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Essays on the marketing and nutritional values of meat substitute product innovations in the European market

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Abstract

In the context of the external effects of meat production on the environment and its negative external effects on public health that are related to red and processed meat consumption, this thesis examines the barriers to meat substitute consumption and product characteristics as well as consumer groups of meat substitutes. Despite a lower external impact on the environment, meat substitutes are still niche products due to the taste of the products, their higher prices and the assumption that they are unhealthy since they are highly processed. Therefore, it is necessary to understand the factors associated with the higher prices, to examine the nutritional composition of meat substitutes, and determine which consumer groups show a high demand for meat substitutes.

Thus, four different research articles are presented in this dissertation to improve the understanding of the prices, nutritional advantages and disadvantages, and consumer groups of meat substitutes. These articles follow a general motivation on the relevance of the topic of meat substitutes, a description of the European meat and meat substitute markets, a common definition of meat substitutes, and a general overview of the literature about the utility, prices, product attributes, and consumer groups of meat and meat substitute products.

The first article analyzes the prices of meat and meat substitute sausages in the German market using an advanced hedonic pricing model that accounts for asymmetric information in the market. Using a sample of 183,717 product price observations, this research finds that meat substitutes carry an average price premium of 0.39 cents per 100g compared to traditional meat products. In addition, product attribute labeling is associated with both higher prices and lower prices, depending on the labelled topic. Finally, we find evidence of the presence of asymmetric information in the market.

The second article analyzes the reliability of product labeling as an indicator for healthier and less artificial, for example, less additive-containing products on the food market. Based on a sample of 5,482 products from the German meat and meat substitute market for the years 2010-2018, we find that vegan and non-vegan meat substitutes contain fewer nutrients to limit, such as salt and saturated fats, relative to poultry and red meat (i.e., pork and beef). In addition, poultry meat and meat substitutes contain fewer additives than red meat. Finally, we note that product labeling is not always consistently related to the nutritional quality of the products.

In the third article, the nutritional composition of products in the meat and meat substitute market is further investigated, considering products from five major European countries: France, Germany, Italy, Spain, and the United Kingdom. Using a sample of 19,941 products

from these countries, we find that meat substitutes are lower in calories, fat, salt, and protein than red meat products but higher in carbohydrates and fiber. However, the results differ to some extent when the products are grouped into more homogenous subgroups, like sausages or cold cuts.

Finally, article four examines the factors associated with lower or higher meat substitute consumption, focusing on consumer characteristics. Here, a sample of IRI's meat and meat substitute product sales, accounting for €472 million in sales volume for three years (2017, 2019, and 2021), is merged with consumer characteristics and electoral behavior in Germany at the two-digit zip code level. The results indicate significant differences in consumer behavior between the German regions, which can be explained by differences in average age and income, but also by differences in liberal vs. conservative voting behavior and voting behavior for climate protection ambitions.

Zusammenfassung

Vor dem Hintergrund der externen Auswirkungen der Fleischproduktion auf die Umwelt und der negativen externen Auswirkungen auf die öffentliche Gesundheit, die mit dem Konsum von rotem und verarbeitetem Fleisch verbunden sind, werden in dieser Arbeit die Barrieren und Produkteigenschaften sowie die Verbrauchergruppen von Fleischersatzprodukten untersucht. Trotz geringerer externer Auswirkungen auf die Umwelt sind Fleischersatzprodukte nach wie vor Nischenprodukte, was nicht nur auf den Geschmack der Produkte, sondern auch auf ihren Preis und die Annahme zurückzuführen ist, dass sie ungesund sind, da sie stark verarbeitet sind. Daher ist es notwendig, die Faktoren zu verstehen, die mit den höheren Preisen zusammenhängen, die ernährungsphysiologische Zusammensetzung von Fleischersatzprodukten zu untersuchen und zu ermitteln, welche Verbrauchergruppen eine hohe Nachfrage nach Fleischersatzprodukten aufzeigen.

Daher werden in dieser Dissertation vier verschiedene Forschungsartikel vorgestellt, um das Verständnis für die Preise, die ernährungsphysiologischen Vor- und Nachteile und die Verbrauchergruppen von Fleischersatzprodukten zu verbessern. Diese Artikel folgen auf eine allgemeine Motivation zur Relevanz des Themas Fleischersatzprodukte, eine Beschreibung der europäischen Fleisch- und Fleischersatzmärkte, eine einheitliche Definition von Fleischersatzprodukten und einen allgemeinen Überblick über die Literatur zu Nutzen, Preisen, Produkteigenschaften und Verbrauchergruppen von Fleisch und Fleischersatzprodukten.

Der erste Artikel analysiert die Preise von Fleisch- und Fleischersatzwürsten auf dem deutschen Markt unter Verwendung eines fortgeschrittenen hedonischen Preismodells, das asymmetrische Informationen auf dem Markt berücksichtigt. Anhand einer Stichprobe von 183.717 Produktpreisbeobachtungen stellen wir fest, dass Fleischersatzprodukte im Durchschnitt mit einem Preisaufschlag von 0,39 Cent pro 100g im Vergleich zu traditionellen Fleischprodukten versehen sind. Darüber hinaus stellen wir fest, dass die Kennzeichnung von Produktattributen je nach Thema mit höheren Preisen, aber auch mit niedrigeren Preisen verbunden sein kann. Schließlich finden wir Hinweise auf das Vorhandensein von asymmetrischen Informationen auf dem Markt.

Der zweite Artikel analysiert die Zuverlässigkeit der Produktkennzeichnung als Indikator für gesündere und weniger künstliche, d.h. weniger Zusatzstoffe enthaltende Produkte auf dem Lebensmittelmarkt. Anhand einer Stichprobe von 5.482 Produkten aus dem deutschen Fleisch- und Fleischersatzmarkt für die Jahre 2010-2018 stellen wir fest, dass bei veganen und nicht-veganen Fleischersatzprodukten weniger zu reduzierende Nährstoffe wie Salz und gesättigte

Fette enthalten sind als bei Geflügel und rotem Fleisch, d.h. Schweine- und Rindfleisch. Außerdem sind in Geflügelfleisch und Fleischersatzprodukten weniger Zusatzstoffe enthalten als in rotem Fleisch. Schließlich stellen wir fest, dass die Produktkennzeichnung nicht immer in einem konsistenten Zusammenhang mit der besseren Nährwertqualität der Produkte steht.

Im dritten Artikel wird die ernährungsphysiologische Zusammensetzung von Produkten auf dem Markt für Fleisch und Fleischersatzprodukte anhand von Produkten aus fünf großen europäischen Ländern weiter untersucht: Frankreich, Deutschland, Italien, Spanien und das Vereinigte Königreich. Anhand einer Stichprobe von 19.941 Produkten aus diesen Ländern stellen wir fest, dass Fleischersatzprodukte einen geringeren Kalorien-, Fett-, Salz- und Proteingehalt haben als Rotfleischprodukte, dafür aber einen höheren Gehalt an Kohlenhydraten und Ballaststoffen. Die Ergebnisse unterscheiden sich jedoch in gewissem Maße, wenn die Produkte in homogenere Untergruppen wie Würste oder Aufschnitt eingeteilt werden.

Schließlich werden in Artikel vier die Faktoren untersucht, die mit einem geringeren/höheren Fleischersatzkonsum verbunden sind, wobei der Schwerpunkt auf Verbrauchereigenschaften liegt. Hier wird eine Stichprobe des IRI-Umsatzes von Fleisch und Fleischersatzprodukten mit einem Umsatzvolumen von 472 Millionen Euro für drei Jahre (2017, -19, -21) mit Verbrauchereigenschaften und Wahlverhalten in Deutschland auf der Ebene zweistelliger Postleitzahlen zusammengeführt. Die Ergebnisse weisen auf signifikante Unterschiede im Verbraucherverhalten zwischen den deutschen Regionen hin, die sich durch Unterschiede im Durchschnittsalter, Einkommen, aber auch durch Unterschiede im liberalen vs. konservativen Wahlverhalten und im Wahlverhalten für Klimaschutzambitionen erklären lassen.

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1 Introduction

1.1 Motivation

Meat is an important source of protein, micronutrients like iron and vitamins like vitamin B12 (Pereira and Vicente, 2013). In 2021, the worldwide production of meat was 357,4 million tons of which 65.1 million tons were produced in Europe and 7.6 million tons were produced in Germany (FAO, 2023a). The per capita consumption of meat in 2021 in Germany amounts to 55 kg (LfL & LEL, 2022). The high levels of meat consumption in high-income countries, like Germany, are, however, associated with negative external effects on the environment, while generating ethical and general health concerns (Godfray *et al.*, 2018; Willett *et al.*, 2019; Springmann, Clark *et al.*, 2018). Thereby, diets including large shares of meat bear a significantly higher carbon footprint in CO_2-equivalents than pescetarian or even vegetarian diets (Tilman and Clark, 2014). Furthermore, consumers in Germany view livestock practices for fattening animals negatively (Birkle, Klink-Lehmann and Hartmann, 2022). Finally, there are rising concerns regarding the health effects of meat and processed meat products on public health (Godfray *et al.*, 2018). Hence, there is a need to reduce the overall adverse effects of meat overconsumption.

