantity that the household consumes. When the two hurdles are uncorrelated, then $\rho = 0$.

To construct the log-likelihood function of the sample, it is necessary to first obtain the weighted-average likelihood for each household i.

Conditional on $d_i = 1$

$$(L_i|d_i = 1, u_i) = \Pi_{t=1}^{T}\Big\{1 - \Phi(\frac{\boldsymbol{x'_{it}}\boldsymbol{\beta} + u_i}{\sigma})\Big\}^{I(y_{it}=0)}\Big\{\frac{1}{\sigma}\phi(\frac{y_{it} - \boldsymbol{x'_{it}}\boldsymbol{\beta} - u_i}{\sigma})\Big\}^{I(y_{it}>0)} \tag{6.10}$$

Conditional on $d_i = 0$

$$(L_i|d_i = 0) = 0 \text{ if } \sum_{t=1}^{T} y_{it} > 0 \qquad (6.11)$$
$$= 1 \text{ if} \sum_{t=1}^{T} y_{it} = 0$$

Combining equations 6.10 and 6.11, I get the weighted-average likelihood:

$$(L_i|u_i) = \Phi(\boldsymbol{z_i'\alpha})(L_i|d_i = 1, u_i)) + \{1 - \Phi(\boldsymbol{z_i'\alpha})\}(L_i|d_i = 0)) \qquad (6.12)$$

Finally, the sample log-likelihood is obtained by the summing across the marginal log-likelihoods of the subjects, L_i.

$$LogL = \sum_{i=1}^{n} \ln L_i \qquad (6.13)$$

6.2 Demand system for proteins with a censored regression approach

In this section, I propose an alternative approach to the double-hurdle model, that goes beyond the determination of the factors that affect the probability of consumption of plant-based meat, and lets me study the substitution patterns among the different types of proteins through a demand system, while taking into account the large number of zero expenditures on plant-based meat. I employ the censored simultaneous-equation model proposed by Heien and Wesseils (1990), which produces unbiased estimates of a demand system using household panels that include significant observations of zero consumption.

This estimation procedure, too, involves two steps. First, a probit regression determines the probability of a household consuming a given protein (i.e., beef, pork, poultry, seafood, and plant-based meat). The probabilities of this stage are then used to compute the Inverse Mills Ratio (hereafter IMR) for each household. The IMR then enters in the demand system of the second stage and represents the latent variables that induced some households to have zero expenditure on plant-based meat on the first stage. The demand system that is used in the second stage is the almost ideal demand system (hereafter AIDS) of Deaton and Muellbauer (1980).

The intuition of the first decision of the household is very similar to the one of the double-hurdle model, but it extends to all proteins instead of only plant-based meat. That is, the decision of the household h to buy protein i in year t is indicated by a binary variable that takes the value of 1, if the budget share spent by the household on this protein was positive, and the value of 0, if the budget share was equal to 0. The probability of this decision is estimated with a probit model. The choice of the probit model is based on the censored regression model assumptions that require the error terms to be normally distributed. Below I demonstrate the model estimation for a protein i.

Let y_{it}^{m} be the expenditure on protein m, from household i, in year t. Let $\boldsymbol{z_{it}^{m}}$ be a $1 \times K$ vector of demographic variables that predict the consumption decision. Then, y_{it}^{m} can be expressed as:

$$y_{it}^{m} = \boldsymbol{z_{it}^{m}}\boldsymbol{\beta} + \nu_{i}^{m} + \epsilon_{it}^{m} \tag{6.14}$$

Stating equation 6.14 in words, an observation on the expenditure of a household on protein m in a given year t, is the result of the household's demographic characteristics, an unobserved effect ν_{i}^{m} that is particular to this household, and an idiosyncratic error, ϵ_{it}^{m}, that changes across time and across households. In this model the term ν_{i}^{m} is treated as a random effect and it is assumed to be uncorrelated with $\boldsymbol{z_{it}^{m}}$.[2]

[2] According to Wooldridge (2010) it is almost always the proper approach to treat the unobserved effect as random draws from the population (p.286).

The probability of the expenditure y_{it}^m being different than zero will be estimated with a probit model via maximum likelihood:

$$P(y_{it}^m \neq 0|\boldsymbol{z_{it}^m}) = \Phi(\boldsymbol{z_{it}^m \beta} + \nu_i^m) \tag{6.15}$$

for $m = 1, ..., 5$ protein types and $i = 1, ..., n$ households and $t = 1, ..., n_h$ years that each household is in the panel. ν_i^m are i.i.d., following a $N(0, \sigma_\nu^2)$ distribution, Φ is the standard normal cumulative distribution function, and ϵ_{it}^m are i.i.d. normally distributed with mean zero and $\sigma_\epsilon^2 = 1$.

The results from the probit estimates are then used to estimate the IMR for each protein and each household. More specifically, I obtain linear predictions, $\hat{y}_{it}^m$, of y_{it}^m and use them to calculate the following formula for a household that consumes protein i:

$$IMR_m(\hat{y}_{it}^m) = \frac{\phi(\hat{y}_{it}^m)}{\Phi(\hat{y}_{it}^m)} \tag{6.16}$$

where ϕ is the standard normal density, and Φ is the standard normal cumulative distribution function. Respectively, the IMR for a household that has not consumed protein i is calculated from:

$$IMR_i(\hat{y}_{it}^m) = \frac{\phi(\hat{y}_{it}^m)}{1 - \Phi(\hat{y}_{it}^m)}. \tag{6.17}$$

In the second stage, an AIDS model is estimated using the previously calculated IMR variables of each protein as regressors along with the deflated, weighted, protein prices faced by each consumer, and each household's demographic characteristics. AIDS was proposed by Deaton and Muellbauer (1980) and has been used repeatedly in studies that focus on substitution patterns among meat types. Note that the technique of a demand system paired with a censored regression can be implemented with any type of demand estimation model. That is, AIDS is not the only model that can be used here (Heien and Wesseils, 1990). However, AIDS is a popular choice because it can be restricted in a way that is consistent with consumer theory and it is not burdensome computationally.

Following the notation of Heien and Wesseils (1990), let w_m be the budget share of protein type m. Then the AIDS demand equation for this protein is:

$$w_m = \alpha_m + \sum_{m=1}^{5} \gamma_{mj} lnp_j + \beta_m ln(\frac{M}{P}) \tag{6.18}$$

where M is the total expenditure on proteins, p_j is the weighted price (see section 4.2.7) of protein j, and P is the following price index:[3]

$$lnP = \alpha_0 + \sum_{m=1}^{5} \alpha_m lnp_m + \frac{1}{2} \sum_{m=1}^{5} \sum_{j=1}^{5} \gamma_{mj} lnp_m lnp_j \tag{6.19}$$

To incorporate the demographic information in equation 6.18, I use the method of demographic scaling proposed by Ray (1983). The intuition of this method is that it compares two households with different composition and calculates their relative cost (i.e., "scales" the expenditure) in order for the households to enjoy the same utility level. That is, it identifies what is the expenditure level that would make, say, a 3-member household as well off as a reference household of 2 members and \$2,000 income. As Ray (1983) explains, the scale is the measure that quantifies the changing needs of a household as its composition changes.

The scale can be spilt into two multiplicative parts: one that varies with prices and utility and one that does not:

$$l_0(z, p, u) = \tilde{l}_0(z)\phi(p, z, u) \tag{6.20}$$

[3]Historically, this index used to be approximated by $\sum_{j=1}^{5} w_m lnp_m$ so that the share equations are linear. In the estimation of the present study this approximation is not used (for details regarding the estimation procedure see Stata (2023)).

where p is the price level, u is the utility leave, and z is the level of the demographic characteristic (e.g., if the household has 3 members z=3). $\phi(p, z, u)$ represents the dependence of the scale on the structure of relative prices and utility and must be non-negative and homogeneous of degree zero in p. The functional form of the basic component, $\tilde{l}_0$, is:

$$\tilde{l}_0 = 1 + \rho z \tag{6.21}$$

where z indicates the level of the demographic variable and ρ is the basic equivalence scale. The specification of $\phi(p, z, u)$ used here is:

$$\phi(p, z, u) = exp(u\Pi_k p_k^{\beta_k}(\Pi_k p_k^{\eta_k z} - 1)) \tag{6.22}$$

where $k = 1, ..., s$ are the demographic variables, $\sum \beta_i = 0$, and $\sum \eta_i = 0$. The η_is allow dependence of the scale on prices and utility and determine the direction of the variation of ϕ with u. With the demographic information incorporated in the model, equation 6.18 becomes for household i:

$$w_{mi} = \alpha_m + \sum_{m=1}^{5} \gamma_{mj} lnp_{ji} + \tilde{\beta}_m ln(\frac{M_h}{\tilde{l}_0(z_i)P_i}) \tag{6.23}$$

where $\tilde{\beta}_m = \beta_m + \eta_m z$.[4] The last component to be added to the demand relation of each protein is the IMRs of each protein. The complete expression of a demand relation of the model is therefore:

[4]Note that the demographic scaling is highly nonlinear and it can be hard to use when the model includes a large number of demographic variables (i.e., the model may not converge). An alternative linear method is the demographic translation. If the latter method were to be used here then the demographic variables would have been incorporated in equation 6.18 in the term α_m. More specifically, α_m is specified as follows:

$$\alpha_m = \rho_{m0} + \sum_{k=1}^{s} \rho_{mk} d_k \tag{6.24}$$

for $m = 1, .., 5$ proteins, and $k = 1, ..., s$ demographic variables, d_k. ρ_{m0} and ρ_{mk} are parameters to be estimated.

$$w_{mi} = \alpha_m + \sum_{m=1}^{5} \gamma_{mj} lnp_{ji} + \tilde{\beta}_m ln(\frac{M}{\tilde{m}_0(z_i)P_i}) + \delta_m IMR_{mi} \tag{6.25}$$

The parameters of the AIDS model are restricted in several ways in order for the model to be consistent with economic theory. These restrictions are:

- **Adding up:** The total expenditure on proteins should add up to 1. Changes in prices work through γ_{mj} and changes in expenditure through β_m. So, if the expenditure increases for a given protein, then it has to decrease for another. For this to be true, conditions 6.26 through 6.28 need to be satisfied.

$$\sum_{m}^{5} \alpha_m = 1; \tag{6.26}$$

$$\sum_{m}^{5} \gamma_{mj} = 0, \quad j = 1, ..., n; \tag{6.27}$$

$$\sum_{j=1}^{5} \beta_m = 0 \tag{6.28}$$

- **Homogeneity:** The demand functions are homogeneous of degree zero in prices and total expenditure, meaning that a proportional increase (or decrease) in prices and income will not affect the optimal protein consumption. That is, in the absence of a change in relative prices and expenditure, the budget share of a household for a given protein will not change. For this to be true in the estimated model, condition 6.29 needs to hold.

$$\sum_{j=1}^{n} \gamma_{mj} = 0, \; m = 1, ..., n \tag{6.29}$$

- **Symmetry:** The demand functions satisfy the Slutsky symmetry, meaning that the model takes into account that the pure substitution effect of a change in price p_j on the quantity chosen of protein q_m, should be identical with the substitution effect of a change in p_m on q_j. For the estimation of the demand system this condition implies that 6.30 needs to hold.

$$\gamma_{mj} = \gamma_{jm},\ m = 1, ..., n\ \forall m, j \tag{6.30}$$

Chapter 7

Results

7.1 Double-hurdle model

Following the road map of chapter 6, in this section I report and discuss the results of the double-hurdle model. Its estimation faced two important challenges. The first is that the model failed to converge when an unbalanced panel was used. To tackle this challenge, I estimate the model with smaller, balanced panels of different durations. Based on this approach, I analyze a total of 10 balanced panels, one for households that stayed in the panel throughout the entire 11 years, another for households that stayed 10 years, 9 years, etc., down to a two-year panel encompassing years 2021 and 2022. This approach means, for example, that a household that has participated in the panel for all 11 years (2012 - 2022) appears in each of the sub panels as well.

For all the panels that are shorter than 11 years, only the most recent years are included. For instance, for the three-year panel, I keep households that were observed in years 2020, 2021, and 2022. This strategy maximizes the size of each balanced panel, as the most recent years have the largest number of observations. A second advantage is that it focuses the analysis on the most recent years in the panel, which are arguably the most relevant to understanding consumption patterns for plant-based meat.

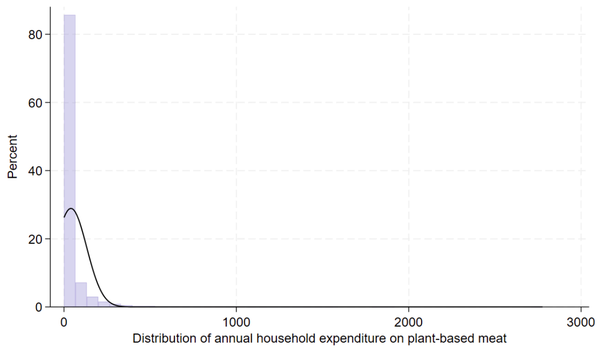
The second challenge arises from the fact that the distribution of expenditures on plant-based meat is highly skewed. As shown in table 7.1, a small number of households (3% of the entire sample) had a total expenditure on plant-based meat greater than $50 per year.[1] This creates a very long distribution tail, which does not satisfy the assumption of the error terms being normally distributed, and results in the model routine failing to converge. As shown in figure 7.1, when this small set of observations is removed from the sample, the skewness of the distribution of total expenditure on plant-based meat improves significantly. For this reason, I exclude this 3% of observations from the econometric estimation.

Table 7.1: Annual expenditure on plant-based meat of households in the sample

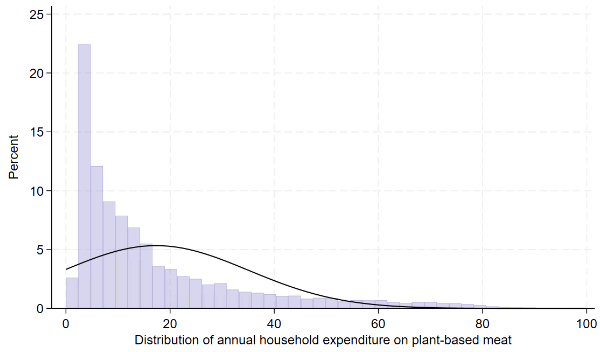
Expenditure level	**Number of households**	**Percentage**	**Cum. Percentage**
Zero	109,104	85.50	85.50
Up to $20	10,907	8.55	94.05
Between $21-$30	1,804	1.41	95.46
Between $30-$50	1,883	1.48	96.94
Between $51-$100	1,793	1.41	98.34
Greater than $100	2,115	1.66	100
Total	127,606	100	

[1]These households were defined as "medium" and "high spenders" in section 5.2.1. Figures 5.11 and 5.12 show the respective percentages of such households in the U.S. population.

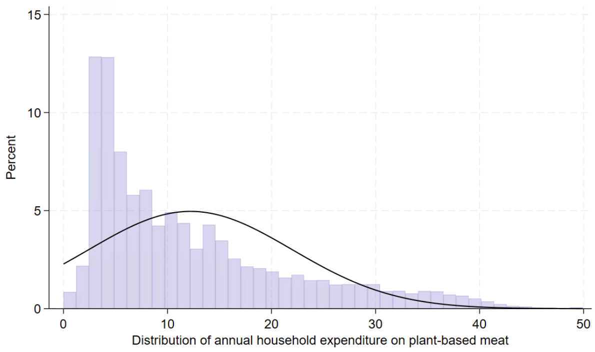
Figure 7.1: Distribution of yearly household expenditures on plant-based meat



((a)) Distribution of expenditures including all observations



((b)) Distribution of expenditures up to $100



((c)) Distribution of expenditures up to $50

(a) Distribution of positive annual household expenditures. (b) Distribution of positive annual household expenditures lower than $100. (c) Distribution of positive annual household expenditures lower than $50.

As mentioned in chapter 4, this study involves two samples, the "main" sample and the "health-survey" sample. The main sample contains fixed-weight and random-weight purchases of households in the static panel along with demographic information about the primary shopper such as income, gender, education, etc. The health-survey sample involves only a subset of households from the main sample which, in addition to reporting basic demographic information, also responded to survey questions regarding the health status of household members (e.g., good or poor health), possible health problems they faced and could be linked to diet habits (e.g., diabetes, cardiovascular diseases), and any concerns they had about food ingredients and food quality. To be able to capture the effect of health and diet factors in the demand for plant-based meat, I run the double-hurdle model separately for each sample.

Throughout the section I use the expression "participation to the plant-based meat market" to refer to the decision of the first hurdle. This is the conventional expression used by the authors who proposed and used the model and it is used here for convenience and not to imply that plant-based meat is its own distinct market. The first set of results focuses on obtaining the proportion p of the households who are willing to consume plant-based meat. As described in section 6.1, this estimate comes from a simplified double-hurdle model, called p-tobit model, which essentially does not contain any explanatory variables in the first hurdle, i.e, it estimates only the constant α_0. The constant is then transformed to a proportion p through $\Phi(\alpha_0)$, where Φ is the cumulative normal distribution function.

Table 7.2 shows the maximum likelihood estimates of the p-tobit model for each balanced panel, starting from the 11-year panel through the 2-year panel. The constant of the first hurdle is highly significant in all panels which means that there are indeed two consumer segments in this industry: consumers who are willing to consume plant-based meat and those who are not. Note that these are merely the estimates of the constant and not the estimates of the proportion p. Their transformation to proportions is presented in table 7.5, where one can see that the average proportion p out of the 10 panels is 29% and reaches a maximum of 36% when only the most recent two years of purchases are used. Combined with the finding portrayed in figure 5.4 (indicating that the proportion of consumers who have actually purchased plant-based meat in the past ranged from 13% in the early years of the panel to 20% in the most recent years), one can conclude that for 9% to 16% of consumers zero expenditure on plant-based meat is a corner solution. That is, upwards of 16% include plant-based meat in their consideration set, yet, given the protein prices and their income, they do not find it optimal to consume it. Most importantly, based on these findings, at least 64% of the households are not willing to consume plant-based meat—not a very promising result if these products are meant to significantly reduce the climate impact of mass animal production.

Looking at the maximum likelihood estimates of the second hurdle, it is noticeable that an increase in income increases the likelihood of non-zero household expenditures on plant-based meat, and that this effect is very consistent across all panels. Increases in the prices of animal proteins also are associated with increases in the likelihood of non-zero expenditures on plant-based meat consumption. When statistically significant, the effect for beef prices is larger in magnitude than the effect for prices of the remaining animal proteins, likely reflecting that beef substitutes represent the most common form of plant-based meat. In contrast, although the estimate of the price of plant-based meat has the expected negative sign across all panels, it is not significant for most of them.

In terms of demographic variables, increases in education of the primary shopper have a highly significant and sizable positive effect on plant-based meat expenditures, and like for income, this effect is consistent across the panels. Female primary shoppers are also significantly more likely to purchase plant-based meats. Although smaller in magnitude and not consistently significant across panels, an increase in household size positively impacts plant-based meat expenditures as well. Finally, the variables included in the second hurdle are jointly significant in each panel according to the reported χ^2 tests.

Tables 7.3 and 7.4 present the maximum likelihood estimates of the p-tobit model using the smaller health survey sample. In addition to the demographic variables that were included in the model presented in table 7.2, these models include demographic variables related to the health status and the diet habits of the household, the age of the primary shopper and the political inclination of the state of residence for each household.[2] The age of the primary shopper was the variable with the most missing observations resulting in many households being excluded from the estimation of this specification. To take advantage of as many household observations as possible, I estimate two alternative specifications: one with and one without this variable. Table 7.3 shows the p-tobit estimates when age is included and 7.4 when it is not.

Although the results of both models are similar to the ones using the larger (main) sample, the model that includes the age varies the most both across the different panels and across models. The constants of the first hurdle are highly statistically significant again, as table 7.5 shows. The highest proportion of consumers who are willing to purchase plant-based meat drops to 33% instead of 36% and the average p is also lower in both models (23% and 27%).

An important difference with the first model is that the price of plant-based meat does have a significant negative effect on a household's expenditure on plant-based meat in several of the panels. Regarding the prices of the other proteins, the prices of beef and poultry are strongly associated with higher expenditures on plant-based meat, but the price of pork is not significant for most panels in both models. The price of seafood is also associated with higher expenditures on plant-based meat, although the effect is statistically significant mainly in the model without the age variable.

The effects of income and education of the second hurdle also remain positive and significant across all models. Finally, the results indicate that the health status of a household affects expenditures on plant-based meat. More specifically households that are concerned about a future health issue (i.e., they are not yet sufferers of a health issue) that could be tied to food consumption (e.g., cardiovascular diseases) are more likely to consume plant-based meat, and the same holds for households who adopt ingredient-

[2] A detailed description of how these variables were constructed is provided in chapter 4.

specific diets such as gluten-free, organic etc. Interestingly, conditional on passing the first hurdle, the consumers who already have a health issue have a lower expenditure on plant-based meat.

Table 7.2: Maximum likelihood estimates of the p-tobit double-hurdle model using the main sample. (Dependent variable: total household expenditure on plant-based meat)

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
Participation										
(1st hurdle)										
constant	0.95***	0.88***	0.98***	0.80***	0.84***	0.81***	0.87***	0.73***	0.54***	0.45***
	(0.11)	(0.12)	(0.11)	(0.09)	(0.11)	(0.10)	(0.11)	(0.11)	(0.09)	(0.10)
Consumption>0										
(2nd hurdle)										
price of plant-based meat	-0.17	-0.40**	-0.14	-0.15	-0.14	-0.17	-0.13	-0.01	0.11	-0.10
	(0.17)	(0.17)	(0.14)	(0.13)	(0.13)	(0.12)	(0.12)	(0.12)	(0.12)	(0.12)
price of beef	0.15	0.26	0.50***	0.59***	0.85***	1.00***	1.13***	1.12***	0.90***	0.96***
	(0.18)	(0.16)	(0.15)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.14)	(0.16)
price of pork	0.20**	0.19**	0.25***	0.22***	0.21***	0.25***	0.26***	0.27***	0.13**	0.29***
	(0.09)	(0.08)	(0.08)	(0.07)	(0.07)	(0.06)	(0.06)	(0.06)	(0.07)	(0.07)
price of poultry	0.49***	0.46***	0.47***	0.44***	0.41***	0.46***	0.47***	0.45***	0.35***	0.41***
	(0.13)	(0.12)	(0.11)	(0.11)	(0.10)	(0.10)	(0.10)	(0.10)	(0.09)	(0.11)
price of seafood	0.36***	0.37***	0.37***	0.42***	0.46***	0.47***	0.47***	0.47***	0.39***	0.46***
	(0.08)	(0.08)	(0.07)	(0.06)	(0.06)	(0.06)	(0.07)	(0.07)	(0.07)	(0.08)
household income	0.98***	1.22***	1.23***	1.30***	1.41***	1.24***	1.19***	0.93***	0.93***	0.77***
	(0.27)	(0.25)	(0.24)	(0.21)	(0.21)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)
female primary shopper	0.85	1.26**	1.98***	2.30***	2.40***	2.44***	2.33***	1.96***	2.35***	1.78***
	(0.63)	(0.60)	(0.54)	(0.49)	(0.47)	(0.44)	(0.43)	(0.43)	(0.43)	(0.45)
household size	0.28	0.36*	0.14	0.12	0.25	0.43***	0.41***	0.71***	0.55***	0.52***
	(0.21)	(0.19)	(0.18)	(0.16)	(0.15)	(0.14)	(0.14)	(0.13)	(0.13)	(0.14)
education of primary shopper	2.61***	2.74***	2.70***	2.90***	2.91***	2.74***	2.64***	2.78***	2.87***	3.35***

Continuation of Table 7.2

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
	(0.35)	(0.33)	(0.31)	(0.28)	(0.25)	(0.24)	(0.23)	(0.23)	(0.23)	(0.24)
ρ	-0.82	-0.74	-0.81	-0.81	-0.77	-0.77	-0.76	-0.78	-0.73	
	(0.03)	(0.04)	(0.03)	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)	(0.07)	
N	88,189	95,919	109,692	129,224	133,406	140,285	132,750	122,428	107,028	83,060
χ^2 (2nd hurdle)	128.16	173.98	215.34	301.36	383.58	444.39	454.44	459.26	389.12	417.02
prob>χ^2 (2nd hurdle)	0	0	0	0	0	0	0	0	0	0

*p<0.1, **p<0.05, ***p<0.01

Table 7.3: Maximum likelihood estimates of the p-tobit double-hurdle model using the health-survey sample. (Dependent variable: total household expenditure on plant-based meat)

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
Participation										
(1st hurdle)										
constant	1.21***	0.88**	1.09***	1.01**	0.60*	0.92	0.32	2.05***	0.66***	0.19
	(0.41)	(0.41)	(0.43)	(0.50)	(0.32)	(0.65)	(0.22)	(0.06)	(0.25)	(0.20)
Consumption>0										
(2nd hurdle)										
price of plant-based meat	-2.60***	-1.73**	-1.81**	-0.66	-0.55	-0.13	-0.02	0.12	0.02	-0.76*
	(0.86)	(0.76)	(0.71)	(0.63)	(0.60)	(0.56)	(0.57)	(0.60)	(0.55)	(0.45)
price of beef	1.74**	1.73***	1.36**	1.16**	0.78	0.70	1.05*	0.93**	1.31**	0.45
	(0.71)	(0.65)	(0.58)	(0.52)	(0.50)	(0.47)	(0.57)	(0.44)	(0.54)	(0.42)
price of pork	0.54*	0.68**	0.61**	0.28	0.31	0.47*	0.49*	0.29	-0.02	0.04

Continuation of Table 7.3

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
	(0.33)	(0.30)	(0.28)	(0.26)	(0.26)	(0.26)	(0.26)	(0.24)	(0.26)	(0.20)
price of poultry	1.17	2.12***	1.81***	1.14**	0.92*	0.85*	1.31***	0.96**	0.87**	0.97**
	(0.75)	(0.66)	(0.61)	(0.53)	(0.51)	(0.49)	(0.48)	(0.44)	(0.41)	(0.41)
price of seafood	0.42	0.40	0.23	0.29	0.25	0.22	0.21	0.34	0.50**	0.34*
	(0.28)	(0.26)	(0.24)	(0.20)	(0.20)	(0.20)	(0.22)	(0.21)	(0.22)	(0.20)
household income	3.52***	5.13***	3.97***	3.03***	2.46***	2.54***	1.95**	2.00***	1.18*	1.12**
	(1.37)	(1.17)	(1.05)	(0.94)	(0.87)	(0.83)	(0.78)	(0.74)	(0.68)	(0.57)
household size	-1.31	-1.14	-2.09*	-1.43	-1.31	-1.38	-0.64	-1.32	-0.74	-1.17*
	(1.47)	(1.23)	(1.21)	(1.09)	(1.12)	(1.09)	(1.01)	(0.91)	(0.82)	(0.67)
education of primary shopper	1.01	2.27	0.65	2.44**	2.70***	2.84***	2.90***	2.68***	3.12***	3.28***
	(1.47)	(1.39)	(1.28)	(1.13)	(1.02)	(1.02)	(0.92)	(0.86)	(0.82)	(0.69)
age	0.002	0.13	0.06	0.12	0.09	0.10	0.02	-0.10	-0.26***	-0.28***
	(0.11)	(0.11)	(0.10)	(0.09)	(0.07)	(0.08)	(0.07)	(0.07)	(0.06)	(0.05)
state politics	-1.87	-1.63	-1.17	0.23	-0.11	0.29	0.48	0.23	0.32	1.47**
	(1.57)	(1.41)	(1.28)	(1.14)	(1.02)	(1.01)	(0.94)	(0.85)	(0.82)	(0.68)
health self assessment	0.56	-0.49	0.02	-0.24	-0.26	0.15	0.01	-0.02	0.46	0.65*
	(0.71)	(0.64)	(0.59)	(0.57)	(0.51)	(0.50)	(0.48)	(0.46)	(0.44)	(0.40)
concerned about health	0.72*	0.65*	0.86***	0.60**	0.50*	0.56**	0.63**	0.24	0.17	0.31
	(0.39)	(0.35)	(0.31)	(0.28)	(0.26)	(0.26)	(0.25)	(0.24)	(0.22)	(0.20)
having health problems	-0.30	0.04	0.32	0.16	0.19	-0.23	-0.31	-0.31	-0.08	-0.35
	(0.52)	(0.46)	(0.41)	(0.38)	(0.35)	(0.34)	(0.33)	(0.30)	(0.28)	(0.25)
ingredient-conscious diet	0.24	0.45**	0.40*	0.53***	0.47**	0.49***	0.54***	0.64***	0.66***	0.53***
	(0.23)	(0.22)	(0.21)	(0.19)	(0.19)	(0.18)	(0.19)	(0.18)	(0.17)	(0.16)
concerned about food quality	0.17	0.03	0.24*	0.28***	0.37**	0.29*	0.33**	0.41***	0.25**	0.17
	(0.16)	(0.13)	(0.13)	(0.13)	(0.15)	(0.15)	(0.15)	(0.14)	(0.12)	(0.11)

Continuation of Table 7.3

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
ρ	-0.75	-0.37	-0.77	-0.81	-0.27	0.02	-0.48	-0.99	-0.93	-0.50
	(0.12)	(0.20)	(0.13)	(0.12)	(0.23)	(0.65)	(0.15)	(0.006)	(0.51)	(0.12)
N	4,598	5,909	7.082	8,751	9,225	9,629	9,119	8,543	8,684	9,829
χ^2 (2nd hurdle)	36.58	63.66	59.47	57.83	55.53	57.02	69.63	73.09	94.03	127.95
prob>χ^2 (2nd hurdle)	0	0	0	0	0	0	0	0	0	0

*p<0.1, **p<0.05, ***p<0.01

Table 7.4: Maximum likelihood estimates of the p-tobit double-hurdle model using the health-survey sample (without the age variable). (Dependent variable: total household expenditure on plant-based meat)

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
Participation										
(1st hurdle)										
constant	1.03***	0.95***	1.04***	1.06***	0.80***	0.80***	0.76***	0.86***	0.60***	0.63***
	(0.23)	(0.20)	(0.42)	(0.23)	(0.19)	(0.13)	(0.15)	(0.16)	(0.13)	(0.16)
Consumption>0										
(2nd hurdle)										
price of plant-based meat	-0.88**	-0.49*	-0.49*	-0.38	-0.47**	-0.50**	-0.38*	-0.17	0.04	-0.10
	(0.41)	(0.28)	(0.27)	(0.25)	(0.24)	(0.23)	(0.23)	(0.23)	(0.21)	(0.20)
price of beef	0.34	0.72**	0.90***	0.98***	1.00***	1.23***	1.16***	1.02***	0.90***	0.58**
	(0.37)	(0.32)	(0.27)	(0.24)	(0.25)	(0.24)	(0.23)	(0.22)	(0.23)	(0.23)
price of pork	0.08	0.07	0.15	0.10	0.06	0.13	0.10	-0.01	-0.01	0.14
	(0.17)	(0.16)	(0.14)	(0.13)	(0.13)	(0.12)	(0.12)	(0.11)	(0.12)	(0.11)

Continuation of Table 7.4

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
price of poultry	1.10***	0.98***	0.82***	0.63***	0.57**	0.47**	0.43**	0.33	0.12	0.32*
	(0.35)	(0.30)	(0.26)	(0.23)	(0.22)	(0.21)	(0.21)	(0.20)	(0.17)	(0.18)
price of seafood	0.40**	0.41***	0.34**	0.41***	0.48***	0.44***	0.43***	0.55***	0.42***	0.37***
	(0.17)	(0.15)	(0.13)	(0.12)	(0.12)	(0.11)	(0.11)	(0.11)	(0.12)	(0.11)
household income	1.10**	0.65	1.17**	1.30***	1.41***	1.67***	1.66***	1.51***	1.32***	1.02***
	(0.35)	(0.48)	(0.47)	(0.40)	(0.37)	(0.36)	(0.35)	(0.33)	(0.31)	(0.29)
female primary shopper	0.05	1.69	1.42	1.16	1.77**	1.71**	2.15***	1.63**	1.57**	1.51**
	(1.30)	(1.20)	(1.01)	(0.89)	(0.86)	(0.80)	(0.80)	(0.75)	(0.71)	(0.66)
household size	-0.57	-0.06	-0.71	-1.06**	-1.12***	-1.08***	-1.14***	-1.06***	-0.75**	-0.75**
	(0.57)	(0.47)	(0.46)	(0.42)	(0.43)	(0.40)	(0.39)	(0.36)	(0.34)	(0.33)
education of primary shopper	2.88***	3.13***	2.47***	3.04***	3.66***	3.20***	3.00***	3.02***	3.07***	3.10***
	(0.73)	(0.66)	(0.62)	(0.52)	(0.50)	(0.45)	(0.45)	(0.42)	(0.38)	(0.36)
state politics	0.42	0.07	-0.04	0.45	0.76	0.68	0.75*	1.03**	1.19***	1.32***
	(0.70)	(0.63)	(0.56)	(0.50)	(0.47)	(0.45)	(0.43)	(0.41)	(0.38)	(0.35)
health self-assessment	0.31	0.29	0.35	0.21	0.19	0.23	-0.03	-0.23	-0.15	-0.46**
	(0.35)	(0.33)	(0.28)	(0.25)	(0.24)	(0.23)	(0.23)	(0.22)	(0.21)	(0.20)
concerned about health	0.45**	0.38**	0.49***	0.46***	0.38***	0.36***	0.25**	0.10	0.14	0.21**
	(0.18)	(0.15)	(0.15)	(0.13)	(0.12)	(0.12)	(0.11)	(0.11)	(0.11)	(0.11)
having health problems	-0.49**	-0.34	-0.37**	-0.41**	-0.31*	-0.56***	-0.68***	-0.87***	-1.10***	-1.48***
	(0.24)	(0.21)	(0.19)	(0.17)	(0.16)	(0.16)	(0.16)	(0.14)	(0.13)	(0.13)
ingredient-conscious diet	0.64***	0.55***	0.52***	0.53***	0.49***	0.51***	0.50***	0.70***	0.66***	0.63***
	(0.12)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)
concerned about food quality	0.20***	0.11*	0.14**	0.21***	0.24***	0.23***	0.28***	0.34***	0.30***	0.33***
	(0.07)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.05)	(0.05)

Continuation of Table 7.4

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
ρ	-0.83	-0.79	-0.68	-0.77	-0.50	-0.78	-0.80	-0.82	-0.79	0.72
	(0.06)	(0.10)	(0.14)	(0.10)	(0.15)	(0.04)	(0.05)	(0.04)	(0.10)	(0.10)
N	19,939	25,906	30,392	37,005	38,714	41,360	40,126	38,057	37,595	34,858
χ^2 (2nd hurdle)	92.14	97.65	114.00	168.62	196.00	235.43	237.19	294.80	319.29	379.58
prob$>\chi^2$ (2nd hurdle)	0	0	0	0	0	0	0	0	0	0

*p<0.1, **p<0.05, ***p<0.01

Table 7.5: Estimated share of households willing to ever consume plant-based meat

Model	**Main sample**	**Health-survey sample with age**	**Health-survey sample without age**
11-year panel	0.25***	0.19***	0.24***
10-year panel	0.27***	0.27***	0.25***
9-year panel	0.25***	0.22***	0.23***
8-year panel	0.29***	0.24***	0.23***
7-year panel	0.28***	0.33***	0.29***
6-year panel	0.29***	0.26	0.29***
5-year panel	0.27***	0.37	0.30***
4-year panel	0.30***	0.05***	0.27***
3-year panel	0.34***	0.32***	0.33***
2-year panel	0.36***	0.39	0.32***
Average of significant estimates	0.29	0.23	0.27
Min of significant estimates	0.25	0.05	0.23
Max of significant estimates	0.36	0.33	0.33

Tables 7.6, 7.7, and 7.8 show the results of the complete rather than simplified double-hurdle model estimated with the main sample and with the health survey sample with and without the age variable, respectively. Compared to the previously discussed results, this specification allows discussing factors that affect households' decision whether to participate in the plant-based meat market segment or not. The coefficient on the price of plant-based meat as well as household income, although they have the expected sign, are not statistically significant and both prices and income appear to play little role in determining participation. This finding is quite interesting and important because it goes against the idea that the main barrier for consumers who do not include plant-based meat in their diet is its high price. According to the model presented in table 7.6, increases in the prices of the animal proteins positively affect the decision to consume plant-based meat. However, these price effects, too, cease to be significant when the health sample is used.