There are several ways to reduce meat consumption. On a policy level, decision-makers could increase taxes on meat products and decrease consumption based on the price elasticity of demand (Springmann, Mason-D'Croz *et al.*, 2018; Funke *et al.*, 2022; Roosen, Staudigel and Rahbauer, 2022). However, there is often little public acceptance of sustainability taxes (Kallbekken and Sælen, 2011) or taxes internalizing carbon emissions (Levi, 2021). Alternatively, product innovations, such as advances in meat substitutes, can promote a more sustainable diet (Tziva *et al.*, 2020). Hence, from a consumer perspective, there is the option to reduce meat consumption by switching to plant-based diets and/or substitute meat products with meat alternatives (Hartmann and Siegrist, 2017). The present work follows the definition by Hoek, van Boekel *et al.* (2011) who define meat substitutes (innovations) as products that resemble meat in its texture, taste, and appearance and/or replace it in a meal context. Other meat alternatives like eggs, insects, cheese, unprocessed nuts and legumes, or cultured meats (Siegrist and Hartmann, 2023) are not considered as meat substitutes in this work. Meat substitute are more environmentally friendly (Saget *et al.*, 2021; Nijdam, Rood and Westhoek, 2012; Humpenöder *et al.*, 2022; Clark *et al.*, 2022) and generate less animal welfare concerns due to their vegetarian or vegan composition. However, meat substitutes are criticized for being unhealthy since they are ultra-processed (Wickramasinghe *et al.*, 2021), artificial (Michel, Hartmann and Siegrist, 2021), and being more expensive than traditional meat (Kerslake, Kemper and Conroy, 2022). Thus, they are consumed less than projected by the investment bank Barclays (2019) in 2019 (Siegrist and Hartmann, 2023). Given meat substitutes' environmental and ethical benefits, this doctoral thesis analyzes the barriers to meat substitute consumption.

Consumers act as utility maximisers in the (food) market (Lancaster, 1966). The products available in the market can be described by a vector of attributes to which consumers have corresponding preferences (Lancaster, 1966). Consumers search for a combination of product attributes that correspond to their overall preferences and hence maximizes the utility they receive (Lancaster, 1966). Accordingly, they are willing to pay a price premium for attributes that match their preferences (Rosen, 1974). These product attributes can be described according to Nelson (1970) by search and experience characteristics. Consumers can actively search for these attributes in the supermarket, like the color of the product, or experience them after the purchase, like the taste of the products. Darby and Karni (1973) extend the work of Nelson (1970) and introduce the credence attributes. Those are attributes that cannot be experienced even after the purchase. To get information on such attributes, the consumer would be required to go through an active and costly search. An example in the food market is the production method. For example, customers are unable to determine if products were organically grown from taste or appearance alone. Hence in order to be informed, the consumer requires additional information, which can be done by labeling the packaging of the product (Karstens and Belz, 2006). The drawback, however, of those labels is that consumers can interpret them beyond the actual meaning of the labeled credence attribute. For example, Schuldt and Schwarz (2010) find that consumers consider organically produced meat to be healthier than conventional meat, despite no differences in calories. Hence, the labeling on the credence attributes can be misleading. Additionally, in the emerging market of meat substitutes information asymmetry exists between consumers and producers about the quality of the products, for example the nutritional quality (Siegrist and Hartmann, 2023). Therefore, product attributes and their labeling play an important role in consumer decision-making, in overcoming barriers to consumption, and in the prices that manufacturers can charge for their products. Finally, the preferences for products in the food market are not homogenous among all consumers but differ largely between consumer groups. However, previous literature show mixed results concerning food preferences among different consumer groups (Onwezen *et al.*, 2021).

Considering the sustainability aspects of current meat consumption in high-income countries (Godfray *et al.*, 2018), this doctoral thesis explores the barriers to meat substitute consumption, various contextual perspectives encompassing prices, product labelling, nutrition and characteristics of meat substitute consumers. Four first-authored articles analyze both the relevant product attributes in the meat and meat substitute market and the drivers of heterogeneity in the preferences of meat substitute consumption. The first article investigates the factors related to the prices in the German meat and meat substitute market for sausages in the period 2020-2021. The study employs a hedonic pricing model that allows to consider the influence of asymmetric information on prices (Chapter 2). The second article examines the relationship between product labeling and the nutritional quality and artificialness in terms of number of food additives of products using a product sample from the German meat and meat substitutes market covering 2010-2018 (Chapter 3). The third article analyzes the nutritional composition of 19,941 meat and meat substitute products from five European countries (France, Germany, Italy, Spain, and the United Kingdom) (Chapter 4). Finally, the fourth article studies the relationship between consumer characteristics, electoral results, and varying meat substitute consumption levels (Chapter 5).

The results presented in the four articles of this doctoral thesis are relevant to stakeholders in the food value chain, consumers, and policymakers. Research on price-related factors is important for food producers and researchers who aim to understand what is valued in the market and how information asymmetry affects prices. The first article determines whether the prices of meat substitutes are indeed higher than those of meat products, which would indicate the need for policies that lower prices and thereby promote more sustainable consumption. The results of the second and third articles enable consumers to make better choices and determine whether the information on labels is a reliable predictor of healthiness in the meat and meat substitute market. Furthermore, these results are relevant to policymakers and nutritional scientists as they determine whether meat substitutes can improve the nutritional composition of diets relative to the inclusion of traditional meat products or whether meat substitutes might be causing new public health concerns. Hence, the results allow for a more target-oriented nutritional policy that combines environmental sustainability and public health aspects. Finally, the results of the fourth study are of interest to meat substitute manufacturers that want to adjust their marketing strategies to target currently unreached consumer segments.

The remainder of this dissertation is structured as follows: Chapter 1.2 provides an overview of the European meat and meat substitute market, with a particular focus on the German market.

Chapter 1.3 outlines the product attributes, nutrients, consumption barriers, and consumer characteristics that are relevant in the context of meat substitute consumption. Chapters 2–5, as the main part of this thesis, include the four first-authored articles. The chief results of these articles and the primary conclusions are included in the final Chapter 6.

1.2 Background on the meat market and meat substitute market

1.2.1 The European meat market

Changes within the food industry affect many stakeholders, as the European *Food Products Manufacture Industry* (C10)[1]—with a total turnover volume of €967 billion in 2019 (EUROSTAT, 2023)—is the largest manufacturing industry in Europe. Figure 1-1 depicts the overall share of each sub-industries' turnovers within the C10. The meat industry is of particular importance, as the *Processing and Preserving of Meat and Production of Meat Industry* (C101) is in most countries—with, for example, the exception of France (20%)—the largest subindustry of the *Food Products Manufacture Industry* (EUROSTAT, 2023) (c.f. Figure 1-1). Hence, a major change within the meat industry would not only affect the employees and entrepreneurs but also the wider population.

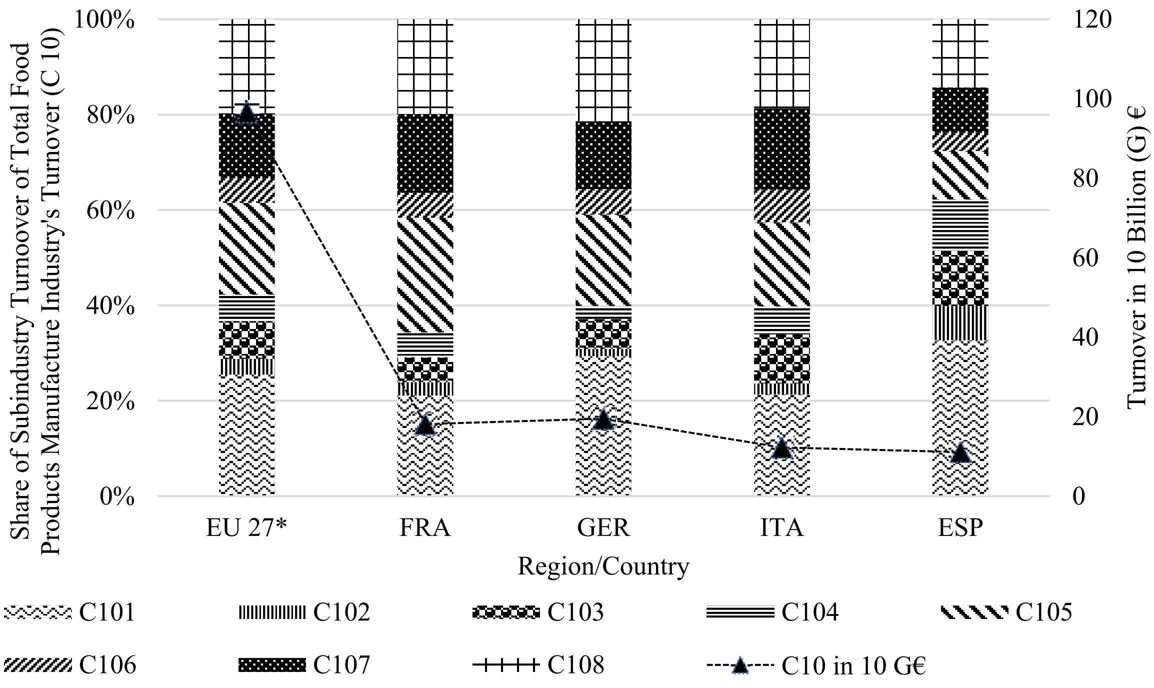

Figure 1-1 Turnover of manufacture industry (NACE: C10) in Europe and selected countries 2019.