The education level of the primary shopper, their age, health and dietary concerns are the major factors that affect the likelihood of a household participating in the plant-based meat market segment. Households with primary shoppers with higher education, ingredient-conscious diets, and concerns about antibiotics and hormones in animal products are more likely to introduce plant-based meat into their shopping basket. On the other hand, households with older primary shoppers and members who already face a health issue that could be linked to their dietary habits are less likely to consider plant-based meat. No conclusion can be drawn about the effect of the household size since its effect is positive in the main sample, but mostly significant and negative in the health sample. Gender of the primary shopper and political leaning of the home state are also not detected to be significant factors in the decision to participate in plant-based meat consumption.[3]

[3]Recall that the variable of political inclination was created by identifying what party received the majority of votes in each state for the past three elections. A detailed description of the variable can be

Conditional on passing the first hurdle, the prices of plant-based meat and other proteins become more important in determining expenditures on plant-based meats, although the coefficients are still often insignificant in many panels. Also, in the main model income is highly significant in the second hurdle while it was insignificant on the first. This means that prices and income affect mostly the decision of the quantity that will be purchased by the households and not their willingness to consume plant-based meat at all. Also, gender becomes significant for the decision of consumption quantity with female primary shoppers being more likely to consume compared to male primary shoppers.

The effect of age in the second hurdle is quite interesting since it has the opposite direction compared to the effect in the first hurdle. As shown in table 7.7, age affects negatively the participation decision but, conditional on the first hurdle being passed, it appears to affect positively the consumption decision. This implies that older consumers are less likely to participate in the plant-based meat market, but those who do participate consume more.

Health concerns do not appear to be a motive for households to participate to the plant-based meat market. However, and in accordance with the p-tobit model, households concerned about members' health that decide to participate, do consume more (i.e., health concerns are significant in the second hurdle). Concerns about antibiotics and hormones in animal products are influential in the decision to participate in the plant-based market and also as a determinant of expenditure.

Looking at the χ^2 tests, the variables that are included in the models are jointly significant for the first hurdle, the second and the overall model too. Also, the estimates of ρ in all models and across all panels reveal that the error terms of the two hurdles are

found on chapter 4 and an analysis on the consumption patterns of plant-based meat and this variable can be found in chapter 5.

highly negatively correlated. Further, its significance in all models suggests that a model that ignores the dependence of the error terms would be incorrect.

Table 7.6: Maximum likelihood estimates of the double-hurdle model using the main sample. (Dependent variable: total household expenditure on plant-based meat)

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
Participation (1st hurdle)										
price of meat sub.	-0.01	-0.02	-0.01	-0.01	-0.01	-0.02*	-0.01	-0.01*	-0.01	-0.01
	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
price of beef	0.12***	0.13***	0.09**	0.08***	0.11***	0.11***	0.10***	0.09***	0.12***	0.21***
	(0.41)	(0.04)	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)	(0.04)
price of pork	0.12***	0.11***	0.15***	0.08**	0.08*	0.02	0.14***	0.03	0.12***	0.25***
	(0.03)	(0.04)	(0.03)	(0.04)	(0.04)	(0.02)	(0.03)	(0.02)	(0.03)	(0.03)
price of poultry	0.61**	0.05**	0.06**	0.05**	0.05***	0.07***	0.08***	0.07***	0.08***	0.11***
	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)
price of seafood	0.04**	0.05***	0.05***	0.05***	0.06***	0.05***	0.07***	0.06***	0.06***	0.08***
	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.1)	(0.02)
household income	0.07**	-0.04	0.01	0.01	0.02	0.01	0.02	0.02	0.04	0.04
	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)
female primary shopper	0.20**	0.14	-0.10	-0.02	-0.03	-0.07	-0.10	-0.10	-0.35	0.01
	(0.09)	(0.1)	(0.10)	(0.08)	(0.08)	(0.09)	(0.09)	(0.10)	(0.33)	(0.10)
household size	0.09***	0.1***	0.08***	0.06***	0.06***	0.07***	0.06***	0.04***	0.01**	0.02
	(0.03)	(0.03)	(0.03)	(0.02)	(0.21)	(0.02)	(0.02)	(0.02)	(0.10)	(0.03)
education	0.25***	0.22***	0.21***	0.19***	0.22***	0.19***	0.21***	0.23***	0.81***	0.15**
	(0.06)	(0.05)	(0.05)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.17)	(0.06)
Consumption>0 (2nd hurdle)										
price of meat sub.	-0.22	-0.46***	-0.20	-0.19	-0.18	-0.21*	-0.18	-0.05	0.10	-0.07
	(0.17)	(0.17)	(0.13)	(0.13)	(0.13)	(0.12)	(0.11)	(0.12)	(0.13)	(0.13)
price of beef	-0.10	0.02	0.25*	0.34**	0.52***	0.69***	0.72***	0.71***	0.27*	0.07

Continuation of Table 7.6

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
	(0.18)	(0.16)	(0.15)	(0.14)	(0.13)	(0.13)	(0.13)	(0.13)	(0.14)	(0.16)
price of pork	0.07	0.07	0.10	0.08	0.06	0.13**	0.06	0.11	-0.18**	-0.13*
	(0.08)	(0.08)	(0.08)	(0.07)	(0.07)	(0.07)	(0.06)	(0.07)	(0.07)	(0.07)
price of poultry	0.37	0.33***	0.32***	0.28***	0.24**	0.28***	0.26**	0.23**	0.10	0.06
	(0.13)	(0.12)	(0.33)	(0.11)	(0.34)	(0.10)	(0.10)	(0.10)	(0.09)	(0.10)
price of seafood	0.27	0.28***	0.26***	0.31***	0.34***	0.35***	0.29***	0.28***	0.11*	0.12
	(0.08)	(0.28)	(0.7)	(0.06)	(0.06)	(0.06)	(0.06)	(0.07)	(0.07)	(0.07)
income	0.20	0.70**	0.88***	0.97***	1.01***	0.89***	0.83***	0.51*	0.30	0.19
	(0.32)	(0.30)	(0.29)	(0.27)	(0.27)	(0.25)	(0.26)	(0.27)	(0.30)	(0.32)
female primary shopper	-1.38	-0.24	3.10***	2.37**	2.61**	3.33***	3.38***	3.29**	2.65**	1.83*
	(1.20)	(1.20)	(1.12)	(1.15)	(1.11)	(1.23)	(1.05)	(1.40)	(1.24)	(1.02)
household size	-0.11	-0.02	-0.22	-0.19	-0.15	-0.06	0.05	0.32	0.19	0.47*
	(0.24)	(0.23)	(0.23)	(0.22)	(0.22)	(0.20)	(0.20)	(0.21)	(0.22)	(0.25)
education	0.23	0.63	0.70	0.65	0.55	0.51	0.57	-0.21	-0.25	1.86***
	(0.53)	(0.53)	(0.51)	(0.51)	(0.47)	(0.45)	(0.45)	(0.49)	(0.53)	(0.54)
ρ	-0.77	-0.72	-0.77	-0.77	-0.74	-0.71	-0.74	-0.74	-0.77	-0.70
	(0.04)	(0.04)	(0.03)	(0.04)	(0.03)	(0.04)	(0.04)	(0.04)	(0.03)	(0.04)
N	88,189	95,919	109,692	129,224	133,406	140,285	132,750	122,428	107,028	83,060
χ^2 (1st hurdle)	129.74	150.83	187.90	237.12	256.86	334.44	306.05	271.17	177.72	277.82
prob> χ^2 (1st hurdle)	0	0	0	0	0	0	0	0	0	0
χ^2 (2nd hurdle)	130.64	155.42	188.49	235.51	254.91	331.78	303.53	267.93	175.75	275.82
prob> χ^2 (2nd hurdle)	0	0	0	0	0	0	0	0	0	0
χ^2 (overall)	130.64	156.14	189.15	238.34	257.87	336.08	307.31	271.17	178.36	278.29
prob> χ^2 (overall)	0	0	0	0	0	0	0	0	0	0

*p<0.1, **p<0.05, ***p<0.01

Table 7.7: Maximum likelihood estimates of the double-hurdle model using the health-survey sample. (Dependent variable: total household expenditure on plant-based meat) (with the age variable)

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
Participation (1st hurdle)										
price of meat sub.	-0.08	-0.17	-0.07	-0.05	-0.05	-0.05	-0.08	-0.13*	-0.13*	-0.03
	(0.20)	(0.16)	(0.13)	(0.07)	(0.06)	(0.05)	(0.05)	(0.06)	(0.05)	(0.03)
price of beef	-0.04	-0.003	-0.05	-0.03	-0.02	-0.01	0.004	0.01	-0.02	0.03
	(0.14)	(0.20)	(0.05)	(0.04)	(0.03)	(0.03)	(0.03)	(0.04)	(0.03)	(0.02)
price of pork	-0.03	-0.02	0.29*	0.04	0.02	0.01	0.01	0.02	0.03	0.01
	(0.11)	(0.07)	(0.13)	(0.04)	(0.03)	(0.03)	(0.02)	(0.03)	(0.02)	(0.01)
price of poultry	0.14	-0.12	-0.23	-0.09	-0.08	-0.01	-0.01	0.01	0.06	0.003
	(0.11)	(0.13)	(0.12)	(0.06)	(0.05)	(0.04)	(0.03)	(0.05)	(0.04)	(0.03)
price of seafood	0.14	0.09	0.05	0.03	0.03	0.02	0.02	0.04	0.01	0.02
	(0.08)	(0.60)	(0.05)	(0.03)	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)	(0.01)
household income	0.04	0.17	0.11	0.14	0.09	0.04	0.01	0.14*	0.05	0.07*
	(0.18)	(0.17)	(0.13)	(0.08)	(0.06)	(0.06)	(0.06)	(0.07)	(0.05)	(0.04)
household size	0.16	-0.06	-0.16	-0.17	-0.16	-0.22**	-0.19**	-0.12	0.05	-0.02
	(0.26)	(0.21)	(0.18)	(0.11)	(0.09)	(0.08)	(0.08)	(0.09)	(0.07)	(0.04)
education	-0.22	-0.22	0.090	0.12	0.17	0.10	0.17	0.17	0.10	0.07
	(0.19)	(0.22)	(0.16)	(0.12)	(0.10)	(0.09)	(0.09)	(0.11)	(0.09)	(0.04)
age of primary shopper	-0.001	-0.02	-0.029*	-0.04**	-0.04**	-0.05**	-0.04**	-0.03*	0.00	-0.01**
	(0.02)	(0.01)	(0.01)	(0.008)	(0.007)	(0.007)	(0.008)	(0.01)	(0.01)	(0.003)
state politics	-0.37	-0.20	-0.12	0.01	0.01	0.01	0.02	0.02	0.001	0.04
	(0.277)	(0.16)	(0.11)	(0.06)	(0.05)	(0.05)	(0.04)	(0.06)	(0.04)	(0.03)
health assessment	0.01	0.01	0.02	-0.01	0.03	-0.02	-0.02	-0.04	-0.01	-0.02
	(0.10)	(0.09)	(0.07)	(0.03)	(0.03)	(0.03)	(0.03)	(-0.01)	(0.03)	(0.02)

Continuation of Table 7.7

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
health concern	-0.04	-0.05	-0.06	-0.01	0.01	-0.004	-0.01	-0.01	-0.002	0.02
	(0.06)	(0.05)	(0.04)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)
health issue	-0.05	-0.07	-0.02	-0.01	-0.02	-0.03	-0.03	-0.04	0.03	-0.03**
	(0.07)	(0.07)	(0.05)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)
ingredient-conscious diet	-0.01	0.05	0.02	0.05*	0.04*	0.04*	0.04*	0.05*	0.02	0.02*
	(0.04)	(0.05)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)
concerned about food	0.03	0.04	0.05	0.04*	0.03*	0.03**	0.04**	0.04*	0.02	0.01
	(0.04)	(0.03)	(0.03)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.007)
Consumption>0 (2nd hurdle)										
price of meat sub.	-2.75**	-2.50**	-2.41**	-1.37*	-0.88	-0.06	0.34	0.11	0.13	-0.38
	(0.82)	(0.78)	(0.74)	(0.66)	(0.62)	(0.58)	(0.59)	(0.65)	(0.58)	(0.34)
price of beef	0.06	1.54*	1.57*	1.60**	0.88	0.72	1.02	0.93	1.53**	0.16
	(0.67)	(0.70)	(0.62)	(0.60)	(0.60)	(0.57)	(0.64)	(0.65)	(0.59)	(0.44)
price of pork	0.27	0.61*	0.50	0.19	0.25	0.40	0.41	0.16	-0.22	0.06
	(0.27)	(0.30)	(0.29)	(0.27)	(0.27)	(0.28)	(0.27)	(0.26)	(0.30)	(0.19)
price of poultry	1.26	1.91**	1.76**	1.11*	0.95	0.63	1.04*	0.75	0.52	0.64
	(0.67)	(0.68)	(0.63)	(0.55)	(0.53)	(0.51)	(0.49)	(0.47)	(0.47)	(0.38)
price of seafood	0.29	0.27	0.100	0.20	0.12	0.02	0.07	0.08	0.39	-0.02
	(0.24)	(0.30)	(0.25)	(0.22)	(0.22)	(0.21)	(0.23)	(0.23)	(0.25)	(0.19)
household income	1.76	3.80*	3.10*	1.62	1.31	2.09	0.68	0.31	0.58	0.42
	(1.14)	(1.51)	(1.35)	(1.21)	(1.96)	(1.14)	(1.13)	(1.07)	(1.05)	(0.60)
household size	-2.38	-1.40	-1.74	-0.72	-0.02	1.03	0.93	-0.97	-1.62	-0.11
	(1.24)	(1.41)	(1.42)	(1.34)	(1.43)	(1.33)	(1.29)	(1.13)	(1.09)	(0.65)
education	3.21*	3.53	-0.73	-0.17	-0.68	0.25	-0.84	0.25	1.47	0.71
	(1.50)	(3.03)	(1.83)	(2.19)	(2.26)	(2.05)	(2.02)	(1.75)	(1.75)	(0.72)

Continuation of Table 7.7

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
age of primary shopper	0.02	0.27	0.34*	0.78**	0.84**	1.04**	0.77**	0.26	-0.23	-0.007
	(0.10)	(0.15)	(0.15)	(0.18)	(1.16)	(0.19)	(0.17)	(0.14)	(0.14)	(0.05)
health assessment	0.01	0.01	0.02	-0.01	0.03	-0.02	-0.02	-0.04	-0.01	-0.02
	(0.10)	(0.09)	(0.07)	(0.03)	(0.03)	(0.03)	(0.03)	(-0.01)	(0.03)	(0.02)
health concern	0.81*	1.13***	1.13**	0.64*	0.45	0.53	0.59*	0.29	0.12	-0.03
	(0.32)	(0.36)	(0.32)	(0.30)	(0.28)	(0.27)	(0.27)	(0.26)	(0.26)	(0.18)
health issue	-0.05	-0.07	-0.02	-0.01	-0.02	-0.03	-0.03	-0.04	0.03	-0.03**
	(0.07)	(0.07)	(0.05)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)
ingredient-conscious diet	0.21	0.36	0.44	0.40	0.34	0.26	0.29	0.37	0.53*	0.16
	(0.19)	(0.22)	(0.22)	(0.22)	(0.22)	(0.21)	(0.21)	(0.21)	(0.21)	(0.15)
concerned about food	0.07	-0.12	0.09	0.02	0.14	0.06	0.06	0.14	0.05	-0.07
	(0.14)	(0.15)	(0.14)	(0.15)	(0.19)	(0.18)	(0.18)	(0.16)	(0.15)	(0.10)
ρ	-0.34	-0.63	-0.72	-0.87	-0.92	-0.93	-0.89	-0.60	-0.63	-0.80
		(0.16)	(0.12)	(0.06)	(0.04)	(0.04)	(0.05)	(0.14)	(0.28)	(0.17)
N	4,202	5,909	7,082	8,751	9,225	9,629	9,119	8,543	8,684	9,574
χ^2 (1st hurdle)	45.97	71.89	80.11	119.10	121.15	133.69	111.43	73.85	75.53	83.39
prob> χ^2 (1st hurdle)	0.023	0	0		0	0	0	0	0	0
χ^2 (2nd hurdle)	53.46	75.30	82,60	119.42	119.86	131.74	110.38	71.55	71.10	75.03
prob> χ^2 (2nd hurdle)	0.004	0	0	0	0	0	0	0	0	0
χ^2 (overall)	53.62	78.03	86.14	120.25	121.63	133.74	111.63	73.85	75.91	84.41
prob> χ^2 (overall)	0.005	0	0	0	0	0	0	0	0	0

*p<0.1, **p<0.05, ***p<0.01

Table 7.8: Maximum likelihood estimates of the double-hurdle model using the health-survey sample (without age). (Dependent variable: total household expenditure on plant-based meat)

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
Participation (1st hurdle)										
price of meat sub.	0.12	-0.006	-0.07	-0.009	-0.01	-0.02	-0.01	-0.01	0.01	-0.0008
	(0.07)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)
price of beef	0.13	0.16	0.16*	0.08	0.03	0.04	0.04	0.05	-0.001	0.05
	(0.08)	(0.08)	(0.08)	(0.07)	(0.04)	(0.03)	(0.03)	(0.03)	(0.01)	(0.05)
price of pork	0.00	0.14	0.18*	0.02	0.02	0.06*	0.06*	0.08**	0.01	0.16**
	(0.026)	(0.11)	(0.09)	(0.03)	(0.02)	(0.03)	(0.03)	(0.02)	(0.01)	(0.04)
price of poultry	-0.03	0.02	-0.03	0.009	0.005	0.03	0.03	0.02	0.04*	0.05
	(0.05)	(0.06)	(0.05)	(0.08)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)
price of seafood	0.04	0.04	0.06	0.07**	0.04**	0.04**	0.04*	0.05**	0.02*	0.06**
	(0.03)	(0.03)	(0.03)	(0.03)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
household income	0.13*	0.002	-0.04	0.04	0.07*	0.07*	0.07*	0.03	0.01	0.10*
	(0.06)	(0.07)	(0.06)	(0.05)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.04)
female primary shopper	0.16	-0.13	-0.51*	-0.48	-0.09	-0.08	-0.08	-0.07	0.12*	-0.01
	(0.21)	(0.24)	(0.23)	(0.30)	(0.12)	(0.14)	(0.14)	(0.12)	(0.05)	(0.12)
household size	-0.03	-0.04	-0.01	-0.07	-0.06	-0.03	-0.03	-0.07	-0.01	-0.08
	(0.09)	(0.09)	(0.09)	(0.07)	(0.04)	(0.04)	(0.04)	(0.04)	(0.02)	(0.04)
education	-0.02	0.01	0.20	0.18*	0.18*	0.21**	0.21**	0.28**	0.10**	0.13
	(0.10)	(0.11)	(0.11)	(0.09)	(0.06)	(0.06)	(0.06)	(0.06)	(0.03)	(0.06)
state politics	-0.10	-0.10	0.02	-0.06	-0.07	-0.04	-0.04	-0.11	0.01	-0.22*
	(0.11)	(0.12)	(0.10)	(0.10)	(0.07)	(0.07)	(0.07)	(0.07)	(0.03)	(0.09)
health assessment	-0.04	-0.06	-0.04	-0.04	-0.04	-0.03	-0.03	-0.01	-0.02	-0.06
	(0.04)	(0.05)	(0.04)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)
health concern	0.02	0.03	0.02	0.03	0.02*	0.01	0.01	0.02	0.01	0.009

Continuation of Table 7.8

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
	(0.03)	(0.03)	(0.02)	(0.03)	(0.01)	(0.01)	(0.01)	(0.01)	(0.008)	(0.01)
health issue	-0.07**	-0.11*	-0.11**	-0.13**	-0.09**	-10**	-0.10**	-0.85**	-0.05**	-0.08**
	(0.03)	(0.03)	(0.02)	(0.03)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
ingredient-conscious diet	0.04	0.03	0.01	0.04*	0.05**	0.07**	0.07**	0.06**	0.02**	0.07**
	(0.03)	(0.03)	(0.02)	(0.1)	(0.01)	(0.01)	(0.01)	(0.01)	(0.007)	(0.02)
concerned about food	0.05*	0.05*	0.05**	0.05**	0.04**	0.05**	0.05**	0.05**	0.01**	0.06**
	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.009)	(0.005)	(0.01)
Consumption>0 (2nd hurdle)										
price of meat sub.	-0.78	-0.43	-0.59*	-0.37	-0.36	-0.29	-0.29	-0.18	0.01	-0.15
	(0.41)	(0.30)	(0.26)	(0.24)	(0.23)	(0.23)	(0.23)	(0.24)	(0.15)	(0.21)
price of beef	0.08	0.39	0.58*	0.72*	0.97**	0.83**	0.83**	0.67**	0.37	0.08
	(0.38)	(0.33)	(0.28)	(0.25)	(0.24)	(0.23)	(0.23)	(0.23)	(0.21)	(0.28)
price of pork	0.02	-0.07	-0.03	0.00	-0.01	-0.11	-0.11	-0.24*	-0.02	-0.30*
	(0.17)	(0.16)	(0.15)	(0.14)	(0.13)	(0.12)	(0.12)	(0.12)	(0.09)	(0.12)
price of poultry	1.01**	0.73**	0.63*	0.43	0.29	0.17	0.17	0.07	-0.06	0.006
	(0.35)	(0.30)	(0.27)	(0.25)	(0.22)	(0.21)	(0.21)	(0.21)	(0.12)	(0.17)
price of seafood	0.32	0.32*	0.23	0.30*	0.32**	0.27*	0.27*	0.35*	0.16	0.06
	(0.17)	(0.15)	(0.14)	(0.12)	(0.11)	(0.11)	(0.11)	(0.11)	(0.10)	(0.12)
household income	0.23	0.53	1.07	0.98	0.98*	0.77	0.77	0.96*	0.77**	-0.17
	(0.66)	(0.57)	(0.55)	(0.50)	(0.46)	(0.48)	(0.48)	(0.46)	(0.28)	(0.47)
female primary shopper	-2.31	2.91	4.99*	5.51*	2.78	2.87	2.87	2.15	-1.70*	1.41
	(2.73)	(2.44)	(1.95)	(2.47)	(1.91)	(2.06)	(2.06)	(1.78)	(0.69)	(1.47)
household size	-1.07	-0.23	-0.96	-0.98*	-0.94*	-1.26**	-1.26**	0.79	0.001	-0.36
	(0.69)	(0.53)	(0.51)	(0.48)	(0.47)	(0.46)	(0.46)	(0.43)	(0.28)	(0.44)
education	2.88*	2.87**	0.79	1.27	0.64	0.14	0.14	-0.54	0.32	1.67*

Continuation of Table 7.8

	(11-year)	(10-year)	(9-year)	(8-year)	(7-year)	(6-year)	(5-year)	(4-year)	(3-year)	(2-year)
	(1.21)	(1.10)	(0.98)	(0.90)	(0.83)	(0.85)	(0.85)	(0.81)	(0.38)	(0.74)
state politics	1.19	0.74	-0.31	1.07	1.75	1.32	1.32	2.49*	0.50	3.74**
	(1.37)	(1.43)	(1.11)	(1.16)	(1.15)	(1.13)	(1.13)	(1.10)	(0.40)	(1.18)
health assessment	0.32	0.38	0.33	0.26	0.33	0.03	0.023	-0.25	-0.02	-0.08
	(0.38)	(0.33)	(0.30)	(0.28)	(0.25)	(0.25)	(0.25)	(0.26)	(0.17)	(0.26)
health concern	0.39*	0.29	0.44**	0.36*	0.20	0.12	0.12	-0.11	0.10	0.11
	(0.19)	(0.17)	(0.15)	(0.14)	(0.12)	(0.12)	(0.12)	(0.12)	(0.09)	(0.13)
health issue	-0.15	0.09	0.13	0.25	0.16	0.05	0.05	-0.16	-0.22	-0.83**
	(0.27)	(0.25)	(0.21)	(0.21)	(0.19)	(0.20)	(0.20)	(0.19)	(0.12)	(0.19)
ingredient-conscious diet	0.52**	0.48**	0.46**	0.41**	0.31**	0.19	0.19	0.35**	0.27**	0.19
	(0.13)	(0.12)	(0.10)	(0.10)	(0.09)	(0.09)	(0.09)	(0.09)	(0.07)	(0.10)
concerned about food	0.11	0.03	0.05	0.09	0.001	-0.01	-0.01	0.03	-0.008	-0.03
	(0.07)	(0.06)	(0.06)	(0.06)	(0.07)	(0.07)	(0.07)	(0.07)	(0.05)	(0.06)
ρ	-0.81	-0.75	-0.77	-0.68	-0.49	-0.75	-0.74	-0.78	-0.55	-0.57
	(0.05)	(0.09)	(0.07)	(0.07)	(0.11)	(0.04)	(0.05)	(0.04)	(0.26)	(0.06)
N	19,939	25,906	30,392	37,005	38,714	41,360	40,126	38,057	35,106	34,858
χ^2 (1st hurdle)	140.90	110.69	142.27	157.78	196.07	221.72	168.65	226.68	180.16	318.34
prob> χ^2(1st hurdle)	0	0	0	0	0	0	0	0	0	0
χ^2 (2nd hurdle)	104.96	112.28	146.00	159.36	197.34	221.59	168.11	225.23	180.06	317.69
prob> χ^2(2nd hurdle)	0	0	0	0	0	0	0	0	0	0
χ^2 (overall)	107.38	112.27	146.00	159.53	197.74	222.82	169.52	226.88	180.16	319.27
prob> χ^2(overall)	0	0	0	0	0	0	0	0	0	0

*p<0.1, **p<0.05, ***p<0.01

7.1.1 Cross-sectional analysis

The final set of results is based on a year-by-year analysis of the sample. Although such analysis does not take into account important information that comes from the panel structure of the data, it is useful in order to study whether the impacts of variables of interest, such as the proportion of consumers vs. nonconsumers changes over time. Tables 7.9, 7.10, and 7.11 show the maximum likelihood estimates of the p-tobit model by year using the main sample and the health sample with and without the age variable, respectively.

The transformed constants presented in table 7.12 show that the proportion of consumers willing to participate in the plant-based meat market, although increasing over time, does not vary a lot from year to year. Also, the estimates of participation proportion are slightly larger in value compared to the results of the panel model, (e.g., the percentage from the main sample was 0.29 on average with the panel and 0.37 on average with the cross-sectional data), none of the estimates exceeds the value of 0.40.

Regarding the second hurdle, the coefficient of the price of plant-based meat is negative in most cross sections and statistically significant in five of 11 years. The prices of competing proteins are consistently associated with greater expenditures on plant-based meat, with beef and poultry prices having the strongest impacts. The income of the household is also strongly associated with greater expenditure on plant-based meat.

Regarding the demographics, female and more educated primary shoppers spend more on plant-based meat than their counterparts, with an effect that is relatively consistent across years. Older primary shoppers were confirmed to be less likely purchasers of plant-based meat based upon the cross-sectional analysis.

Households with concerns about food quality and with ingredient-conscious diets are likely to consume more plant-based meat, and there is no discernible trend in their effects over time. The same holds for households which face health problems. In general, these households are likely to spend less on plant-based meat, but this effect does not present a noticeable trend over time. The effect of household size is unclear as it alters sign across the two samples. It is positive when the entire sample is used and negative with the health-survey sample. This may be an indication that there is a systematic difference in behavior between the households which chose to participate in the health survey and those that did not.

Table 7.9: Maximum likelihood estimates of the p-tobit double-hurdle model using the main sample, by year. (Dependent variable: total household expenditure on plant-based meat)

	(2012)	(2013)	(2014)	(2015)	(2016)	(2017)	(2018)	(2019)	(2020)	(2021)	(2022)
Participation (1st hurdle)											
constant	-0.37***	-0.40***	-0.08	-0.42***	-0.06	0.25	-0.18	-0.26***	-0.39***	0.08	-0.01
	(0.08)	(0.07)	(0.12)	(0.06)	(0.12)	(0.20)	(0.10)	(0.07)	(0.04)	(0.09)	(0.19)
Consumption>0 (2nd hurdle)											
price of plant-based meat	0.06	-1.23***	-0.59	0.24	-0.81***	-1.55***	-0.22	-0.35	0.08	-0.79***	-0.10
	(0.31)	(0.31)	(0.33)	(0.23)	(0.27)	(0.30)	(0.21)	(0.26)	(0.23)	(0.26)	(0.13)
price of beef	1.30***	2.38***	1.87***	2.35***	2.39***	1.78***	2.82***	1.93***	1.95***	1.74***	1.52***
	(0.42)	(0.39)	(0.36)	(0.32)	(0.31)	(0.24)	(0.31)	(0.27)	(0.30)	(0.22)	(0.25)
price of pork	0.84***	0.59***	0.73***	0.97***	0.55***	0.55***	0.55***	0.73***	0.41***	0.53***	-0.37**
	(0.22)	(0.19)	(0.18)	(0.18)	(0.13)	(0.12)	(0.15)	(0.14)	(0.12)	(0.11)	(0.11)
price of poultry	1.23	0.98***	1.75***	1.57***	1.36***	1.70***	1.47***	1.90***	1.67***	1.12***	0.60***
	(0.31)	(0.31)	(0.29)	(0.25)	(0.24)	(0.21)	(0.25)	(0.25)	(0.24)	(0.18)	(0.15)
price of seafood	0.72***	0.80***	1.02***	0.64***	0.91***	0.75***	0.78***	0.98***	0.97***	0.84***	0.70***
	(0.22)	(0.21)	(0.17)	(0.17)	(0.14)	(0.12)	(1.46)	(0.14)	(0.14)	(0.13)	(0.12)
household income	1.76***	2.32***	2.36***	1.97***	1.49***	1.27***	1.39***	1.44***	1.49***	0.74***	0.97***
	(0.32)	(0.31)	(0.31)	(0.29)	(0.27)	(0.25)	(0.27)	(0.26)	(0.24)	(0.22)	(0.22)
female primary shopper	2.29***	2.49***	4.07***	2.83***	3.20***	3.07***	4.04***	1.67***	2.92***	1.48***	1.42***
	(0.64)	(0.64)	(0.63)	(0.59)	(0.55)	(0.53)	(0.58)	(0.55)	(0.53)	(0.50)	(0.51)
household size	0.17	-0.12	0.04	0.22	0.15	0.38**	0.40**	0.47***	0.39***	0.69***	0.29
	(0.22)	(0.22)	(0.21)	(0.20)	(0.18)	(0.16)	(0.18)	(0.17)	(0.29)	(0.15)	(0.16)
education of primary shopper	3.72***	4.09***	4.65***	4.73***	3.90***	4.26***	3.86***	4.08***	3.96***	3.67***	2.99***

Continuation of Table 7.9

	(2012)	(2013)	(2014)	(2015)	(2016)	(2017)	(2018)	(2019)	(2020)	(2021)	(2022)
	(0.40)	(0.40)	(0.38)	(0.36)	(0.32)	(0.30)	(0.32)	(0.31)	(0.29)	(0.27)	(0.28)
N	32,754	35,427	39,510	45,426	49,773	53,845	54,050	54,236	52,753	51,277	50,119

*p<0.1, **p<0.05, ***p<0.01

Table 7.10: Maximum likelihood estimates of the p-tobit double-hurdle model using the health-survey sample, by year. (Dependent variable: total household expenditure on plant-based meat)

	(2012)	(2013)	(2014)	(2015)	(2016)	(2017)	(2018)	(2019)	(2020)	(2021)	(2022)
Participation (1st hurdle)											
constant	-0.23	-0.14	-0.04	-0.31**	0.17	0.47	-0.10	0.01	-0.30***	0.96	0.82***
	(0.14)	(0.19)	(0.25)	(0.13)	(0.29)	(0.43)	(0.22)	(0.23)	(0.08)	(0.69)	(0.21)
Consumption>0 (2nd hurdle)											
price of plant-based meat	-0.37	-1.32**	-1.50**	-0.23	-1.59***	-2.11***	-0.10	-1.64***	0.40	-1.12**	-0.24
	(0.58)	(0.64)	(0.70)	(0.48)	(0.52)	(0.59)	(0.46)	(0.63)	(0.36)	(0.54)	(0.37)
price of beef	1.15	2.14***	1.65**	2.41***	1.15**	1.55***	2.21***	2.05***	2.28***	1.13***	0.80*
	(0.82)	(0.62)	(0.74)	(0.55)	(0.57)	(0.48)	(0.65)	(0.68)	(0.70)	(0.38)	(0.41)
price of pork	1.07**	0.61	1.10***	0.64	0.19	0.38	0.48	0.87***	0.85***	0.35***	0.26
	(0.41)	(0.32)	(0.36)	(0.36)	(0.22)	(0.24)	(0.31)	(0.30)	(0.30)	(0.17)	(0.19)
price of poultry	0.54	0.32	1.73***	1.24***	1.22**	1.15***	1.00**	1.24***	1.53***	1.38***	0.65
	(0.55)	(0.61)	(0.63)	(0.47)	(0.50)	(0.42)	(0.50)	(0.54)	(0.52)	(0.27)	(0.40)
price of seafood	0.35	0.57	0.56	0.31	0.78***	0.52***	0.09	0.48	0.82***	0.81***	0.40*

Continuation of Table 7.10

	(2012)	(2013)	(2014)	(2015)	(2016)	(2017)	(2018)	(2019)	(2020)	(2021)	(2022)
	(0.34)	(0.36)	(0.36)	(0.33)	(0.26)	(0.19)	(0.27)	(0.26)	(0.24)	(0.21)	(0.20)
household income	1.68***	2.41***	3.04***	2.23***	1.42***	0.58	2.12***	2.06***	1.58***	1.21***	1.62***
	(0.59)	(0.60)	(0.63)	(0.59)	(0.54)	(0.50)	(0.56)	(0.58)	(0.48)	(0.44)	(0.43)
female primary shopper	-0.09	0.90	3.80***	2.17**	2.73***	2.08**	3.21***	-0.53***	2.30**	0.19	-0.30
	(0.77)	(1.07)	(1.11)	(1.04)	(0.95)	(0.89)	(1.01)	(1.03)	(0.90)	(0.81)	(0.80)
household size	-1.09	-1.13	-1.36**	-1.75***	-2.35***	-2.10***	-2.56***	-1.28**	-1.85***	-0.68	-1.05**
	(0.77)	(0.63)	(0.63)	(0.60)	(0.58)	(0.52)	(0.59)	(0.64)	(0.56)	(0.49)	(0.50)
education of primary shopper	2.81***	3.84***	3.99***	4.20***	4.89***	4.86***	3.03***	2.58***	3.97***	3.34***	1.93***
	(0.74)	(0.74)	(0.76)	(0.72)	(0.53)	(0.59)	(0.66)	(0.67)	(0.60)	(0.53)	(0.54)
age	-2.04**	-2.64***	-0.82	-0.90	-2.27***	-2.53***	-3.86***	-2.16***	-2.59***	-2.57***	-0.20***
	(0.79)	(0.81)	(0.85)	(0.78)	(0.66)	(0.60)	(0.68)	(0.73)	(0.64)	(0.58)	(0.03)
state politics	0.46	1.99***	-0.14	1.55**	2.11***	1.76***	1.07	1.82***	0.93	1.01***	1.39***
	(0.68)	(0.68)	(0.72)	(0.68)	(0.60)	(0.55)	(0.62)	(0.65)	(0.56)	(0.50)	(0.50)
health self-assessment	0.23	0.78	0.51	0.04	0.23	0.42	0.58	-0.08	-0.21	-0.25	0.71*
	(0.47)	(0.47)	(0.47)	(0.44)	(0.40)	(0.37)	(0.42)	(0.44)	(0.38)	(0.34)	(0.34)
concerned about health	0.14	0.43	0.20	-0.003	0.27	0.43**	-0.11	0.76***	0.03	0.57***	0.45**
	(0.24)	(0.24)	(0.25)	(0.23)	(0.22)	(0.20)	(0.23)	(0.22)	(0.19)	(0.17)	(0.17)
having health problems	-0.99***	-1.01***	-1.04***	-1.94***	-1.13***	-0.92***	-0.59**	-1.49***	-1.27***	-1.41***	-0.58***
	(0.32)	(0.30)	(0.31)	(0.29)	(-0.27)	(0.26)	(0.27)	(0.27)	(0.23)	(0.21)	(0.20)
ingredient-conscious diet	1.37***	0.91***	0.75***	0.92***	0.84***	0.67***	0.80**	0.93***	0.91***	0.58***	0.40***
	(0.16)	(0.15)	(0.16)	(0.15)	(0.14)	(0.12)	(0.14)	(0.15)	(0.14)	(0.12)	(0.14)
concerned about food quality	0.12	0.96***	0.79***	1.33***	0.34***	0.55***	0.39**	0.40***	0.49***	0.37***	0.1
	(0.14)	(0.27)	(0.29)	(0.28)	(0.08)	(0.08)	(0.09)	(0.10)	(0.09)	(0.08)	(0.08)
vegan											10.31***
											(2.01)