[1] The code C10 refers to the NACE classification of European Union, whereby the C refers to the economic area of *Manufacturing.*

Source (EUROSTAT, 2023). C101: Processing and preserving of meat and production of meat products. C102: Processing and preserving of fish, crustaceans, and mollusks. C103: Processing and preserving of fruit and vegetables. C104: Manufacture of vegetable and animal oils and fats. C105: Manufacture of dairy products. C106: Manufacture of grain mill products, starches, and starch products. C107: Manufacture of bakery and farinaceous products. C108: Manufacture of other food products. *The value for C105 of the EU is taken from 2020. EU 27: European Union without the United Kingdom. FRA: France. GER: Germany. ITA: Italy. ESP: Spain.

In general, the level of self-sufficiency for meat products in Europe was 130 % in 2021 (LfL & LEL, 2022). Thus, a considerable amount of meat is exported to third countries. Figure 1-2 illustrates the annual meat production across the EU 27, France, Germany, Italy, Spain and the United Kingdom in 1,000 tons (FAO, 2023a). Over the last decades, the production volumes in the EU27 increased from 17 million tons in 1961 to over 44 million tons in 2021. Similarly, the production levels in the individual countries increased, with the highest increase for Spain from 0.66 million tons in 1961 to 7.65 million tons in 2021, while France's peak production was in 1998 with 7.5 million tons. Thus, there is a high dynamic in the European meat market, and the production volume contradicts the call to reduce overall meat production in the face of environmental and health concerns.

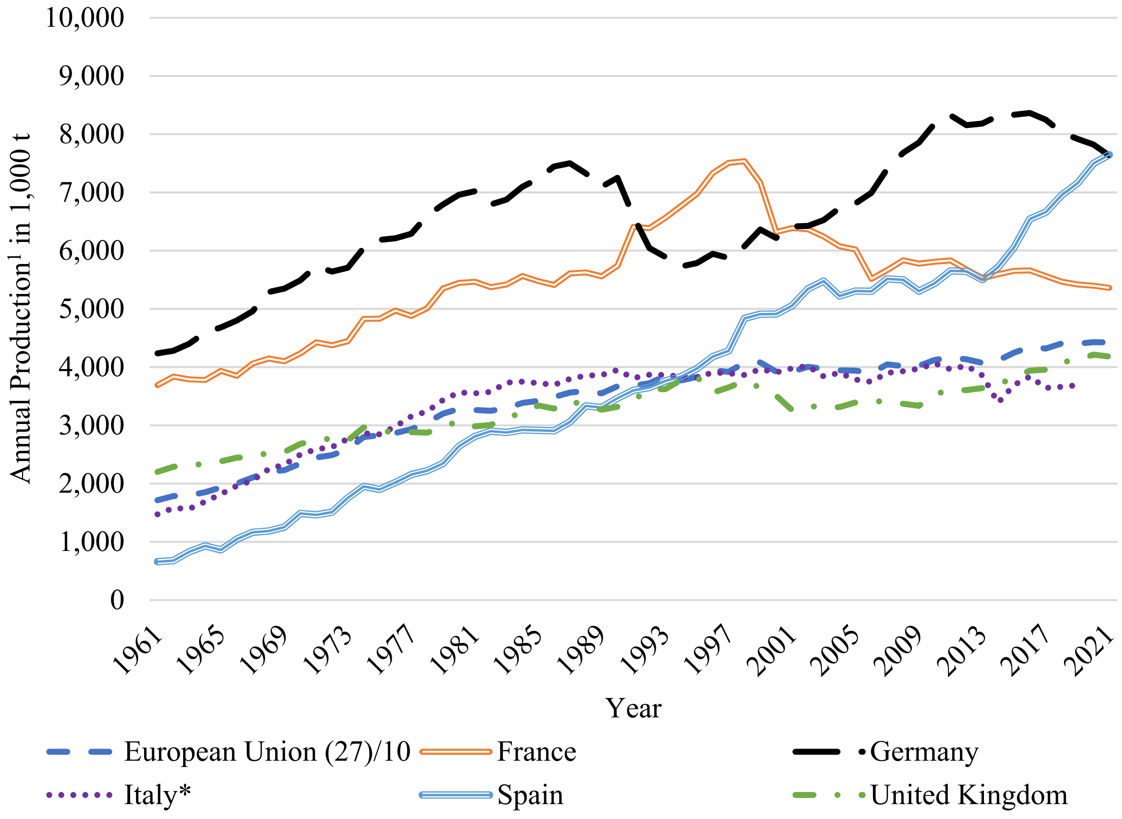

Figure 1-2 Annual meat production in the European Union and selected countries.
Source: (FAO, 2023a). [1] "The FAO defines meat as the flesh of animals used for food", (FAO, 2023a). ' The Value for the EU 27 (without the UK) is divided by 10. * The source does not provide production volumes for Italy in 2020 and 2021.

Similar to the total production, the production of meat per capita as shown in Figure 1-3 increased in most of the reported countries as well. One factor explaining the high production value is the high meat consumption levels across Europe. The per capita production worldwide increased from 23 kg/capita in 1961 to 45 kg/capita in 2021 (FAO, 2023a). The per capita production in Europe on the other side reached a high point of nearly 100 kg/capita in 2021 (FAO, 2023a). The production in Germany alone increased from 57 kg/capita to 92 kg/capita. (FAO, 2023a) The high production levels and growths underlie the important role of meat in comparison to the rest of the world despite scientific calls to reduce meat overconsumption (Willett *et al.*, 2019).

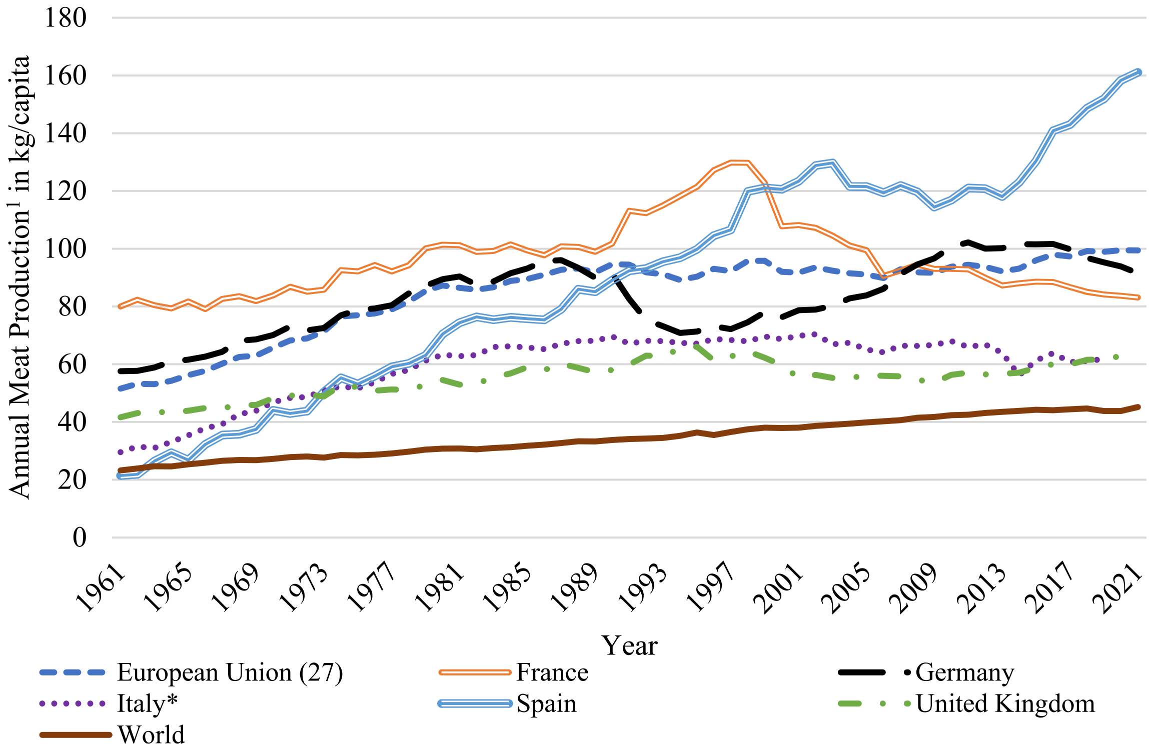

Figure 1-3 Annual per capita production of meat across selected countries, the world and the EU 27.
Source: (FAO, 2023a) "The FAO defines meat as the flesh of animals used for food", (FAO, 2023a). *The Source does not provide production volumes for Italy in 2020 & 2021.

The production and consumption do vary across the meat categories, which include red meat (e.g., pork, beef) and poultry meat (e.g., chicken) (Henchion *et al.*, 2014). The meat supply quantities[2] by meat category in the year 2020 provided by the FAO are presented in Figure 1-4 (FAO, 2023b). While other meats and meats from mutton and goats are of low relevance in

[2] The value represents the "food supply quantity" and is calculated as sum of production, stock changes and imports minus exports divided by the population in the given country. It represents the food potentially available to human consumption (FAO , 2023b).