Continuation of Table 7.10

	(2012)	(2013)	(2014)	(2015)	(2016)	(2017)	(2018)	(2019)	(2020)	(2021)	(2022)
vegetarian											10.49***
											(1.77)
pescatarian											2.64
											(2.39)
flexitarian											9.02***
											(0.95)
N	9,331	10,768	10,233	12,116	12,978	14,412	13,359	11,092	12,298	13,166	11,806

*p<0.1, **p<0.05, ***p<0.01

Table 7.11: Maximum likelihood estimates of the p-tobit double-hurdle model using the health-survey sample, by year (without age). (Dependent variable: total household expenditure on plant-based meat)

	(2012)	(2013)	(2014)	(2015)	(2016)	(2017)	(2018)	(2019)	(2020)	(2021)	(2022)
Participation (1st hurdle)											
constant	-0.16	-0.19*	-0.03	-0.25**	0.10	0.28	-0.09	-0.18	-0.34***	0.23	0.96***
	(0.11)	(0.11)	(0.81)	(0.09)	(0.19)	(0.22)	(0.53)	(0.11)	(0.05)	(0.12)	(0.14)
Consumption>0 (2nd hurdle)											
price of plant-based meat	-0.40	-1.55***	-0.81	0.18	-1.24***	-1.69***	-0.27	-1.20***	0.45	-0.57	-0.009
	(0.43)	(0.40)	(0.45)	(0.35)	(0.37)	(0.41)	(0.32)	(0.42)	(0.30)	(0.37)	(0.21)
price of beef	1.04	2.14***	1.35***	1.87***	1.37***	1.23***	1.99***	2.17***	1.48***	1.02***	0.58**
	(0.59)	(0.49)	(0.52)	(0.40)	(0.41)	(0.29)	(0.42)	(0.48)	(0.43)	(0.31)	(0.27)

Continuation of Table 7.11

	(2012)	(2013)	(2014)	(2015)	(2016)	(2017)	(2018)	(2019)	(2020)	(2021)	(2022)
price of pork	0.53**	0.44	0.76***	0.62***	0.39**	0.42***	0.46**	0.63**	0.47**	0.39***	0.37***
	(0.25)	(0.23)	(0.25)	(0.22)	(0.16)	(0.16)	(0.20)	(0.20)	(0.19)	(0.14)	(0.13)
price of poultry	0.56	0.69	1.67***	1.59***	1.11**	1.37***	1.01***	1.66***	1.26***	1.04***	0.38*
	(0.40)	(0.39)	(0.38)	(0.32)	(0.33)	(0.28)	(0.33)	(0.42)	(0.34)	(0.22)	(0.17)
price of seafood	0.68**	0.57**	0.73***	0.43**	0.86***	0.64***	0.40***	0.94***	0.80***	0.98***	0.58***
	(0.27)	(0.24)	(0.24)	(0.20)	(0.19)	(0.15)	(0.18)	(0.23)	(0.18)	(0.18)	(0.15)
household income	2.00***	1.94***	2.42***	1.88***	1.39***	1.26***	1.28***	1.61***	1.70***	1.17***	1.29***
	(0.44)	(0.40)	(0.43)	(0.39)	(0.37)	(0.33)	(0.38)	(0.40)	(0.34)	(0.32)	(0.30)
female primary shopper	2.03**	2.41***	4.46***	2.40***	2.83***	2.86***	4.09***	1.26	2.81***	1.32	0.31
	(0.88)	(0.82)	(0.86)	(0.79)	(0.75)	(0.70)	(0.81)	(0.83)	(0.74)	(0.69)	(0.65)
household size	-1.33**	-1.62***	-1.78***	-1.89***	-2.12***	-2.04***	-1.28***	-1.23***	-1.44***	-0.67	-0.58*
	(0.57)	(0.41)	(0.42)	(0.40)	(0.40)	(0.35)	(0.40)	(0.43)	(0.38)	(0.35)	(0.34)
education of primary shopper	2.68***	3.85***	4.29***	4.60***	4.48***	4.53***	4.09***	3.72***	4.53***	3.82***	2.27***
	(0.55)	(0.51)	(0.52)	(0.48)	(0.44)	(0.39)	(0.45)	(0.43)	(0.41)	(0.39)	(0.36)
state politics	0.83	1.41***	0.13	1.64***	1.67***	1.30***	0.56	0.59	0.95**	0.77**	1.45***
	(0.50)	(0.46)	(0.48)	(0.45)	(0.42)	(0.37)	(0.42)	(0.45)	(0.39)	(0.36)	(0.33)
health self-assessment	0.12	0.60	0.35	-0.17	0.16	0.16	0.04	-0.41	-0.26	-0.63**	-0.32
	(0.34)	(0.31)	(0.31)	(0.30)	(0.27)	(0.25)	(0.28)	(0.30)	(0.26)	(0.24)	(0.22)
concerned about health	0.17	0.31	-0.17	-0.08	0.13	0.38***	0.10	0.61***	0.18	0.41***	0.30**
	(0.18)	(0.17)	(0.17)	(0.16)	(0.15)	(0.13)	(0.15)	(0.16)	(0.13)	(0.13)	(0.12)
having health problems	-1.42***	-1.33***	-1.00***	-1.95***	-1.47***	-1.53***	-1.55***	-1.47***	-1.55***	-1.93***	-1.05***
	(0.22)	(0.19)	(0.20)	(0.19)	(0.18)	(0.16)	(0.18)	(0.18)	(0.15)	(0.15)	(0.14)
ingredient-conscious diet	1.37***	0.92***	0.96	1.03***	0.84***	0.73***	0.80***	0.86***	0.92***	0.79***	0.52***
	(0.11)	(0.10)	(0.11)	(0.19)	(0.09)	(0.09)	(0.10)	(0.11)	(0.10)	(0.09)	(0.10)
concerned about food quality	0.25**	1.15***	1.04***	1.35***	0.43***	0.54***	0.39***	0.44***	0.45***	0.43***	0.17**

Continuation of Table 7.11

	(2012)	(2013)	(2014)	(2015)	(2016)	(2017)	(2018)	(2019)	(2020)	(2021)	(2022)
	(0.10)	(0.19)	(0.20)	(0.19)	(0.06)	(0.05)	(0.06)	(0.07)	(0.06)	(0.06)	(0.06)
vegan											12.30***
											(1.40)
vegetarian											12.83***
											(1.24)
pescatarian											6.47***
											(1.73)
flexitarian											9.88***
											(0.66)
N	16,359	20,964	20,889	24,894	26,723	29,609	27,898	23,296	25,345	25,434	25,363

*p<0.1, **p<0.05, ***p<0.01

Table 7.12: Estimated share of households willing to ever consume plant-based meat, by year

Model	**Main sample**	**Health-survey sample with age**	**Health-survey sample without age**
2012	0.37***	0.38	0.39
2013	0.36***	0.39	0.39*
2014	0.39	0.39	0.39
2015	0.36***	0.38**	0.38**
2016	0.39	0.39	0.39
2017	0.38	0.35	0.38
2018	0.39	0.39	0.39
2019	0.38***	0.39	0.39
2020	0.36***	0.38***	0.37***
2021	0.39	0.25	0.38
2022	0.39	0.28***	0.25***
Average of significant estimates	0.37	0.35	0.35
Min of significant estimates	0.36	0.28	0.39
Max of significant estimates	0.38	0.38	0.25

Tables 7.13 and 7.14 show the results of the double-hurdle model by year with each sample.[4] In general, the results of the cross-sectional analysis are consistent with the findings of the panel models. Most variables for the participation hurdle are not statistically significant. The variable that consistently has a positive effect on participation in the plant-based meat market is the price of beef. Household income is not significant for most years in both samples, nor is the price of plant-based meat. Education of the primary shopper has a positive impact in some years of the sample but not others.

The price of plant-based meat is a negative and significant determinant in the expenditure hurdle in about half of the years and for both samples. The prices of the protein substitutes do not exhibit consistent effects across the years in the sample, and household income is generally not statistically significant.

Among demographic variables, education of the primary shopper is strongly associated with greater plant-based meat expenditures, as for most years is the primary shopper being female in the full sample. Households with health issues are associated with significantly lower plant-based meat expenditures in most years. Notably, the vegan, vegetarian, pescatarian, and fleitarian variables, available only in 2022 are not significantly associated with a greater participation in the plant-based meat segment, but all except pesctarian are associated with higher expenditures in the second hurdle. This may imply that consumers who restrict their diet to fish are likely less interested in the taste of meat in general.

[4]To avoid repetitions of similar results, the results of the health survey sample without the age variable are not presented here.

Table 7.13: Maximum likelihood estimates of the double-hurdle model using the main sample, by year. (Dependent variable: total household expenditure on plant-based meat)

	(2012)	(2013)	(2014)	(2015)	(2016)	(2017)	(2018)	(2019)	(2020)	(2021)	(2022)
Participation (1st hurdle)											
price of meat sub.	0.01	-0.06**	-0.02	-0.01	-0.01	-0.06**	-0.01	-0.01	-0.008	-0.02	0.002
	(0.3)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)
price of beef	0.46***	0.03	0.27***	0.14***	0.53***	0.38***	0.40***	-0.10***	0.24***	0.40***	0.43***
	(0.10)	(0.03)	(0.05)	(0.04)	(0.06)	(0.06)	(0.05)	(0.02)	(0.02)	(0.05)	(0.05)
price of pork	0.39***	-0.02**	-0.05***	0.30***	0.31***	0.44***	-0.06***	0.38***	-0.008	-0.08***	0.41***
	(0.06)	(0.01)	(0.01)	(0.05)	(0.05)	(0.04)	(0.01)	(0.05)	(0.008)	(0.01)	(0.45)
price of poultry	0.22***	0.10***	0.24***	-0.003	0.18***	0.15	0.10***	0.38***	-0.01	0.24***	-0.01
	(0.08)	(0.03)	(0.04)	(0.04)	(0.05)	(0.09)	(0.02)	(0.05)	(0.01)	(0.05)	(0.009)
price of seafood	-0.08***	-0.008	0.12***	0.10***	-0.05***	0.11***	0.14***	0.17***	-0.004	0.19***	-0.06***
	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)	(0.03)	(0.008)	(0.02)	(0.01)
income	0.07	0.07**	0.11***	-0.01	0.08	-0.03	0.07	-0.03	0.01	-0.06	0.08
	(0.05)	(0.03)	(0.04)	(0.04)	(0.05)	(0.05)	(0.04)	(0.05)	(0.02)	(0.05)	(0.04)
female primary shopper	-0.02	0.24***	0.08	0.15*	0.11	0.08	0.15	-0.06	0.19***	0.10	0.21**
	(0.05)	(0.05)	(0.08)	(0.08)	(0.11)	(0.11)	(0.10)	(0.11)	(0.04)	(0.10)	(0.10)
household size	-0.02	-0.005	-0.02	0.03	-0.08*	0.01	-0.04	0.03	-0.01	-0.03	-0.04
	(0.03)	(0.02)	(0.03)	(0.03)	(0.04)	(0.03)	(0.03)	(0.03)	(0.01)	(0.03)	(0.03)
education	-0.08	0.07**	0.14***	0.28***	0.06	0.16**	0.10	0.07	0.02	-0.01	-0.09
	(0.07)	(0.03)	(0.05)	(0.06)	(0.07)	(0.07)	(0.07)	(0.06)	(0.02)	(0.06)	(0.07)
Consumption>0 (2nd hurdle)											
price of meat sub.	-0.37	-0.36	-0.60	0.47*	-0.85***	-1.61***	-0.26	-0.65**	-0.89***	-0.02	-0.14
	(0.38)	(0.36)	(0.43)	(0.27)	(0.30)	(0.33)	(0.24)	(0.30)	(0.25)	(0.28)	(0.15)
price of beef	-1.29**	1.71**	-1.66***	-0.08	-0.74*	-0.11	-1.24***	2.45***	-2.04***	-0.22	-0.51

Continuation of Table 7.13

	(2012)	(2013)	(2014)	(2015)	(2016)	(2017)	(2018)	(2019)	(2020)	(2021)	(2022)
	(0.54)	(0.86)	(0.48)	(0.36)	(0.41)	(0.30)	(0.42)	(0.32)	(0.29)	(0.27)	(0.26)
price of pork	-0.56**	1.29***	2.04***	-1.23***	-0.39	-0.55***	1.72***	-0.45***	0.59***	1.52***	-0.46***
	(0.25)	(0.31)	(0.31)	(0.16)	(0.15)	(0.15)	(0.26)	(0.14)	(0.21)	(0.17)	(0.12)
price of poultry	-0.25	-0.91	-1.20***	1.32**	0.62	0.62	2.65***	-0.48	1.86***	0.02	0.54***
	(0.42)	(0.57)	(0.38)	(0.65)	(0.38)	(0.38)	(0.43)	(0.30)	(0.42)	(0.19)	(0.17)
price of seafood	1.38***	1.02***	-0.44**	-0.52***	0.15	0.15	-0.23	-0.02	1.02***	-0.17	1.08***
	(0.31)	(0.38)	(0.20)	(0.20)	(0.13)	(0.13)	(0.15)	(0.14)	(0.20)	(0.13)	(0.19)
household income	0.90*	0.80	0.41	1.88***	1.19***	1.19***	0.43	1.54***	1.23**	1.05***	0.35
	(0.53)	(0.68)	(0.74)	(0.62)	(0.43)	(0.43)	(0.62)	(0.49)	(0.49)	(0.40)	(0.37)
female primary shopper	2.47**	-2.69**	0.82	2.36**	2.59***	2.59***	2.27	2.33**	-0.37	0.86	0.04
	(1.06)	(1.29)	(1.42)	(1.31)	(0.91)	(0.91)	(1.36)	(0.98)	(1.05)	(0.94)	(0.90)
household size	0.39	-0.003	0.50	-0.36**	0.30	0.30	0.94**	0.16***	0.71**	0.98***	0.61***
	(0.35)	(0.45)	(0.50)	(0.42)	(0.30)	(0.30)	(0.46)	(0.33)	(0.34)	(0.29)	(0.31)
education	4.01***	2.68***	2.55***	0.67	3.03***	3.03***	2.56***	3.21***	3.59***	4.02***	4.03***
	(0.63)	(0.80)	(0.92)	(0.79)	(0.53)	(0.53)	(0.94)	(0.61)	(0.59)	(0.54)	(0.53)
N	32,754	35,427	39,510	45,426	49,773	53,845	54,050	54,236	52,735	51,277	50,119
χ^2 (1st hurdle)	296.60	376.27	351.94	360	449.86	436.54	498.50	485.83	639.33	614.04	532.40
prob> χ^2 (1st hurdle)	0	0	0	0	0	0	0	0	0	0	0
χ^2 (2nd hurdle)	84.71	48.81	84.66	55.27	119.03	110.00	111.60	131.92	138.40	202.91	128.19
prob> χ^2 (2nd hurdle)	0	0	0	0	0	0	0	0	0	0	0
χ^2 (overall)	296.64	379.08	352.27	363.59	458.44	463.32	498.73	485.89	659.80	619.02	533.72
prob> χ^2 (overall)	0	0	0	0	0	0	0	0	0	0	0

*p<0.1, **p<0.05, ***p<0.01

Table 7.14: Maximum likelihood estimates of the double-hurdle model using the health-survey sample, by year. (Dependent variable: total household expenditure on plant-based meat) (with the age variable)

	(2012)	(2013)	(2014)	(2015)	(2016)	(2017)	(2018)	(2019)	(2020)	(2021)	(2022)
Participation (1st hurdle)											
price of meat sub.	-0.03	0.09**	0.01	-0.005	0.04	-0.03***	-0.004	0.01	0.004	-0.04	0.01
	(0.05)	(0.03)	(0.05)	(0.02)	(0.04)	(0.04)	(0.37)	(0.06)	(0.02)	(0.04)	(0.04)
price of beef	0.52***	0.05	0.34***	0.08***	-0.30***	-0.16***	0.60***	-0.20***	-0.11**	0.26***	-0.009
	(0.13)	(0.04)	(0.09)	(0.02)	(0.07)	(0.06)	(0.13)	(0.06)	(0.04)	(0.09)	(0.05)
price of pork	0.34***	-0.02	0.27***	-0.001	0.09	0.34***	-0.05	-0.07***	-0.01	-0.06***	0.18***
	(0.09)	(0.01)	(0.07)	(0.004)	(0.05)	(0.06)	(0.03)	(0.02)	(0.01)	(0.01)	(0.05)
price of poultry	-0.11	0.10	0.25***	0.03**	0.25**	-0.13***	0.11	0.28***	-0.009	0.22***	0.01
	(0.05)	(0.10)	(0.09)	(0.01)	(0.11)	(0.04)	(0.17)	(0.10)	(0.04)	(0.08)	(0.08)
price of seafood	0.05	0.11*	0.14***	0.03	0.12**	0.13	-0.09***	-0.06***	0.05*	-0.03	0.01
	(0.06)	(0.05)	(0.04)	(0.01)	(0.05)	(0.04)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)
household income	0.06	0.17	0.22***	0.07***	-0.03	-0.10	0.19**	0.19*	0.06	0.10	0.10
	(0.08)	(0.05)	(0.08)	(0.02)	(0.10)	(0.09)	(0.10)	(0.11)	(0.04)	(0.09)	(0.09)
female primary shopper	0.38**	0.05	0.16	0.06	-0.15	0.13	0.17	-0.08	0.04	0.04	-0.14
	(0.17)	(0.09)	(0.14)	(0.02)	(0.18)	(0.16)	(0.20)	(0.21)	(0.08)	(0.14)	(0.10)
household size	-0.009	0.001	-0.09	-0.06***	0.009	-0.002**	-0.10	-0.22*	-0.11**	-0.27***	0.01
	(0.12)	(0.06)	(0.07)	(0.02)	(0.10)	(0.09)	(0.10)	(0.12)	(0.04)	(0.09)	(0.06)
education	0.05	0.02	0.13	0.10***	0.14	0.07***	0.16	0.14	0.01	0.03	0.17**
	(0.10)	(0.06)	(0.09)	(0.02)	(0.12)	(0.12)	(0.17)	(0.14)	(0.05)	(0.09)	(0.07)
age of primary shopper	-0.16	-0.24***	-0.11	-0.02	-0.11	-0.20	-0.15	-0.42***	-0.10*	-0.31**	-0.04
	(0.09)	(0.07)	(0.11)	(0.03)	(0.12)	(0.10)	(0.12)	(0.15)	(0.06)	(0.12)	(0.07)
state politics	0.23	-0.02	-0.17	0.02	-0.15	-0.06*	-0.02	0.28*	0.17**	0.13	-0.09

Continuation of Table 7.14

	(2012)	(2013)	(2014)	(2015)	(2016)	(2017)	(2018)	(2019)	(2020)	(2021)	(2022)
	(0.11)	(0.06)	(0.12)	(0.02)	(0.11)	(0.12)	(0.14)	(0.16)	(0.07)	(0.16)	(0.07)
health assessment	-0.13	0.07	0.002	0.009	0.02	0.10	-0.02	-0.10	0.01	0.01	0.01
	(0.07)	(0.04)	(0.05)	(0.018)	(0.07)	(0.02)	(0.07)	(0.07)	(0.03)	(0.05)	(0.04)
health concern	-0.09***	0.09***	-0.002	0.005	0.08*	0.03	-0.02	0.007	0.01	0.09	0.06***
	(0.03)	(0.02)	(0.03)	(0.009)	(0.04)	(0.02)	(0.05)	(0.05)	(0.01)	(0.06)	(0.02)
health issue	0.06	-0.01	0.02	-0.06***	-0.08*	-0.008*	-0.07	-0.03	-0.01	0.002	-0.01
	(0.04)	(0.03)	(0.04)	(0.01)	(0.04)	(0.05)	(0.04)	(0.04)	(0.02)	(0.04)	(0.02)
ingredient-conscious diet	-0.03	0.10***	0.11***	0.02***	0.09***	0.09	0.17***	0.16**	0.007	0.11**	0.05***
	(0.02)	(0.02)	(0.03)	(0.01)	(0.03)	(0.03)	(0.05)	(0.07)	(0.01)	(0.05)	(0.02)
concerned about food	-0.03	0.02	0.01	0.02***	0.05***	0.04*	0.01	0.05**	0.007	0.05***	0.03**
	(0.01)	(0.02)	(0.03)	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.007)	(0.02)	(0.01)
vegan in the household											1.25
											(1.84)
vegetarian											5.76
											(226.72)
pescatarian											5.78
											(291.99)
flexitarian											5.48
											(99.42)
Consumption>0 (2nd hurdle)											
price of meat sub.	-0.49	0.002***	-1.99**	0.26	-1.40**	-0.29	0.01	-2.22***	0.33	-0.96	-0.46
	(0.71)	(0.82)	(0.89)	(0.30)	(0.60)	(0.52)	(0.06)	(0.72)	(0.36)	(0.57)	(0.37)
price of beef	-2.41**	1.29	-1.82*	-0.53	5.34***	-1.42*	-0.20*	4.21***	4.90***	-0.46	0.81
	(1.05)	(0.81)	(1.03)	(0.37)	(0.99)	(0.81)	(0.06)	(1.06)	(0.95)	(0.57)	(0.98)
price of pork	-0.46	1.16**	-0.72*	0.76**	-0.37	1.01*	-0.07*	1.71***	1.15**	1.26***	-0.73***

Continuation of Table 7.14

	(2012)	(2013)	(2014)	(2015)	(2016)	(2017)	(2018)	(2019)	(2020)	(2021)	(2022)
	(0.41)	(0.48)	(0.41)	(0.30)	(0.27)	(0.55)	(0.02)	(0.42)	(0.46)	(0.32)	(0.20)
price of poultry	1.56	-1.63	-0.70	0.29	-0.78	-0.04	0.28	-0.47	1.55	0.62**	1.19*
	(0.81)	(1.55)	(0.75)	(0.32)	(0.64)	(0.87)	(0.10)	(0.68)	(1.12)	(0.32)	(0.69)
price of seafood	-0.14	-1.11**	-0.80*	-0.57**	-0.06	1.25**	-0.06**	1.34***	-0.08	1.16**	0.61
	(0.46)	(0.54)	(0.45)	(0.25)	(0.30)	(0.51)	(0.02)	(0.38)	(0.31)	(0.39)	(0.40)
household income	0.78	-0.98	-0.06	0.48	1.50	0.22	0.19	0.41	0.47	0.14	1.24*
	(0.9)	(1.20)	(1.21)	(0.51)	(1.00)	(1.07)	(0.11)	(1.27)	(0.89)	(0.88)	(0.69)
female primary shopper	2.88	-0.14	2.01	0.12	4.19**	1.62	-0.08	-0.005	1.71	-0.34	1.00
	(1.77)	(1.90)	(1.90)	(0.86)	(1.76)	(2.00)	(0.21)	(1.76)	(1.74)	(1.41)	(1.37)
household size	-1.43	-1.23	-0.11	0.60	-2.50***	-1.70*	-0.22*	0.01	0.21	1.76*	-1.01
	(1.40)	(1.14)	(1.09)	(0.44)	(0.90)	(0.97)	(0.12)	(1.30)	(1.07)	(0.86)	(0.77)
education	2.31**	3,49***	2.44**	-0.11	3.54***	4.25***	1.52	1.42	3.55***	2.96**	-0.19
	(1.07)	(1.29)	(1.22)	(0.57)	(1.28)	(1.28)	(1.53)	(1.14)	(1.11)	(0.94)	(0.96)
age of primary shopper	-0.06	1.94	0.37	-0.52	-1.26	-2.81**	-0.42**	0.90	-1.01	-0.10	-2.45*
	(1.10)	(1.53)	(1.49)	(0.62)	(1.19)	(1.15)	(0.15)	(1.25)	(1.33)	(1.38)	(0.95)
state politics	-1.88	2.54*	1.95	0.75	3.10***	1.13	0.28	-0.30	-1.94	-0.41	2.56***
	(1.38)	(1.32)	(1.62)	(0.57)	(1.19)	(1.36)	(0.16)	(1.43)	(1.28)	(1.70)	(0.96)
health assessment	1.30	-0.62	0.44	-0.07	-0.02	0.63	-0.10	0.64	-0.43	-0.34	0.36
	(0.72)	(0.88)	(0.72)	(0.36)	(0.69)	(0.66)	(0.07)	(0.71)	(0.70)	(0.54)	(0.57)
health concern	1.04**	-1.22**	0.22	0.01	-0.46	0.03	0.007	0.56	-0.26	-0.12	-0.36
	(0.41)	(0.49)	(0.41)	(0.18)	(0.41)	(0.50)	(0.05)	(0.43)	(0.34)	(0.39)	(0.30)
health issue	-1.64***	-1.04	-1.30**	0.14	-0.47	-0.02	-0.03	-1.19***	-0.90**	-1.46***	-0.55*
	(0.45)	(0.56)	(0.53)	(0.23)	(0.48)	(0.43)	(0.04)	(0.39)	(0.44)	(0.38)	(0.31)
ingredient-conscious diet	1.68***	-0.57***	-0.31	0.04	0.23	-0.11	0.16	0.23	0.77***	0.01	-0.13
	(0.27)	(0.20)	(0.24)	(0.12)	(0.21)	(0.24)	(0.07)	(0.22)	(0.29)	(0.20)	(0.19)

Continuation of Table 7.14

	(2012)	(2013)	(2014)	(2015)	(2016)	(2017)	(2018)	(2019)	(2020)	(2021)	(2022)
concerned about food	0.54**	0.56	0.58	0.25	-0.02	0.30*	0.05*	0.08	0.36**	-0.01	-0.19
	(0.23)	(0.42)	(0.50)	(0.20)	(0.14)	(0.18)	(0.02)	(0.16)	(0.16)	(0.13)	(0.13)
vegan in the household											6.58***
											(1.61)
vegetarian											4.97***
											(1.43)
pescatarian											-0.74
											(1.82)
flexitarian											2.47***
											(0.90)
N	9,331	10,768	10,233	12,116	12,978	14,412	13,359	11,092	12,298	13,166	11,806

*p<0.1, **p<0.05, ***p<0.01

7.1.2 Summary of double-hurdle model results

Key results from the double hurdle model investigation are that significantly fewer than half of the household panelists considered participation in the plant-based meat market segment. Across the 10 panels, the estimated average share willing to consider plant-based meat varied from 25% to 36% with an average of 29%. The estimates were slightly lower for the health survey subsample. The average of estimates from the cross-sectional analysis was slightly higher at 35% - 37%.

Analysis of the participation decision showed that higher prices of substitute proteins had a positive effect on the plant-based meat segment participation decision, but the price of plant-based meat itself tended to have little effect on participation. Education of the primary shopper was a strong positive determinant of participation for the full sample, and for the subsample that completed the health survey once the age variable was excluded. In this same subpanel, consumers who expressed concern about food and pursued an ingredient-consious diet were significantly more likely to participate in the plant-based meat segment.

In terms of the second hurdle, the expenditure decision, the price of plant-based meat is consistently negatively correlated with expenditure, but the effect is not always statistically significant. The prices of the protein substitutes tend to be more significant determinants of expenditure on plant-based meat. The price of beef in particular is consistently and significantly associated with higher expenditure on plant-based meat. The price of poultry is also significantly associated with higher plant-based meat expenditure in most estimations. More household income is significantly associated with higher plant-based meat consumption in the full panel, but not always in the subpanel that completed the health assessment survey. Household income is also always associated with higher plant-based meat expenditure in the cross-sectional analysis with the full sample.

Demographic variables that play a consistent role in explaining plant-based meat expenditure include having a female primary shopper, having a more highly educated primary shopper, households that express concerns about health and who pursue an ingredient-conscious diet. Conversely household size does not tend to have a consistent and significant impact, nor do the politics of the state of residence or the age of the primary shopper. Households experiencing health problems tend to spend less on plant-based meat, other factors constant.

7.2 Demand system for proteins with a censored regression approach

This section presents the results of the AIDS demand system with the use of censored regression. As described in chapter 6, the key characteristic of this model is that the demand system, in addition to expenditure shares and protein prices, is estimated using each household's demographic information and the Inverse Mills Ratios (IMR) for each protein.

To calculate the IMR, I estimated a panel probit model for the 11-year balanced panel ("main model") and for the health-survey panel using a binary indicator of whether the household purchased a specific protein or not each year as the dependent variable. I conducted the analysis using both the 11-year balanced main sample and the 11-year balanced health-survey sample because the health-survey sample has richer demographic information. A linear prediction of this indicator was then computed from these models and was used to construct the IMR of the respective protein. For each sample, the AIDS model was then estimated with the corresponding IMR.

The results of the probit models for plant-based meat are presented in table 7.15 and for the rest of the proteins results are presented in appendix B. Although the purpose of the probit model is to construct the IMR and not to make inferences about households' preferences for plant-based meat, the direction and significance of the effects reported here for plant-based meat are consistent with what was revealed in the double-hurdle model. The prices of pork and seafood are associated with a significantly higher probability of consuming plant-based meat. The price of beef is associated with a higher probability of consuming plant-based meat, but the effect is significant only in the health-survey panel. The price of plant-based meat is not statistically significant in the main sample but is associated with a lower probability of consumption in the health-survey sample.

Higher education of the primary shopper is strongly associated with a higher probability of plant-based meat purchases. Ingredient conscious consumers and consumers concerned about health were more likely to purchase plant-based meat, while those experiencing a health issue were less likely to do so, all findings consistent with results from the double hurdle model.

Table 7.15: Coefficients of the panel probit for plant-based meat. (Dependent variable: yearly indicator of a household purchasing plant-based meat.)

	Main sample	**Health-survey sample**
price of plant-based meat	0.005	-0.03*
	(0.009)	(0.02)
price of beef	0.03	0.07*
	(0.01)	(0.04)
price of pork	0.06***	0.03***
	(0.01)	(0.03)
price of poultry	-0.02	-0.06
	(0.02)	(0.05)
price of seafood	0.06***	0.08***
	(0.009)	(0.01)
household income		
$15,000-$34,999	-0.07	-0.02
	(0.05)	(0.11)
$35,000-$59,999	-0.01	0.09
	(0.05)	(0.11)

Continuation of Table 7.15

	Main sample	**Health-survey sample**
$60,000 or more	0.05	0.13
	(0.05)	(0.12)
female primary shopper	0.04	0.08
	(0.03)	(0.08)
household size		
household of 2	-0.04	-0.07
	(0.03)	(0.06)
household of 3	0.01	-0.02
	(0.03)	(0.09)
household of 4	0.10	0.07
	(0.04)	(0.11)
household of 5	-0.02	-0.29*
	(0.06)	(0.17)
household of 6	-0.15	-0.19
	(0.09)	(0.28)
household of 7	-0.23	0.12***
	(0.18)	(0.79)
household 8 or more	-0.25	
	(0.28)	
education		
graduated college	0.19***	0.28***
	(0.02)	(0.06)
post-graduate degree	0.43***	0.47***
	(0.04)	(0.09)
health assessment		0.05***
		(0.01)
health concern		0.02**
		(0.009)
health issue		-0.03**
		(0.05)
ingredient conscious		0.03***
		(0.005)
concerned about food		0.01***
		(0.001)
N	98,312	134,951

Continuation of Table 7.15

	Main sample	**Health-survey sample**
households in panel	8,966	71,540

*p<0.1, **p<0.05, ***p<0.01

The IMR generated from the probit models estimates were then incorporated as independent variables in the AIDS model, which was estimated for both the main sample and the health-survey sample once more. Tables 7.16 and 7.17 report the uncompensated (Marshallian) own-price and cross-price elasticities of demand for proteins for the main sample and health-survey sample, respectively.

Own-price elasticities are highly statistically significant for both samples. Beef, pork, poultry, and seafood own-price elasticities are very similar across the two panels. Both beef and poultry demands exhibit near unitary own-price elasticities, whereas pork demand is moderately price elastic (-1.28 and -1.08 in the main and health survey samples, respectively). Seafood demand, conversely, is inelastic in own price, with estimated values of -0.46 in the main sample and -0.54 in the health-survey sample.

The estimated own-price elasticity for plant-based meat, however, differs somewhat across the two samples, ranging from quite inelastic (-0.50) in the main sample to near unit elastic (-0.94) in the health-survey sample. The difference likely owes to fundamental differences in the panelists who chose to provide health information relative compared to those in the full panel.

Recall from chapter 6 that the “income” variable in the proteins demand system is household annual expenditure on proteins. Figure 5.6 reported expenditure shares for the five proteins across the 11-year study period. Beef, poultry, and pork each had an expenditure share in excess of 25% across the study period. Seafood’s share increased over time, but ranged from 10% to 15%. Plant-based meat’s share of protein expenditures also increased slowly over the study period, but remained well below 5% throughout the period.

Revisiting these statistics is important in the context of understanding the estimated cross-price elasticities and comparing the uncompensated (Marshallian) elasticities reported in tables 7.16 and 7.17 with the compensated (Hicksian) elasticities reported in tables 7.19 and 7.20. As is well-known based upon the Slutsky equation, uncompensated price elasticities include both the net substitution and income or expenditure effects from the price change, whereas the compensated elasticities include only the net substitution effect. As noted, income or expenditure in the proteins demand system is represented by total protein expenditure, meaning that income effects can be large, especially for the proteins (beef, poultry, pork) that comprise large shares of the protein budget. Conversely, income effects for price changes for plant-based meat will tend to be small (compensated and uncompensated elasticities will be similar) because plant-based meat has a very small share of the protein budget.

The other factor impacting the strength of income effects is the responsiveness of demand for the good in question to changes in protein expenditure or the protein budget. Table 7.18 contains the estimated expenditure elasticities for the five proteins from estimation of the AIDS model for both the main sample and the health-survey sample. These elasticities are very comparable across the two samples and each is quite close to 1.0. Plant-based meat has an estimated expenditure elasticity in excess of 1.0 (1.11 and 1.12 across the two samples), consistent with an earlier result from the double-hurdle model that higher incomes (reflected here as higher protein expenditure) are associated with greater consumption of plant-based meat. Beef also has estimated expenditure elasticities mildly in excess of 1.0, while pork, poultry, and seafood expenditure elasticities are slightly less than 1.0.

From the perspective of household behavior, these results indicate that as households spend more on proteins, the shares of the budget to each protein item remain relatively constant. From the perspective of understanding differences in the compensated and uncompensated price elasticities, the main factor distinguishing the five proteins is the share of each in the protein budget. This means that compensated and uncompensated elasticities do not differ much for the price of plant-based meat, given its small budget share, but will exhibit significant differences for changes in the prices of the other proteins, given each has a relatively large protein budget share and an expenditure elasticity near 1.0. Because all of the proteins are "normal" goods as it pertains to the expenditure elasticities, the income effect of a price increase is always negative—higher price for a given protein budget implies a reduced protein budget in real terms and a lower expenditure for any given protein.