European countries, the supply of the meat categories and the overall supply varies considerably. With 102 kg per capita, Spain has the highest supply, while Italy has the lowest supply with 70 kg per capita. In most countries, pork is the major source of meat, followed by poultry; in the United Kingdom, however, most meat is poultry meat, followed by pork. In all observed countries, beef is the third largest source of meat.

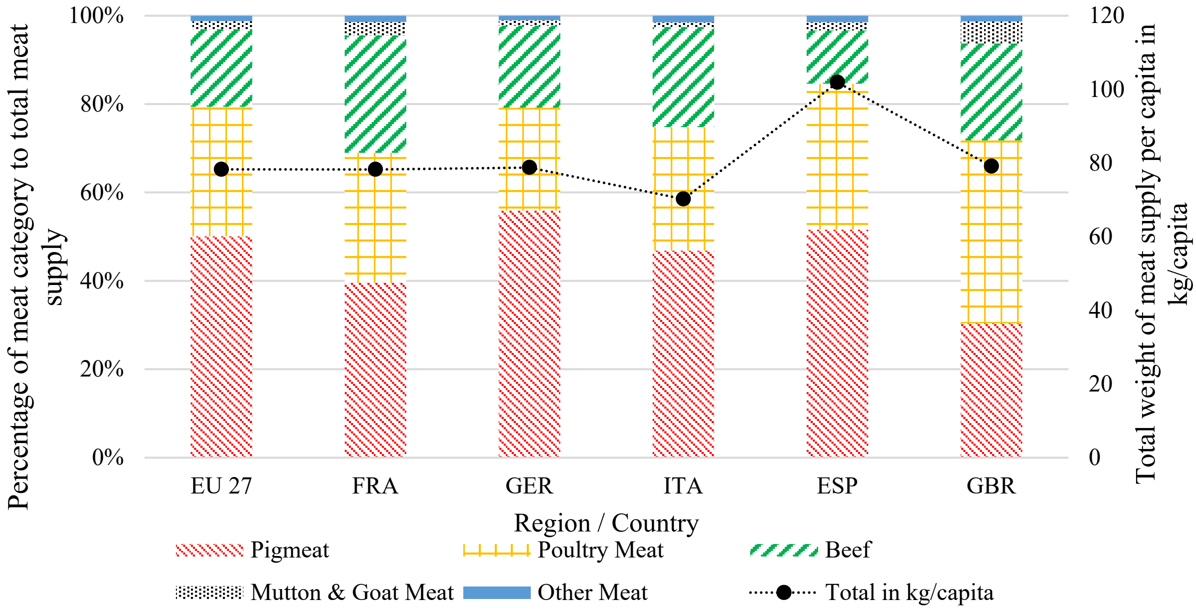

Figure 1-4 Meat supply by meat category across Europe in 2020.
Note: Source: (FAO, 2023b). FRA: France. GER: Germany. ITA: Italy. ESP: Spain. GBR: Great Britain.

Figure 1-5 illustrates the meat category consumption of meat in Europe for 2021. The total 69.8 kg per capita consumption of meat in Europe is mainly based on pork (32.5 kg/capita) followed by poultry meat (23.5 kg/capita), beef (10.4 kg/capita) and sheep meat (1.3 kg/capita) (EC, 2021). However, the consumption level of pork is expected to decline in the coming years while the amount of poultry is projected to increase (EC, 2021).

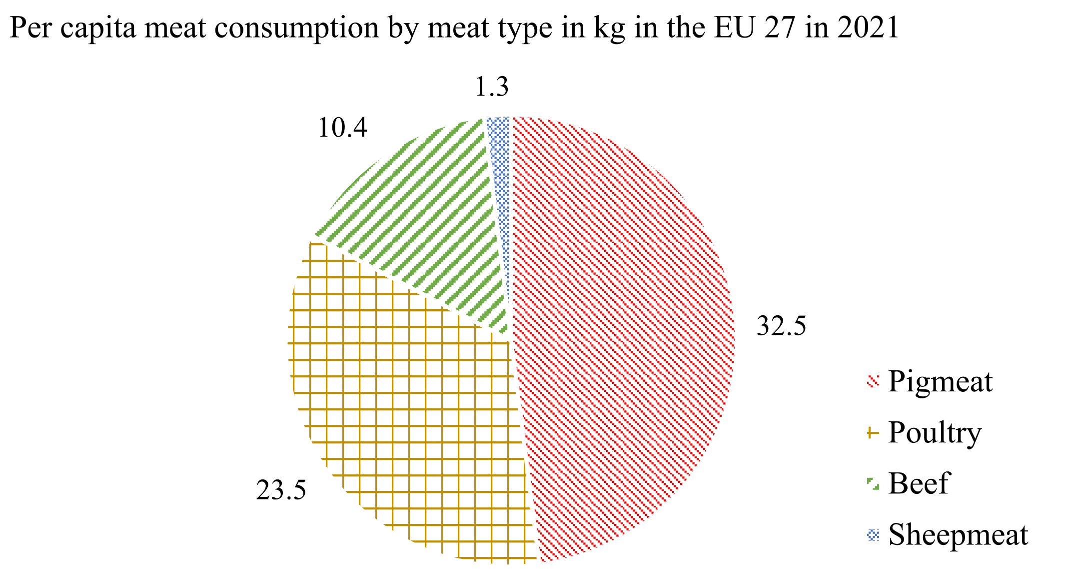

Figure 1-5 Per capita meat consumption by meat category in Europe in 2021.
Source: EC (2021).

In summary, meat and its production are an important source of economic prosperity in the European Union. Moreover, despite calls for a reduction in meat consumption, meat consumption is still high, with pork being the most important source of meat followed by poultry meat.

1.2.2 The meat alternative market in Germany[3]

There are several synonymous words to describe meat substitutes, like meat alternatives or plant-based meat. Hence, meat substitutes are products that resemble the texture, taste, smell, and appearance of meat products (cf. the second paper). This doctoral thesis considers meat substitutes only if they aim to replace meat in a meal context as a protein supply. There are also other forms of meat substitutes like artificially printed meat or products using insects (Siegrist and Hartmann, 2023). However, based on the current availabilities, they play little role in the meat substitute market (Siegrist and Hartmann, 2023). Hence, they are not considered in this work as meat substitutes. Additionally, this research does not consider plain cheeses, vegetables, or legumes in an unprocessed form as meat substitutes. Hence, when referring to meat substitutes, this work refers to products like soy-based salami or tofu and not insect-based burger patties or lab-grown meat.

[3] Note: There are no official figures on the production volume and sales of meat substitutes in the European Union.

Figure 1-6 presents the market value and the growth rate of the market value of meat substitutes produced in Germany between 2019 and 2022[4].

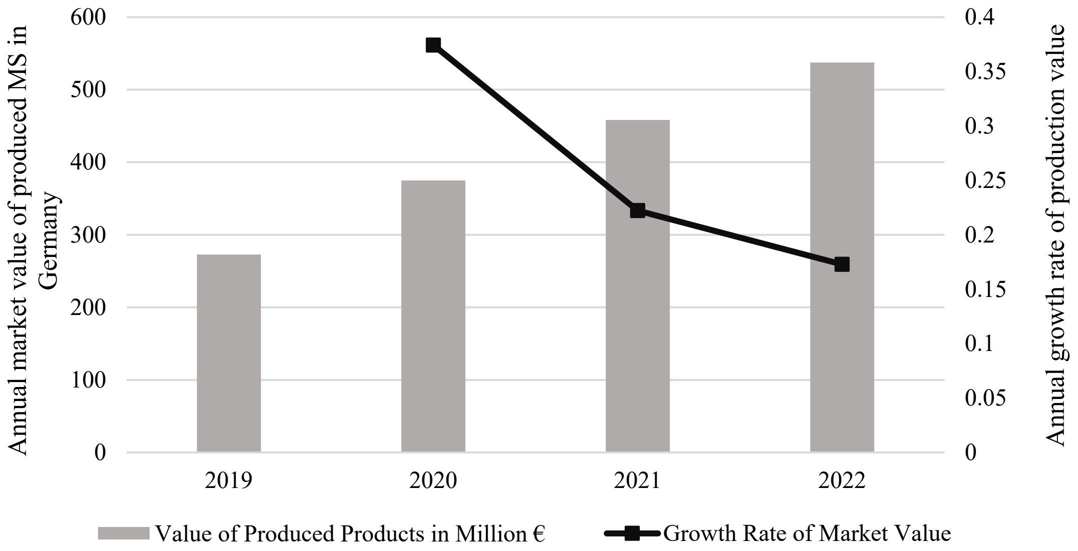

Figure 1-6 Market value and its annual growth rate of MS between produced in Germany 2019-2022.
Note: Source: (DESTATIS, 2022, 2023a). MS: Meat Substitutes.

The market value of produced meat substitutes had high growth rates, increasing from 272.8 million Euros in 2019 to 537.4 million in 2022. The growth rate of the market value, however, has decreased in the most recent years, decreasing from 37.4% in 2020 to 17.2% in 2022. Controlling for the high inflation of food prices in Germany in 2021 (3.2%) and 2022 (13.4%) (DESTATIS, 2023b) further reduces the magnitude of the growth in market value: The market value of the produced meat substitutes in 2021 was 458.2 Million Euro, which is approximately 80 times lower than the market value of traditional meat in Germany (DESTATIS, 2022).