This means that compensated own-price elasticities are always less in absolute value in this model and that cross-price elasticities are lower due to the income effect, which means that relationships that are net complements, (an increase in the price of protein i is associated with reduced consumption of protein j, $j \neq i$) are strengthened by the expenditure effect, while net substitute relationships (an increase in price of i is associated with increased consumption of protein j, $j \neq i$) are offset by the income effect, and it is possible for net substitute goods to be gross complements due to the expenditure effect.

This effect is illustrated for example in the relationship between beef and pork. These two proteins are often used as classroom illustrations of goods that are substitutes, but in table 7.16 the goods appear as gross complements due to the strong expenditure effect offsetting the positive net substitution effect that is depicted in table 7.19 where a 1% increase in the price of pork is associated with a 0.35% increase in expenditure on beef and a 1% increase in the price of beef is associated with a 0.48% increase in the expenditure on pork.[5]

The relationship between the net (compensated) and gross (uncompensated) substitution effects is especially important when considering the substitution relationships involving plant-based meat. The results in tables 7.19 and 7.20 show that plant-based meat and beef are net complements, while plant-based meat and pork are net substitutes. These are important and rather intuitive results. To date, most plant-based meat products represent alternatives to beef, suggesting that the two product categories might be substitutes, but if the availability of a plant-based beef substitute for, say, vegan or vegetarian family members or attendees at a gathering, enables conventional beef to be served at meals or parties, the two foods could be net complements in the sense that they are served together. This result has significant implications for the policy question of whether plant-based meat can play a significant role in reducing beef consumption and the harmful environmental effects associated with cattle production.

As I noted, beef and pork are often presented as the quintessential example of substitutes, a belief supported by the results of this study. If conventional beef and pork are substitutes, but conventional beef and plant-based meat are complements, then it follows that plant-based meat and pork are likely to be substitutes as well, given the limited plant-based alternatives to pork available in the market during this study period. The elasticities reported in tables 7.19 and 7.20 are consistent with this intuition. The substitution relationships between plant-based meat and poultry are weak and not statistically significant in either the main sample or the health-survey sample. Seafood exhibits a weak complementary relationship with plant-based meat that is significant in the main sample but not the health-survey sample.

[5]From consumer theory, the net substitution effects are symmetric, but they are no longer symmetric when converted to their elasticity form.

Table 7.16: Uncompensated own- and cross-price elasticities of the main sample

Price/Good	**Plant-based**	**Beef**	**Pork**	**Poultry**	**Seafood**
Plant-based	-0.50***	-0.08***	0.10***	0.00004	-0.06***
	(0.17)	(0.01)	(0.01)	(0.01)	(0.02)
Beef	-1.40***	-1.05***	-0.16***	0.03	-0.03
	(0.20)	(0.03)	(0.03)	(0.03)	(0.04)
Pork	1.34***	-0.07***	-1.31***	-0.17***	-0.12***
	(0.20)	(0.02)	(0.03)	(0.02)	(0.04)
Poultry	-0.06	-0.03	0.16***	-0.97***	-0.23***
	(0.21)	(0.02)	(0.03)	(0.04)	(0.04)
Seafood	-0.52	-0.04***	-0.07***	-0.12***	-0.46***
	(0.16)	(0.01)	(0.02)	(0.02)	(0.04)

*p<0.1, **p<0.05, ***p<0.01 elasticities estimated at price and expenditure means; clustered s.e. at household level.

Table 7.17: Uncompensated own- and cross-price elasticities of the health-survey sample

Price/Good	**Plant-based**	**Beef**	**Pork**	**Poultry**	**Seafood**
Plant-based	-0.94***	-0.07***	0.17***	-0.05	-0.04
	(0.28)	(0.02)	(0.03)	(0.03)	(0.05)
Beef	-1.02***	-1.03***	0.07	0.001	0.08
	(0.35)	(0.06)	(0.06)	(0.06)	(0.08)
Pork	1.78***	0.01	-1.28***	0.25***	-0.26***
	(0.36)	(0.04)	(0.08)	(0.06)	(0.08)
Poultry	-0.60	-0.06	0.22***	-0.99***	-0.14*
	(0.37)	(0.05)	(0.06)	(0.08)	(0.08)
Seafood	-0.34	-0.07	-0.17***	-0.08	-0.54***
	(0.38)	(0.03)	(0.05)	(0.05)	(0.09)

*p<0.1, **p<0.05, ***p<0.01; elasticities estimated at prices' and expenditure means; clustered s.e. at household level.

Table 7.18: Protein expenditure elasticities

	Main sample	**Health-survey sample**
Plant-based	1.11***	1.12***
	(0.01)	(0.05)
Beef	1.10***	1.14***
	(0.001)	(0.005)
Pork	0.95***	0.95***
	(0.002)	(0.05)
Poultry	0.95***	0.89***
	(0.002)	(0.006)
Seafood	0.89***	0.92***
	(0.004)	(0.01)

*p<0.1, **p<0.05, ***p<0.01; elasticities estimated at prices' and expenditure means; clustered s.e. at household level.

Table 7.19: Compensated own- and cross-price elasticities of the main sample

Price/Good	**Plant-based**	**Beef**	**Pork**	**Poultry**	**Seafood**
Plant-based	-0.44***	-0.06***	0.12***	0.01	-0.05**
	(0.17)	(0.01)	(0.01)	(0.01)	(0.02)
Beef	-1.03***	-0.67***	0.48***	0.32***	0.27***
	(0.20)	(0.03)	(0.03)	(0.03)	(0.04)
Pork	1.61***	0.35***	-1.08***	0.39***	0.10**
	(0.20)	(0.02)	(0.03)	(0.02)	(0.04)
Poultry	0.23	0.25***	0.41***	-0.73***	0.006
	(0.21)	(0.02)	(0.03)	(0.04)	(0.04)
Seafood	-0.36**	0.11***	0.05**	0.003	-0.33***
	(0.16)	(0.01)	(0.02)	(0.02)	(0.04)

*p<0.1, **p<0.05, ***p<0.01; elasticities estimated at prices' and expenditure means; clustered s.e. at household level.

Table 7.20: Compensated own- and cross-price elasticities of the health-survey sample

Price/Good	**Plant-based**	**Beef**	**Pork**	**Poultry**	**Seafood**
Plant-based	-0.91***	-0.04*	0.19***	-0.02	-0.02
	(0.28)	(0.02)	(0.03)	(0.03)	(0.05)
Beef	-0.65*	-0.65***	0.38***	0.28***	0.38***
	(0.35)	(0.06)	(0.06)	(0.06)	(0.08)
Pork	2.06***	0.29***	-1.03***	0.47***	-0.03
	(0.36)	(0.04)	(0.08)	(0.06)	(0.08)
Poultry	-0.32	0.22***	0.47***	-0.77***	0.08
	(0.37)	(0.05)	(0.06)	(0.08)	(0.08)
Seafood	-0.17	0.18***	-0.02	0.04	-0.40***
	(0.37)	(0.03)	(0.05)	(0.05)	(0.09)

*p<0.1, **p<0.05, ***p<0.01; elasticities estimated at prices' and expenditure means; clustered s.e. at household level.

7.2.1 Summary of censored regression model results

The censored regression model yielded estimation results that complement the results from the double hurdle model. The first-stage probit estimation for plant-based meat yielded results consistent with the findings from the double hurdle model regarding impacts of prices and demographic variables on households' decisions regarding whether to purchase plant-based meat products.

The inverse mills ratios constructed from the probit regression results were used as explanatory variables, along with protein prices, protein expenditures and demographic variables in the AIDS demand system. Results of this estimation revealed that all five of the proteins studied in this analysis have near unitary expenditure elasticities, meaning that as household expenditures on proteins increases, expenditures on each protein rise in a nearly proportional manner.

Plant-based meat demand was price inelastic in both the main sample and health-survey sample, but the demand was more elastic (indeed, near unit elastic) for the health-survey panel, suggesting some fundamental differences in behavior for the subgroup that chose to provide health information relative to the full panel.

The cross-price effects involving plant-based meat are especially important for this analysis. Compensated and uncompensated cross-price elasticities differed considerably due to strong income effects for all proteins in the system except plant-based meat. Estimated cross-price effects for the traditional proteins were consistent with prior meat demand studies. Importantly, results indicated that plant-based meat and beef are net complements. This finding is consistent with Zhao et al. (2022) and may indicate that plant-based meat products are consumed by some members in the household and beef by others while they are both served at the same meal. An increase in the price of beef reduces the amount of beef consumed by the household and, in turn, this affects the quantity of plant-based meat consumed. This result is at odds with the common belief that plant-based meat can become a significant substitute for beef in consumers' diets, thereby leading to reduced methane emissions and other harmful environmental effects associated with cattle production. This key topic is pursued further in chapter 8.

Chapter 8

Implications for the environment and climate change

The composition of diets across the world in the 21st Century will be a critical factor in addressing climate change, food security, and other environmental concerns. Production and consumption of animal products in the 21st Century presents a key challenge for policy makers because a lynchpin of strategies to address these concerns calls for less consumption of these products, not more. Animals convert feeds into human food less efficiently than if the lands producing foods for animals were used to produce food directly for humans (Herrero et al., 2013). That is, under optimum conditions, young healthy individuals of each livestock species may convert about one-third of the digestible protein in its feed into tissue protein in its body. Of this tissue protein, about half is used as food (Byerly, 1967). Animals, especially cattle, also emit a lot of greenhouse gases—14.5% of total GHG emissions according to one estimate (Kristiansen et al., 2021). Other estimates are that upwards of 60% of emissions from the agrifood sector are due to animal-source diets (Sutton et al., 2024). A highly cited study in *Science* by Poore and Nemecek (2018) estimates that converting to diets that exclude animal products could reduce food's total GHG emissions by 49%.

Despite the imperative for the world to reduce its consumption of animal products, it is well known that diets become more diverse as incomes grow and include greater consumption of animal proteins. Meat and dairy products are among the most income-elastic foods, especially for low to moderate income levels, and these foods tend to occupy a greater share in food budgets as consumers' incomes rise.

Meat consumption is indeed increasing worldwide (Ritchie et al., 2017). According to United Nations Food and Agriculture Organization data, world meat production in 1961 was 71 million metric tons. It was 355 million metric tons in 2022, an increase of 400%, with the largest increases in production coming in Asia amidst the rapid income growth of many Asian economies.

Total meat consumption has also increased in the United States. The highest total per capita availability in history, 208.2 pounds, occurred in 2020 and 2021. Beef consumption is the biggest animal protein concern from an emissions perspective, and it has fallen from a peak of 94.1 pounds in 1976 to 58.8 pounds per capita in 2021. Chicken has replaced beef as the most-consumed meat in the United States.

The story is similar in the European Union. Pork production has been relatively stable over the most recent 15 years, while beef production has declined slightly. Poultry production, however, has risen by about 25% over this same time period (Eurostat Statistics Explained, 2021).

Moreover, the experts anticipate that global meat consumption will increase through much of this century. The UN FAO and the Organisation for Economic Co-operation and Development (OECD) expect world consumption of poultry, pigmeat, and beef to increase by 15%, 11%, and 10% respectively from 2023 - 2032, with most of the growth occurring in lower- and middle-income countries (OECD/FAO, 2023). These experts expect global consumption to increase until at least 2075.

Expanded consumption of animal products can confer important nutritional benefits in poor countries, where such products add needed proteins and other nutrients to diets built around starchy traditional staples. From a global-welfare perspective, reduced meat consumption, thus, needs to occur in wealthier countries where per capita consumption likely exceeds the optimal amount for health purposes and contributes to obesity and obesity-related diseases. The United States is the leading meat-consuming country at nearly 127 kg (279 lbs.) per capita per year, followed by Australia (122 kg), Mongolia (116 kg), and Argentina (115 kg).

European countries are also significant meat consumers, led by Spain at 100 kg per capita. Europe's Farm-to-Fork strategy for food production and consumption is a key component of the European Green Deal intended to make Europe net zero in terms of GHG by 2050 (European Comisson, 2024). The European Commission attributes 10.3% of Europe's GHG emissions to agriculture and says that animal agriculture is responsible for 70% of those emissions. As part of its Farm-to-Fork strategy, the European Commission advocates "moving to a more plant-based diet with less red and processed meat and with more fruits and vegetables" (p.14).

The United Nations' FAO also recommends changing dietary patterns including reduced use of animal proteins (United Nations, 2021). A similar policy prescription emerges from the World Bank. Although animal agriculture practices may be modified to reduce GHG emissions, World Bank researchers argue that the greater mitigation potential is "from humans changing their own diets, for example, through the reduced consumption of meat" (Sutton et al., 2024) p.87, a conclusion consistent with the findings of Poore and Nemecek (2018).

Whether and how to get rich countries like the United States and those in the European Union to eat less meat is a key policy issue for the 21st century. Meat taxes have been discussed and analyzed extensively. In its 2023 report, *The State of Food*

Security and Nutrition in the World, UN FAO lists "Taxation of energy-dense foods and beverages high in fats, sugars and/or salt," first among its list of policies and investments for healthy diets. Nonetheless, commentators have been critical that the UN has not gone far enough to promote reduced meat consumption worldwide (Verkuijl et al., 2024; Irgini, 2024). To date, governments have largely been unwilling to impose fat or meat taxes because such taxes would likely be highly unpopular. The world's one good example of a tax on meat is Denmark's tax on fats implemented in 2011 and abolished 15 months later due to widespread opposition (Bødker et al., 2015).

Much hope hinges on the success of plant-based, fungi-based, and lab-cultured meat substitutes as replacements for traditional meats. In a recent report, the UN's Environment Programme summarized studies of projected growth for these products varying from a 4% market share to 60% by 2040 (Verkuijl et al., 2023). Political scientist and best-selling food author Robert Paarlberg in his 2021 book *Resetting the Table: Straight Talk about the Food We Grow and Eat* emphasizes the positive role plant- or fungus-based meat substitutes can play moving forward in reducing traditional meat consumption and the harms associated with it (Paarlberg, 2022).

But is this hope realistic? The results of this study suggest it may not be. On the positive side, the number of UPCs for plant-based meat substitutes skyrocketed over the 11-year study period, from a low of about 600 in 2013 to nearly 2,000 in 2022. The share of panel households that have tried plant-based meats increased from 13% to 20% over the study period, but the share of purchasers has been flat since 2020. Among households that tried plant-based meat, only about 10% became regular purchasers, with 45% never again purchasing the product in their duration in the panel. The remaining 45% returned to the plant-based segment sporadically over the years.

However, despite the increase in number of plant-based meat products and an increasing share of households willing to give them a try, the share of expenditures going to the plant-based alternatives for beef, pork, poultry, and seafood was relatively stagnant over the 11-year study period, topping out at a mere 2.5% of U.S. protein expenditures in 2022. The plant-based share on a quantity basis is even lower because the plant-based products are more expensive per unit than any of the actual meats, averaging from $8-$9 over the study period.

The average panelist purchased just $9.95 annually on plant-based meat. Plant-based meat did become a billion-dollar industry in the U.S. in 2020, but total expenditures have been flat or declining slightly since then. Figures 5.30 and 5.31 show that the plant-based meat share of the protein budget increases dramatically as the number of vegan and vegetarian household members increases, topping out at a near 70% share for five-person vegan/vegetarian household members. Such households are consuming little animal meat in any event, so their adding a meat substitute into the diet does little to impact animal meat consumption.

The econometric results contained in chapter 7 also shed considerable light on the potential for plant-based meat to have a significant impact on the consumption of animal-based proteins. Results of the p-tobit double hurdle model revealed estimates of the percentage of panel households that were willing to even consider purchase of plant-based meat. This share tended to increase with the shorter (more recent) panels, reaching a maximum of 36% in the two-year (2021–2022) panel, and averaging 29% across the 10 panels. Estimates of the p-tobit model for each of the 11 yearly cross sections were similar, averaging 37% and showing a slight tendency to increase over time. Growth of the plant-based meat segment of the proteins market is inherently limited if nearly two-thirds of households are unwilling to consider it as an option.

Importantly, estimation of the full double-hurdle model for both the full panel and the health-survey panel revealed that the price of plant-based meat was, in general, not a significant factor in either the participation decision or the decision as to expenditure.

Whereas we might expect the price of plant-based meat to decline relative to animal proteins if its market share increases, enabling manufacturers to better exploit scale economies, the econometric results do not support lower prices having a major impact on either market participation or purchases. Rather, the prices of the competing proteins, especially beef and poultry, tended to be significant positive factors inducing households to try plant-based meat and to increase expenditures on it. Higher prices for these proteins could, thus, trigger expansion of the plant-based share, e.g., as could occur if significant meat taxes were imposed. As noted, however, despite calls to impose such taxes, policy makers to date have exhibited little appetite to do it.

Estimation of the proteins demand system using the AIDS model with the censored regression framework also yielded key insights regarding plant-based meat's ability to contribute to reduced production and consumption of animal proteins. Demand for plant-based meat was estimated to be inelastic in own price, a result consistent with the finding from the double-hurdle model that plant-based price was not a major factor in either hurdle. It suggests, however, that if plant-based meat manufacturers are able to improve production efficiency and lower prices, in itself that won't contribute to much increased consumption.

A finding of major significance is that plant-based meat and beef are net complements based upon the compensated (Hicksian) cross-price elasticities. As noted, most plant-based meat products are intended to imitate beef. The finding that the two products are net complements means that for many households beef and its plant-based analog are used together, such as both being served at a family meal or party. This finding casts major doubt on what appears to be an article of faith among those who believe plant-based meats can cause consumers to substitute away from animal meats.

Chapter 9

Conclusion

Three promotional branches have supported the second generation of plant-based meat: protection of animal welfare, of the environment, and of consumers' health through the reduction of animal meat consumption. The goal of this study was to understand whether consumers view plant-based meat as a way to reduce meat consumption and, in turn, benefit their health and the environment.

The present study addresses this question using a dataset that consists of households' protein purchases over time, combined with household demographic and health information. The access to these data was granted through the U.S. Department of Agriculture, Economic Research Service, which acquires access to the data from the research company, Circana. The data contain detailed information on 127,606 U.S. households' meat purchases, from 2012 to 2022, along with their demographic information and, for some of them, their medical information as well. Seven percent of the households were traced across all 11 years and around 31% of the households are in the sample for 5 years or more. This detailed dataset makes it feasible to study the differences and similarities of demographic characteristics of each consumer segment and also to estimate own-price and cross-price meat demand elasticities in models that contain the effects of the households' demographic and health information.