Figure 1-7 illustrates the total weight of meat substitutes produced in Germany for the years 2019-2022 (DESTATIS, 2022, 2023a). The total 104 thousand tons produced in Germany in 2022 is considerably lower than the production of red and white meat products (cf. Figure 1-3). Observing the per capita production in Germany for 2022, 1.24 kg per capita of meat substitute products were produced. This is an increase compared to 2019, but the per capita production is still low compared to the production volume of conventional meat (cf. Figure 1-4).

[4] Note: There are no official numbers on the production volume presented in the official statistics before 2019.

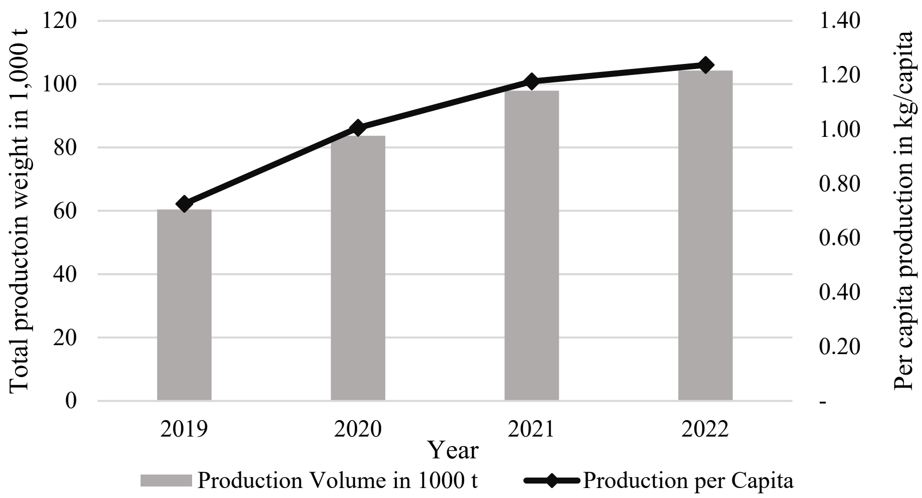

Figure 1-7 - Total and per capita production of meat substitutes in Germany between 2019 and 2022.
Note: Source: (DESTATIS, 2022, 2023a).

Despite large projected growth for the meat substitute market (Siegrist and Hartmann, 2023), the meat substitute market in Europe, at the example of Germany, is still small in comparison with the traditional red and poultry meat market.

1.3 Background and previous literature on barriers to consumption of meat and meat substitutes

In general, consumers base their decisions to purchase a distinct product on the utility they receive from the product in comparison to utility levels of the other products available (Lancaster, 1966). In the food market, consumers decide to purchase foods based on the expected quality of the product characteristics, the price (cost to consumers), and expected fulfillment (Grunert, 2005), which is illustrated in Figure 1-8. The expected quality is based on intrinsic product attributes, such as the color or the fat content, and extrinsic product attributes, such as the origin (Grunert, 1997, 2005). However, a distinction must be made by consumer groups, as not all consumers have the same preferences for specific product attributes (Smith, 1956). Moreover, consumer factors such as socio-demographics play an important role in, for example, explaining consumer demand for meat (Bernués, Olaizola and Corcoran, 2003).

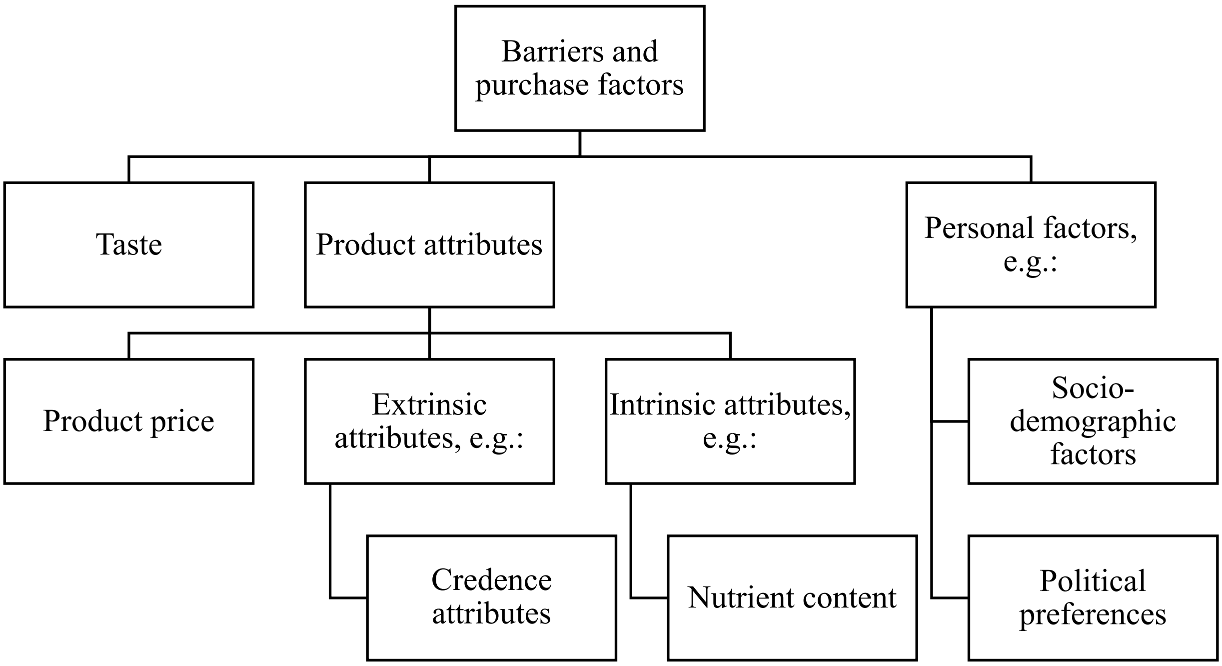

Figure 1-8 - Overview on barriers and purchase factors of meat and meat substitutes.
Note: Own illustration of the purchase factors and barriers based on Grunert (1997, 2005) and Bernués, Olaizola and Corcoran (2003).

Notably the expected taste, is one of the most important decision factors in food decisions (Malone and Lusk, 2017). Taste is also one of the major barriers to meat substitute consumption (Hoek, Luning *et al.*, 2011; Onwezen *et al.*, 2021), as consumers, in general, demand for meat substitutes that are similar to traditional meat products (Michel, Hartmann and Siegrist, 2021). However, there are additional reasons why consumers choose to adopt or not to adopt meat and meat substitutes in their diets, which are analyzed in this thesis: the prices, the naturalness, the healthiness of the products and differing preferences for meat substitutes.

1.3.1 Prices in the meat and meat substitute market

One of the most discussed topics of sustainability research is internalizing the external costs of food to public health and the environment by increasing the prices and lowering the demand (Bodirsky *et al.*, 2020). A recent review of the external costs of meats concludes that the prices for meat are, considering the environmental and the health costs, too low (Funke *et al.*, 2022). Consumers are sensitive to price changes in the meat market, as a study for the German fresh meat market revealed that an increase in the tax level leads to a decrease in fresh meat consumption of 11% across different meat types and different household groups (Roosen, Staudigel and Rahbauer, 2022). Springmann, Mason-D'Croz *et al.* (2018) integrate the associated health cost of meat overconsumption into the prices of meat and processed meat products, finding that the products would need a price increase by 25% for red meat and 111% for processed meat products in high-income countries. These increases in prices would decrease consumption by 25%, further showing the price sensitivity of consumers in the markets (Springmann, Mason-D'Croz *et al.*, 2018). On the other hand, studies on the meat substitute market find that consumers perceive the prices of meat substitute as too high considering this a "vegan-tax" (Kerslake, Kemper and Conroy, 2022). Hence, to understand the barriers to meat substitute consumption it is necessary to understand what drives the prices in the market in comparison to meat products.

In general, the prices consumers are willing to pay depend on the utility they receive from the products (Rosen, 1974). For the combined meat and meat substitute market, several studies exist that aim to determine and compare the utility consumers obtain and the prices they are willing to pay in the market. Apostolidis and McLeay (2016) compare the attributes of intrinsic and extrinsic product attributes of meat and meat substitute products using minced meat. They employ a choice experiment in order to derive the utility consumers receive based on the product attributes: Fat content, carbon footprint, type of mince, method of production, price and origin (Apostolidis and McLeay, 2016). They discover that meat free alternatives yield the lowest utility, while beef yields the highest utility (Apostolidis and McLeay, 2016). In a follow up study Apostolidis and McLeay (2019) compare the same product attributes using a specified sample of three consumer segments: meat eaters, meat reducers, and vegetarians (Apostolidis and McLeay, 2019). The vegetarian group is the only consumer segment with a positive utility for meat substitutes in comparison to meat (Apostolidis and McLeay, 2019). Furthermore, Slade (2018) compares the preferences for meat and meat substitute burgers and reports larger preferences for beef burgers. van Loo, Caputo and Lusk (2020) employ a choice experiment to determine the willingness to pay for lab-grown, plant-pea, plant-yeast and beef burger patties in the United States. They find that consumers are willing to pay more for beef than for alternatives (van Loo, Caputo and Lusk, 2020). Carlsson, Kataria and Lampi (2022) use a sample of Swedish consumers to determine the price difference that would be necessary for consumers to switch from beef burger patties to either veggie burgers, meat substitute burgers, or lab-based burgers. They report that consumers would switch when the alternative had a price one-third lower than the original meat on average. Finally, Katare *et al.* (2023) compare the willingness to pay for farm raised beef and plant-based meat substitutes using an auction, finding a lower willingness to pay for the latter. In summary, the literature indicates that consumers receive a lower utility from meat substitutes than from meat products.