The data of households' plant-based meat expenditures include a large number of zero-expenditure observations since the majority of the households does not purchase these products. This particularity of the data informed the two econometric approaches that were used in this study. The first approach was a two-part or "hurdle" model —a popular model in an array of contexts where many observations are zero. This model breaks a household's decision to consume a product into two processes ("hurdles"): the decision to participate, and, conditional on participating, the decision of how much to consume.

The structure of the double-hurdle model makes it possible to quantify the proportion of households that are interested in consuming plant-based meat products, including households that consider plant-based meat in their choice set, yet their optimal consumption quantity has been zero. The quantification of such a parameter is very useful in understanding the population's actual acceptance rate of plant-based meat products which is different from the proportion of the population that has been observed purchasing them. By breaking down the decision into a "participation" and a "consumption" choice, it became possible to understand what demographic, market, health, and dietary factors affect each part. This shed light on the factors preventing a household from considering trying a plant-based meat product and the factors preventing not-abstaining households from increasing their expenditure on plant-based meats.

The second econometric model estimated was an Almost Ideal Demand System for proteins with a censored regression. These estimations shed light upon the substitution patterns between plant-based meat and animal proteins while taking into account the large number of zero plant-based meat expenditures with the use of Inverse Mills Ratios. Although the plant-based products analyzed in this research are commonly viewed as substitutes to animal products, there are good reasons to think that there exist complementary relationships between these products as well. For instance, shoppers may buy animal protein for some of the household members, but plant-based protein for others. Another possibility is that plant-based meat products are merely a fad that increases the variety of proteins available to consumers, but does not actually cause a reduction in meat consumption. This analysis was focused on understanding better this relationship.

According to the summary statistics of this study, it is clear that there is an upward trend on the market availability of plant-based alternatives. However, even in the most recent years, where the sales of these products have reached their peak, their share in stores is less that 5% of the total meat products. Plant-based meat is consistently the most expensive category throughout years, with an average price gap of around $3 relative to poultry—a protein not as burdensome for the environment or consumers' health as the proteins from ruminants, and one that is widely available in a less-processed form compared to plant-based meat.

The relative proportions of households consuming each animal protein are very stable over time with poultry being the most consumed, followed closely by pork and beef. All animal proteins show a small and steady decrease of the percentage of households that consume them. Beef has the largest attrition of households, moving from 94% of U.S. households consuming beef in 2012 to 90% in 2022. During the same time period, the share of households consuming pork dropped from 95% to 91%, poultry from 97% to 94%, and seafood from 87% to 84%. Regarding households that consume plant-based meat specifically, the percentage fluctuated between 13% and 14% in the early years, but has notably increased by 6 percentage points from 2018 to 2020, although, the rate of increase diminishes after 2020. Despite a significant increase in the availability of these products in recent years, only two out of ten households have purchased plant-based meat so far. In contrast, nine out of ten households continue to purchase beef at retail.

The average expenditure share of beef in 2012 was 0.32, and it has been declining every year, reaching a share of 0.29 in 2021 and 2022 (10% decrease). The two proteins with increasing share over time are seafood and plant-based meat. Households' expenditure on seafood has risen from 0.12 in 2012 to 0.16 in 2022 (25% change). Although the share of plant-based meats has increased by 66%, expenditure shares remain minuscule (0.025 in 2022). To put this percentage in perspective, households spend on average $10 annually on plant-based meat substitutes—an amount eleven times lower than the next smallest annual expenditure on meats, which is the amount households spend on seafood (i.e., $113.84).

The vast majority of households are nonconsumers of plant-based meat and, although this percentage is decreasing over time, 80% of the U.S households in 2022 did not purchase a plant-based meat product even once. The percentage of both, frequent and infrequent consuming households is increasing over time, reaching a little over 3% and 16% respectively in 2022. The number of households spending more than $100 per year on plant-based food is also increasing, but, even at its peak, this percentage does not exceed 2.6% of the U.S. population.

Nonetheless, the total expenditure on animal proteins is inversely proportional to plant-based meat expenditure. That is, out of all consumer categories, plant-based meat nonconsumers spend the most on beef, pork, and poultry together and the high plant-based meat spenders are spending the least. Interestingly, seafood spending increases along with plant-based meat spending, but the difference in seafood spending among the consuming categories of plant-based meat is very small. Pork and beef are the two protein types that have the biggest expenditure reductions as a household's consumption of plant-based meat intensifies.

Moving on to the demographics of the primary shopper, the most-consuming households have primary shoppers below 30 years old (18.3%) and 30 to 40 years old (17.5%).

Households where the primary shopper has college or post-graduate studies have higher percentages of consuming households, i.e., 20% and 16.7% respectively. On the other hand, households with primary shoppers who have graduated high school tend to have a lower percentage of plant-based consumers (11%). The highest percentage of consuming households is in 3-member (16%) and 4-member families (16.5%), while in the remaining household sizes, the consuming cases are 14%.

Looking at the consumption patterns across years, it is evident that the adoption of plant-based meat does signify a household's intention to reduce meat consumption overall. The households that permanently adopted plant-based meat over the years reduced meat consumption by 10% (specifically, beef by 11%, pork by 10%, and poultry by 8%) and increased seafood consumption by 13%. Overall, the expenditure on proteins (plant-based meat included) increased by 29% which implies that households increased the variety of proteins with plant-based meat but did not fully replace an animal protein with it.

Regarding the effect of health status on protein consumption, the number of health problems that a household has and could be tied to food habits affects protein purchasing pattern. More specifically, households with none or a few health problems, spend 0.01% more on plant-based meat, 5% more on poultry, and 2% more on seafood. They also spend 5% less on beef and 4% less on pork. It is important to note, that although plant-based meat spending differs between the two groups, the relatively higher expenditure on plant-based meats for households with fewer health problems is not higher than average expenditure share observed in the data.

Only households with members classified as vegans and vegetarians have expenditure shares on plant-based meat that exceed the national average of 2.6%, and in some cases, is as high as 70%. This suggests that plant-based meats were purchased by individuals who eat very little or zero animal meat to begin with, and potentially to complement animal meat purchases of the same household.

The key results from the double hurdle model estimation are that significantly fewer than half of the household panelists considered participating in the plant-based meat market segment. Across the 10 balanced panels that the sample was broken down to, the estimated average share willing to consider plant-based meat varied from 25% to 36% with an average of 29%.

Analysis of the participation decision showed that the prices of substitute proteins had a positive effect on the plant-based meat segment participation decision, but the price of plant-based meat itself tended to have little effect on participation. Education of the primary shopper was a strong positive determinant of participation for the full sample, and for the subsample that completed the health survey once the age variable was excluded. In this same subpanel, consumers who expressed concern about food and pursued an ingredient-consious diet were significantly more likely to participate in the plant-based meat segment.

In terms of the second hurdle, the expenditure decision, the price of plant-based meat is consistently negatively correlated with expenditure, but the effect is not always statistically significant. The prices of the protein substitutes tend to be more significant determinants of expenditure on plant-based meat. The price of beef in particular is consistently and significantly associated with higher expenditure on plant-based meat. The price of poultry is also significantly associated with higher plant-based meat expenditure in most estimations.

Household income is significantly associated with higher plant-based meat consumption in the full panel, but not always in the subpanel that completed the health assessment survey. Household income is always associated with higher plant-based meat expenditure in the cross-sectional analysis with the full sample. Demographic variables that play a consistent role in explaining plant-based meat expenditure include having a female primary shopper, having a more highly educated primary shopper, households that express concerns about health and those who pursue an ingredient-conscious diet. Conversely, household size does not tend to have a consistent and significant impact, nor do the politics of the state of residence or the age of the primary shopper. Finally, households experiencing health problems tend to spend less on plant-based meat, other factors constant.

The censored regression model yielded estimation results that complement the results from the double hurdle model. The first-stage probit estimation for plant-based meat yielded results consistent with the findings from the double hurdle model regarding impacts of prices and demographic variables on households' decisions regarding whether to purchase plant-based meat products. The Inverse Mills Ratios constructed from the probit regression results were used as explanatory variables, along with protein prices, protein expenditures, and demographic variables in the AIDS demand system. Results of this estimation revealed that all five of the proteins studied in this analysis have near unitary expenditure elasticities, meaning that as household expenditures on proteins increases, expenditures on each protein rise in a nearly proportional manner. Plant-based meat demand was price inelastic in both the main sample and health- survey sample, but the demand was more elastic (indeed, near unit elastic) for the health-survey panel, suggesting some fundamental differences in behavior for the subgroup that chose to provide health information relative to the full panel.

The cross-price effects involving plant-based meat are especially important for this analysis. Compensated and uncompensated cross-price elasticities differed considerably due to strong income effects for all proteins in the system except plant-based meat. Estimated cross-price effects for the traditional proteins were consistent with prior meat demand studies. Importantly, results indicated that plant-based meat and beef are net complements, a finding at odds with the common belief that plant-based meat can become a significant substitute for beef in consumers' diets and lead to reduced methane emissions and other harmful environmental effects associated with cattle production. This finding casts major doubt on what appears to be an article of faith among those who believe plant-based meats can cause consumers to substitute away from animal meats.

9.1 Limitations of the study

The data used in this study are an extensive and useful resource. However, one should keep in mind the complexity and specific data properties when using these data and interpreting results. A first consideration is that these data capture purchases in the retail channel only and exclude consumption in the food service channel which could be an avenue for future research as more and more data on this channel become available. Second, the price paid by a certain household may not be identical to the price assigned by Circana to each product. More specifically, to make the participation in the survey easier, the household does not always report the dollars paid for a certain product, and instead, Circana assigns an average weekly price that comes from data collected at the store level (Muth et al., 2016).

Another limitation is related to projection factors of the static panel that were discussed in section 4.2. Although the projection factors are meant to make the sample representative of the U.S. population, in reality there might be significant differences between the general population and the sample population that arises as a result of the multiplication of each household in the sample by its projection factor.

Muth et al. (2016) compared the Circana projection factors with the U.S. Census and the American Community Survey, and they concluded that the Circana static panel (i) includes substantially fewer households with heads under age 35, (ii) fewer households in the lowest income bracket, (iii) fewer one-person households, (iv) more two- and three-person households, (v) fewer Hispanic and Black households and (vi) fewer households with children. This is particularly important for the research on plant-based meat since, as this study suggests, younger primary shoppers tend to consume more of these products. It is unknown if these limitations have been addressed in more recent years, and after the report was published. In this study, I assume that these issues have persisted over time and, therefore, it is necessary to be taken into account when discussing the demographic characteristics of the households that affect the demand for plant-based meat.

Further, most demographics refer to the primary shopper of the household who is not necessarily the person consuming the product. As it was shown in the results, even households who have vegan members still purchase animal proteins. This implies that it is unclear what the gender, the age, and the education level of the actual consumer really is. Finally, as shown in the summary statistics presented in chapter 5, although this study only includes households who have reported their expenditures consistently, there is still a small number of households that report very few shopping trips. However this limitation has no effect on the per-unit prices estimated nor on the average expenditure shares.

Another important consideration is related to the significant skewness of the plant-based meat expenditure data. Most of the households have zero plant-based meat expenditures and from those who have positive expenditures, the majority spends less than \$50 annually. This resulted in performing two important edits to the data that may have affected the conclusions drawn from this study. First, the quantities consumed were aggregated at the year level to be able to moderate the amount of zero-expenditure observations for plant-based meat entering the model. Therefore, the analysis presented here does not capture households who buy based on what is "on sale." That is, it is likely that households' short-run own-price elasticity is much more negative than their long-run elasticity and their cross-price elasticity is much more positive across goods in the short-run because they buy based on daily or weekly price anomalies, however, this behavior is not represented in the present analysis. Second, the double-hurdle model was sensitive to the sparseness of the data above $50 (3% of the total sample) and was unable to converge. This resulted in this 3% of these high-spending observations being dropped which is not ideal. Future research could address this limitation by finding a way to incorporate these observations to the model.

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Appendix A

Annual average CPI

Table A.1: Annual average CPI

Year	CPI
2012	229.6
2013	233.0
2014	236.7
2015	237
2016	240
2016	245.1
2018	251.1
2019	255.7
2020	258.8
2021	271.0
2022	291.7

Appendix B

Probit coefficients of animal proteins

Table B.1: Coefficients of panel probit for animal proteins using the 11-year panel of the main sample. (Dependent variable: yearly indicator of a household purchasing plant-based meat.)

	Beef	**Pork**	**Poultry**	**Seafood**
price of plant-based meat	-0.002	-0.02	-0.002	0.01
	(0.01)	(0.01)	(0.01)	(0.01)
price of beef	-0.04	-0.09**	0.13***	0.07
	(0.03)	(0.02)	(0.04)	(0.02)
price of pork	-0.03	-0.09***	-0.07**	0.08
	(0.02)	(0.02)	(0.03)	(0.01)
price of poultry	0.06*	-0.16***	-0.07	-0.039
	(0.03)	(0.04)	(0.04)	(0.02)
price of seafood	-0.06***	-0.08***	-0.02	-0.005
	(0.01)	(0.01)	(0.01)	(0.01)
household income				
$15,000-$34,999	-0.08	-0.04	0.03	0.02
	(0.07)	(0.08)	(0.08)	(0.05)
$35,000-$59,999	0.09	0.12	0.16*	0.10*
	(0.08)	(0.09)	(0.09)	(0.05)
$60,000 or more	0.06	-0.008	0.16*	0.07
	(0.08)	(0.09)	(0.09)	(0.05)
female primary shopper	0.06	0.09	0.14	0.08**
	(0.05)	(0.05)	(0.05)	(0.03)

Continuation of Table 7.15

	Beef	**Pork**	**Poultry**	**Seafood**
household size				
household of 2	0.74***	0.77***	0.79***	0.34***
	(0.04)	(0.04)	(0.05)	(0.03)
household of 3	0.90***	0.78***	1.05***	0.35***
	(0.06)	(0.06)	(0.08)	(0.04)
household of 4	0.91***	0.88***	1.08***	0.33***
	(0.07)	(0.08)	(0.10)	(0.04)
household of 5	0.97***	1.11***	1.13***	0.39***
	(0.11)	(0.13)	(0.16)	(0.06)
household of 6	1.15***	1.27***	1.46***	0.28***
	(0.18)	(0.23)	(0.30)	(0.09)
household of 7	1.92***	0.72	-	0.45**
	(0.57)	(0.33)		(0.20)
household 8 or more	0.92	-0.64	-	0.08
	(0.64)	(0.47)		(0.30)
education				
College degree	-0.26***	-0.35***	-0.16***	0.005
	(0.04)	(0.04)	(0.05)	(0.02)
Post-graduate degree	-0.56***	-0.59***	-0.39***	0.04
	(0.06)	(0.06)	(0.07)	(0.04)
N	98,602	98,602	98,602	98,602
$n_{households\ in\ panel}$	8,966	8,966	8,966	8,966

*p<0.1, **p<0.05, ***p<0.01

Table B.2: Coefficients of panel probit for animal proteins using the 11-year panel of the main sample. (Dependent variable: yearly indicator of a household purchasing plant-based meat.)

	Beef	**Pork**	**Poultry**	**Seafood**
price of plant-based meat	0.02	-0.06**	-0.02	-0.13
	(0.02)	(0.02)	(0.03)	(0.01)
price of beef	-0.14**	-0.03	0.10	0.13***
	(0.06)	(0.07)	(0.08)	(0.04)
price of pork	0.005	-0.08	-0.07	0.11***
	(0.05)	(0.05)	(0.06)	(0.03)

Continuation of Table 7.15

	Beef	**Pork**	**Poultry**	**Seafood**
price of poultry	0.07	-0.06	0.01	-0.04
	(0.07)	(0.08)	(0.09)	(0.05)
price of seafood	-0.05**	-0.06*	0.01	-0.01
	(0.02)	(0.03)	(0.03)	(0.01)
household income				
2	-0.03	0.28	0.31*	0.10
	(0.14)	(0.17)	(0.16)	(0.10)
3	0.22	0.30	0.42***	0.30***
	(0.15)	(0.17)	(0.17)	(0.11)
4	0.18	0.12	0.40***	0.34***
	(0.15)	(0.18)	(0.17)	(0.11)
female primary shopper	0.10	0.13	0.02	-0.06
	(0.11)	(0.12)	(0.12)	(0.08)
household size				
household of 2	0.67***	0.92	0.85***	0.39***
	(0.09)	(0.10)	(0.11)	(0.06)
household of 3	0.90***	1.14	1.29***	0.48***
	(0.14)	(0.16)	(0.20)	(0.09)
household of 4	0.91***	1.10	0.93***	0.45***
	(0.21)	(0.23)	(0.25)	(0.13)
household of 5	1.24***	2.09	1.20***	0.62***
	(0.36)	(0.52)	(0.43)	(0.21)
household of 6	0.50***		0.90	-0.10
	(0.45)	()	(0.60)	(0.29)
household of 7				
		()	()	()
household 8 or more				
		()	()	()
education				
2	-0.20***	-0.38***	-0.33***	-0.15**
	(0.09)	(0.10)	(0.10)	(0.06)
3	-0.60***	-0.65***	-0.62***	-0.20**
	(0.12)	(0.13)	(0.14)	(0.09)
health assessment	-0.04*	-0.01	-0.007	0.06***
	(0.02)	(0.02)	(0.03)	(0.01)
health concern	-0.001	-0.0007	0.001	0.01*

Continuation of Table 7.15

	Beef	**Pork**	**Poultry**	**Seafood**
	(0.01)	(0.01)	(0.01)	(0.009)
health issue	0.09***	0.08***	0.01	0.02***
	(0.02)	(0.02)	0.02	(0.01)
ingredient-conscious diet	-0.008	-0.004	0.03***	0.01***
	(0.009)	(0.01)	0.01	(0.007)
concerned about food	-0.01***	-0.02***	-0.007	0.0005
	(0.005)	(0.006)	(0.007)	(0.004)
N	22,440	22,440	22,440	22,440
$n_{households\ in\ panel}$	2,042	2,042	2,042	2,042

*p<0.1, **p<0.05, ***p<0.01