Despite the lower utility of meat substitutes and the lower indicated willingness to pay for meat substitutes Zhao *et al.* (2022) report a higher per unit price for meat substitutes than for meat products based on a scanner data sample from the United States. Hence, the prices are perceived by consumers as expensive and too high (Kerslake, Kemper and Conroy, 2022; Weinrich, 2018). Consequently, there is a barrier for consumers to adopt meat substitutes. However, no study exists for the European or German meat substitute market that compares the market prices of meat and meat substitutes.

An exception is the study by Katare *et al.* (2023) which uses an auction mechanism, while most previous studies use stated preference methods to determine the willingness to pay for the products and their respective attributes. These stated preference methods, however, have the disadvantage of hypothetical bias, resulting in the overestimation of the willingness to pay for products and product-attributes (Huffman and McCluskey, 2017). While stated-preference methods are necessary when introducing new products, in more mature market it is possible to adopt revealed preference methods (Huffman and McCluskey, 2017). Revealed preference methods based on the hedonic pricing models can estimate the prices of products and their attributes based on data revealed by consumers, that is, scanner data on a greater number of product attributes (Costanigro and McCluskey, 2011). Hence, the first article (Chapter 2) aims at filling this research gap and by identifying the factors related to higher or lower prices in the meat and meat substitute market using a revealed preference method and a sample of product-price combinations from the German market.

The traditional hedonic pricing model, however, has the limitation of assuming perfect information in the market (Costanigro and McCluskey, 2011). In this model, the consumers are assumed to have full information about each product in the market and can therefore buy according to their known preferences. Additionally, the producer has full information about the consumers and their willingness to pay. However, real market situations are far from perfect information. Hence, Polachek and Yoon (1987) introduced the two tier stochastic frontier that considers imperfect information in the market. This was later incorporated into the hedonic pricing model and then applied to the housing market by Kumbhakar and Parmeter (2010) and the market for yogurt by Bonanno *et al.* (2019). Hence, to account for information asymmetry in the meat and meat substitute market, the first article (Chapter 2) employs a hedonic pricing model that considers the effects of information asymmetry on the prices.

1.3.2 Nutritional and health aspects of meat and meat substitute consumption

In general, meat is a good source of high-quality protein and an important supplier of micronutrients, like iron or zinc (Pereira and Vicente, 2013). The current meat overconsumption in high-income countries, however, is not only related to negative external effects on the environment (Springmann *et al.*, 2016) but red meat and processed meat consumption is linked to detrimental health effects especially non-communicable diseases (NCDs) such as diabetes or colorectal cancer (Godfray *et al.*, 2018; Wolk, 2017; O'Sullivan *et al.*, 2013). This also raises public-health costs (Springmann, Mason-D'Croz *et al.*, 2018). Hence, the dietary guidelines in most European countries and the World Cancer Research Foundation recommend a limited intake of meat and even less of processed meats. (Cocking *et al.*, 2020). The World Cancer Research Foundation recommends an intake of less than 350-500 grams of red and processed meat per week (World Cancer Research Fund, 2018). However, the mean intake of meat in Europe ranges from 93-233 grams per day in adults (Cocking *et al.*, 2020). The European Commission reports an intake of beef, pork and sheep meat in the EU of 850 grams per week on average (EC, 2021), which is larger than the recommended amount by the World Cancer Research Foundation.

The overconsumption of processed meats, such as ham or salami, is also associated with an intake of nutrients, mainly, salt, saturated fats and energy dense foods that should be consumed in limited quantity (Inguglia *et al.*, 2017; O'Sullivan *et al.*, 2013). The nutrients to limit are summarized in the Ofcom's A-score as a combination of energy-density, sugar, saturated fat and salt per 100g of product weight (Ofcom, 2009). Sodium and chloride as the basis of dietary salt are an essential part of the human body's fluid system (Gibson, Armstrong and McIlveen, 2000). However, the overconsumption of salt is related to cardiovascular diseases (CVDs) (He and MacGregor, 2018). While the World Health Organization (WHO) recommends a limit of 5 grams of salt per day for adults (WHO, 2012) the average intake in Europe ranges from 8 to 12 grams (European Commission, 2012). The overconsumption of energy dense foods, like processed meats, is related to obesity and in turn to NCDs (Vandevijvere *et al.*, 2015; Vernarelli *et al.*, 2018; Gortmaker *et al.*, 2011). Additionally, fat is the major supplier of energy in meat products (Valsta, Tapanainen and Männistö, 2005). The WHO recommends an intake of less than 30% of the necessary energy from fat and less than 10% of the total energy from saturated fats (WHO, 2022), as saturated fats, from meat are related to CVDs (O'Sullivan *et al.*, 2013). However, the actual intake of saturated fats in Europe ranges from 8.9% to 15.5% of the total energy and is thus mostly higher than the recommendation of the WHO (Eilander, Harika and

Zock, 2015). Meat is one of the major sources for saturated fats (Eilander, Harika and Zock, 2015). The reduction of saturated fats by replacing them with unsaturated or polyunsaturated fats, e.g. from vegetables, reduces the risk for cardiovascular diseases (Sacks *et al.*, 2017). From a public health perspective, substituting meat for (plant-based) meat substitutes could have benefits if the meat substitutes were nutritionally beneficial.

Recently, however, there is a growing criticism on the rising consumption of ultra-processed products (Hall *et al.*, 2019). Following Monteiro, Cannon *et al.* (2018), foods can be classified in the NOVA classification scheme into four distinct product groups: 1.Unprocessed or minimally processed foods, 2. processed culinary ingredients, 3. processed foods and 4. ultra-processed foods. The first group contains products that are only processed in a way to preserve and prepare natural foods for storage and cooking. The second group is products that contain further ingredients to the foods of group 1 such as oils, salt, and other substances with the purpose of increasing the durability and improving the taste. Processed foods such as canned fruits or cheese contain a variety of ingredients and are processed in a way to increase the taste and improve the durability of foods, originally classified in group one. Finally, group four encompasses products that contain a variety of ingredients that are already highly processed like soya protein isolate, are processed in a way that is usually not done for home cooking, like hydrolyzation or extrusion. These products are meant to be convenient foods (Monteiro, Cannon *et al.*, 2018). Hence, according to the schema, meat substitutes are classified as ultra-processed foods and are thus considered unhealthy (Wickramasinghe *et al.*, 2021).

One study for the New Zealand market found that most packaged foods in the domestic market were ultra-processed foods and had a worse nutritional composition than less processed foods (Luiten *et al.*, 2016). However, a contradictory study for products available in the United Kingdom found no such relationship and highlights that it is important to consider the individual nutrients (Derbyshire, 2019). Still, ultra-processed foods are to larger extent included in modern European diets and are associated with excessive energy consumption and thus obesity as well (Monteiro, Moubarac *et al.*, 2018; Hall *et al.*, 2019). A French study based on 21,212 participants found that vegans and vegetarians had a higher intake of ultra-processed foods in diets in comparison to omnivores (Gehring *et al.*, 2021). Given the ultra-processed product nature of meat substitutes, it is necessary to understand whether meat substitutes can provide nutritional benefits compared to meat products to improve public health recommendations. Further, it is important for consumers who want to eat nutritionally adequate—and who thus avoid ultra-processed products—to know whether meat substitutes can be beneficial. Therefore, the second article (Chapter 3) analyzes the nutritional composition of meat substitutes based on the aggregated Ofcom score, which summarizes the nutrients to limit, and the third article compares the nutrient composition of meat and meat substitute products in five European countries based on individual nutrients considering homogeneous meat product subgroups (Chapter 4).

There is a second concern of consumers regarding the healthiness of meat substitutes besides the ultra-processed product nature. A study based on 534 consumers from the German speaking areas of Switzerland indicates that consumers evaluate meat substitutes as less environmentally friendly, less healthy and less natural when compared to traditional meat products (Hartmann, Furtwaengler and Siegrist, 2022). In that respect, Siegrist and Sütterlin (2017) highlight the influencing factor of food additives on the perception of the naturalness of the products. Additionally, consumers consider products that are perceived as natural to be more healthy (Siegrist and Hartmann, 2020). Hence, a high usage of food additives would impose a further barrier for consumers. Therefore, the second article of this thesis does not only analyze and compare the nutritional composition of meat and meat substitutes but also compares the usage of food additives (Chapter 3).

1.3.3 Extrinsic product attributes in the meat and meat substitute market

Product attributes, as described in Chapter 1.1, can be grouped into search, experience and credence attributes (Nelson, 1970, 1974; Darby and Karni, 1973). The product attributes related to the sustainability or healthiness of the products, which are relevant for consumers in their purchase decision, are extrinsic and thus credence attributes attributes. Despite being extrinsic product attributes, their labelling on product’s packaging can influence how consumers perceive the quality, sustainability, or healthiness and thus the utility of the products. There are numerous studies analyzing the willingness to pay of consumers for certain product attributes (Katt and Meixner, 2020). In a meta-analysis, Li and Kallas (2021) summarize the willingness to pay of consumers for sustainability related product attributes in livestock products, finding in the literature a hypothetical bias in the estimates for the willingness to pay for sustainability attributes. A way to reduce the hypothetical bias is to use revealed preference data instead of stated preference methods (Huffman and McCluskey, 2017). No previous study has applied a hedonic pricing model, in other words, a model in which prices can be described by the willingness to pay for a given combination of product attributes (Rosen, 1974), to meat and meat substitute products to determine how the credence attribute labeling influences the prices. Hence, the first study in Chapter 2 includes a hedonic pricing model to determine the underlying relationships between credence attributes and product prices in the meat and meat substitute market.

Despite the advantages of the hedonic pricing model in determining the implicit prices for product attributes, it assumes perfect information between the seller (producer) and the buyer (consumer) on the product quality and on the willingness to pay (Polachek and Yoon, 1987). However, there is asymmetric information on product attributes in the food market (Unnevehr *et al.*, 2010) and thus likely in the meat and meat substitute markets. The two-tier stochastic frontier approach allows to account for information asymmetry in a hedonic pricing model (Kumbhakar and Parmeter, 2010) and was first applied to the food market by Bonanno *et al.* (2019). Thus, to account for the potential effect that asymmetric information between consumers and producers about the product quality has on the price, the first study employs the hedonic pricing model with the stochastic frontier.

In the food market, labels and claims on product packaging often relate to the healthiness of products. From that perspective, André, Chandon and Haws (2019) developed a model to cluster product labels into four distinct groups that indicate the healthiness of the products. These labels and claims can be separated into two dimensions, first the natural–scientific dimension and second the presence–absence dimension (André, Chandon and Haws, 2019). The idea is that consumers can perceive attributes to occur or be added naturally, which makes the individual products healthier, or whether there is scientific evidence that the attribute is healthier or not (André, Chandon and Haws, 2019). According to André, Chandon and Haws (2019), this leads to four distinct combinations, illustrated in Figure 1-9:

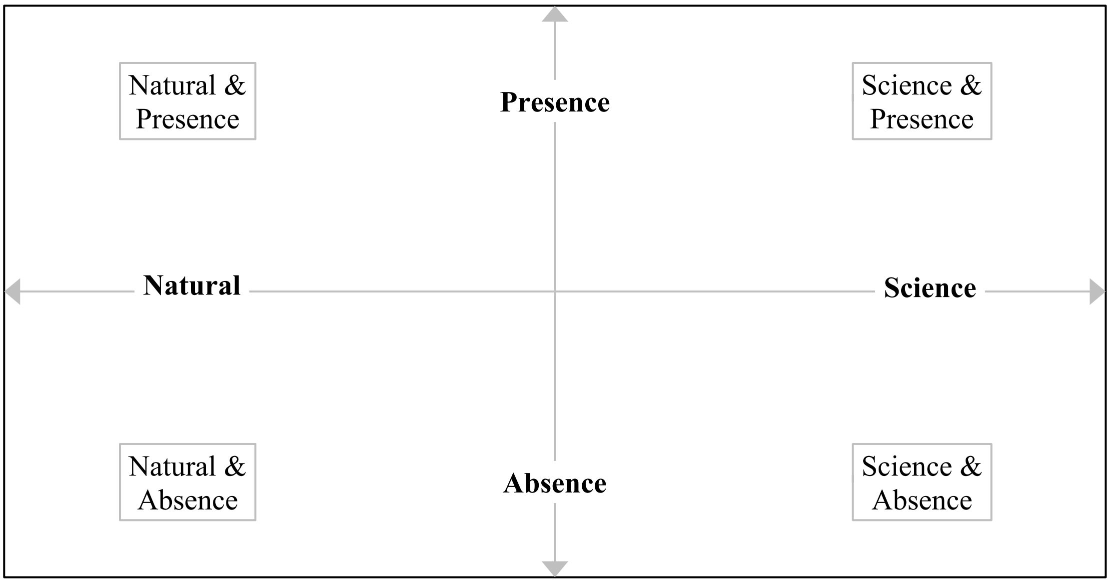

Figure 1-9 - Dimensions of healthiness labelling.
Source: André, Chandon and Haws (2019: 176, Figure 1).

A product label can indicate that the product is healthier using a natural and absence focus, such as foods without flavor enhancers. Here, the perspective is that the flavor enhancer is something unnatural that is not added to the product. Therefore, it is healthier than a product that contains flavor enhancers. The second combination is a natural and presence focus, like an organic claim. Here, the idea is that consumers perceive the production method of organic farming as more natural than the conventional method and further assume that such a product is healthier than a conventional product. The third combination is the scientific and absence focus, like products reduced in fat. In this, the product label considers an attribute like fat, which based on scientific evidence is associated with negative effects on health if overconsumed; the absence or reduced amount makes the product healthier. Finally, the fourth combination is the science and presence focus, like fiber content. The label aims again at the idea that some attribute, like fiber, is scientifically found to be healthier, and hence, the presence makes the overall product healthier. (André, Chandon and Haws, 2019)

Regulation No. 1924/2006 on nutrition and health claims in the European Union regulates, which products are allowed to bear claims and, which are allowed to directly target at the healthiness of the products, like “high in protein” or “low-fat” (European Parliament & European Council, 2006). However, product attributes that are not originally targeted at healthiness, like the organic production method, are by some consumers perceived to influence the healthiness of the products (Fernan, Schuldt and Niederdeppe, 2018; Schuldt and Schwarz, 2010). Though these kinds of claims are found to influence consumers in the decision-making process they are not always related to healthier products per se. The study of Schuldt and Schwarz (2010) demonstrated that consumers perceive organically produced foods as less caloric than conventionally produced meat, even though there are no differences in the calories per 100g. Hence, from a public health and consumer perspective it is necessary to understand whether these labels are related to healthier products and can help consumers in the market to identify healthier product choices. Hence, the second paper of this dissertation (Chapter 3) analyzes the relationship of these claims with the overall nutritional quality of the products, using a sample from the German meat and meat substitute markets.

1.3.4 Consumer characteristics, political opinions, and meat-substitute consumption

Consumers have different tastes and heterogeneous preferences for product attributes, but despite their individuality, they can be segmented into clusters with more homogeneous preferences (McFadden, 1986). Considering this allows for directed marketing targeted towards consumer subgroups. Hence, when examining factors related to the consumption and adoption of meat and meat substitutes, it is important to consider the individual segments and consumer groups that may be related to varying levels of acceptance, adoption, and consumption. On a more general level, several studies from the food market analyze the differences in utility levels, preferences, and involvement in meat consumption. In the case of meat, several studies have investigated different involvement levels by consumer segments (Verbeke and Vackier, 2004), preferences for meat product attributes and how they differ between consumer segments (Koistinen *et al.*, 2013; Peschel and Grebitus, 2023), and the differences in preferences by consumer segments for product attributes (Apostolidis and McLeay, 2019, 2016). In this regard, there are factors such as young age, high education, and income that likely explain meat substitute consumption (Onwezen *et al.*, 2021).

However, individuals' social environments are often not considered in the studies analyzing the demand for meat substitutes. In that respect, Jost (2017) highlights the relevance of the political identities of consumers in explaining different consumption patterns. A straightforward interpretation is to cluster beliefs into liberal/left and conservative/right views. For the case of plant-based milk, Wolf, Malone and McFadden (2020) demonstrate that those households that are more liberal are also more likely to consume plant-based milk, based on a study with 995 participants from the US. On the other hand, the study by Li *et al.* (2023) showed no relationship between political beliefs and the purchase intention of plant-based meat substitutes.

Additionally, Marcus, Klink-Lehmann and Hartmann (2022) found that consumers' reported environmental and animal welfare concerns did not explain attitudes toward meat substitutes and behavioral intention to consume meat substitutes. Considering the potential benefits of meat substitutes, the low acceptance of meat substitutes, and the inconclusive results on factors related to the consumption of meat substitutes, the fourth study (Chapter 5) aims to identify consumer characteristics related to the consumption of meat substitutes in Germany. This involves investigating whether sustainable consumption can be explained by political beliefs as manifested in voting behavior for liberal or conservative parties or by voting for strong climate protection measures.

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2 Meat and Meat Substitutes - A Hedonic-Pricing Model for the German Market

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Thies Petersen had the original idea for the research, developed the research objectives, defined the methodology, created and analyzed the data, and wrote the first manuscript. Milan Tatic provided assistance in creating the data set as well as developing the research objectives and revising the manuscript. Monika Hartmann and Stefan Hirsch provided supervisory support in developing the research objectives, methodology, and writing the final manuscript.

Abstract:

In this study, a hedonic pricing model with a stochastic frontier is applied to a sample of 183,717 observations of product sales of sausages in Germany to determine the valuation of attributes in the market. The average price of sausages is €1.14/100g, with meat substitutes valued at €1.53/100g and meat sausages at €1.01/100g. Our results show that credence attributes can induce a price premium, but that the effect strongly depends on the type of attribute. This may be important for deriving marketing strategies, as uniform measures may not be effective for both markets.

Keywords:

Hedonic-pricing; meat; meat substitutes; credence attribute

2.1 Introduction

Meat is a traditional part of the German diet, with an annual per capita consumption of 55 kg in 2021 (LfL & LEL, 2022), with sausages being a product with a particular cultural component. While meat is a rich source of, for example, high-quality protein, it also contains high levels of saturated fat and salt, and thus nutrients whose intake should be limited (Petersen, Hartmann and Hirsch, 2021). In addition, excessive consumption of red and especially processed meat, such as sausages, has been linked to adverse health conditions, including an increased risk of cancer (Bouvard *et al.*, 2015; Godfray *et al.*, 2018). Moreover, a meat-rich diet has been criticized for its negative impact on the environment (Willits-Smith *et al.*, 2020) and the animal welfare conditions in husbandry systems are also criticized (Birkle, Klink-Lehmann and Hartmann, 2022).

In response to these concerns, a new market has emerged: the meat substitute market. Although meat substitutes can be characterized by a beneficial nutritional profile (Petersen, Hartmann and Hirsch, 2021), they are considered artificial and unhealthy due to their ultra-processed nature (Wickramasinghe *et al.*, 2021). In addition, consumers have high expectations of meat substitutes, as they are expected to resemble meat in terms of taste and texture (Michel, Hartmann and Siegrist, 2021). Therefore, the consumption of these products, although increasing, is still limited. In the German meat market, meat substitutes accounted for only 0.9% of total sales in 2020 (Zandt, 2022). Recent results from the U.S. also show that the market share of meat substitutes is rather low and unit prices are high compared to those of meat-based counterparts (Zhao *et al.*, 2022). Since price is one of the most important factors influencing consumer purchasing decisions (Lusk and Briggeman, 2009; Carlsson, Kataria and Lampi, 2022; Onwezen *et al.*, 2021), higher prices have been identified as an important barrier to consumer acceptance of meat substitutes (Elzerman, van Boekel and Luning, 2013; Apostolidis and McLeay, 2019; Clark and Bogdan, 2019; Blanco-Gutiérrez, Varela-Ortega and Manners, 2020; Kerslake, Kemper and Conroy, 2022). However, the factors that influence the market prices of meat and meat substitutes are not sufficiently understood. Therefore, the objective of this study is to investigate the product- and process-based attributes that influence the market prices of meat and meat substitutes.

Previous studies on consumer choices for meat and meat substitute products mostly analyze consumers' Willingness-to-Pay (WTP) using stated preference methods such as choice experiments. Araújo *et al.* (2022) highlight in a review the relevance of credence attributes such as sustainability (e.g., organic), regional origin, traditional production methods, or health benefits in consumers' meat choices. Studies that also include meat substitutes focus on product characteristics, e.g. main ingredients (e.g. Apostolidis and McLeay, 2016, 2019; Carlsson, Kataria and Lampi, 2022) or WTP for product's credence attributes, such as the region of origin or carbon footprint (Apostolidis and McLeay, 2016, 2019). A recent study on the US meat market combines a sensory experiment with a choice experiment, finding the taste to be an essential predictor of preference (Caputo, Sogari and van Loo, 2023). Findings from stated-preference methods, however, depend on the setting, may have the limitation that they suffer from hypothetical bias and potential overestimation of the WTP for attributes (Murphy *et al.*, 2005).

In addition to stated preference approaches, revealed preference techniques have been widely applied to study price premiums for product and process attributes in different food markets. Bimbo, Bonanno and Viscecchia (2016) apply a hedonic pricing model to the Italian yogurt market to evaluate the extent to which health claims contribute to product prices. Their results show that price premiums differ depending on the type of claim. While the hedonic pricing model has generally been applied to various food products such as eggs (Karipidis *et al.*, 2015), honey (Ballco, Jaafer and Magistris, 2022) or alternative dairy beverages (Yang and Dharmasena, 2020), there exist few studies for the meat market and, none, that considers the market for meat and meat substitutes. Ribeiro, Gschwandter and Revoredo-Giha (2019) apply a hedonic pricing model to chicken purchase scanner data and find that UK consumers are willing to pay a 135% or £6.36/kg premium for organic. Staudigel and Trubnikov (2022) apply a hedonic pricing model to data from the German meat market. The authors show that consumers' valuation for the products differs by the distribution channels, meat type, product type and production method. Regarding the latter, they find significant variations in price premiums for organic products, e.g. depending on the meat type (Staudigel and Trubnikov, 2022).

In market situations where the quality of the product is unclear, for example, if the producer has more information about the product's characteristics than the consumer, asymmetric information exists (Unnevehr *et al.*, 2010). Asymmetric information can lead to market prices that are lower than the hedonic price from the producer's perspective and higher than the hedonic price from the consumer's perspective (Kumbhakar and Parmeter, 2010). The empirical approach to considering market asymmetry was initially introduced by Polachek and Yoon (1987) and applied to situations in the labor market. More recently, Bonanno *et al.* (2019) have applied the hedonic pricing approach with the stochastic frontier to the Italian yogurt market.

In emerging markets like the market for meat substitutes, information asymmetries between consumers and producers are likely of special relevance, for example, in the assessment of the healthiness of the products (Siegrist and Hartmann, 2023). Hence, by applying a hedonic pricing model that considers information asymmetry, we add to the literature by providing novel evidence on the valuation of main ingredients, credence attributes, and nutritional facts for the meat and meat substitute market under consideration of information asymmetry between consumers and producers.

The main objectives of this study are to (1) gain a better understanding of the drivers of price heterogeneity in the meat and meat substitutes market, (2) test the relevance of communicating information about credence attributes as a competitive strategy to secure a price premium, and (3) investigate similarities and differences between the meat and meat substitutes markets. In doing so, the study makes two contributions to the literature: (i) we apply a hedonic-pricing model to the branded meat and meat substitutes market to investigate the factors that influence the market valuations of the products, (ii) we use a novel approach in hedonic price modeling, the two-tier stochastic frontier method that allows considering information asymmetry between consumers and producers. Our findings are of relevance to both market researchers and food manufacturers. For the former, as our results reveal differences in prices that are associated with product attributes, for the latter as they indicate how food manufacturers can achieve prices closer to the hedonic price by labeling credence attributes. Sausages were selected as the study object because they are consumed in large quantities in Germany (DFV, 2022). In addition, sausages are ideal for comparing the market for meat and meat substitutes due to the similarity of the products in appearance and intended use.

The rest of the paper is structured as follows. First, we introduce the theoretical and empirical framework. Next, we provide information on the data used and the estimation process, followed by the presentation and discussion of the results. In the last section, conclusions are drawn.

2.2 Theoretical and empirical framework

Products in the market can be described as combinations of an attribute vector z. When making purchasing choices, consumers search for products with a combination of attributes that, according to their preferences, maximize their total utility (Lancaster, 1966). Two main empirical ways exist to determine the resulting valuations reflected in the implicit prices for the product attributes (McCluskey and Winfree, 2022). On the one hand, stated-preference approaches like choice experiments or contingent valuation methods; on the other hand, revealed preference approaches, like experimental auctions or hedonic pricing models (McCluskey and Winfree, 2022). Using revealed preference methods allows to go beyond the potential hypothetical bias of stated-preference methods. The Hedonic pricing model, also allows for comparing a larger number of product attributes as surveys are limited by the cognitive overload of participants (Chernev, Böckenholt and Goodman, 2015). Contrary to stated preference methods, the hedonic pricing model is advantageous to investigate market valuations and price premiums in highly differentiated and heterogenous markets, like the food market in general and the sausage market, specifically (Costanigro and McCluskey, 2011).

The hedonic pricing model, as developed by Rosen (1974), can be specified as follows:

$$P_h = h(z) + v \quad (1)$$

The hedonic price P_h can be described as a function of the vector of product characteristics (z) – representing all relevant attributes of the buyer's value function and seller's offer function – and a random error v. Hence, the model in (1) allows for determining the market valuations (implicit prices) for certain product characteristics z.

However, in a market situation such as the food market, there can be asymmetric information about the quality of products, especially regarding credence attributes (Unnevehr *et al.*, 2010). Thus, there is a market situation where the producer/seller has more information about the products than the consumer (Golan *et al.*, 2001). An example of asymmetric information is the healthiness of meat substitutes, which are classified as unhealthy by consumers based on the heuristic that ultra-processed foods are generally unhealthy despite the more favorable nutritional composition of meat substitutes relative to processed meat products (Siegrist and Hartmann, 2023; Petersen, Hartmann and Hirsch, 2021).

Asymmetry of information can, according to Polachek and Yoon (1987) and Kumbhakar and Parmeter (2010) lead to a deviation from the price in (1) leading to a market price P_m^s for the seller of:

$$P_m^s = P_b - u \quad (2)$$

Similarly, the buyer's market price P_m^b is defined as:

$$P_m^b = P_s + w \quad (3)$$

Where P_b is consumers' maximum willingness to pay for a product and P_s is the sellers' lowest willingness to accept, u represents the penalty or costs to the seller of not being able to reach consumers with the highest WTP for a product with a particular set of attributes (Bonanno *et al.*, 2019), while w is the additional cost to the buyer for being uninformed. It is assumed that both u and w are greater than or equal to 0. Therefore, the market price equation P_m can be rewritten as follows:

$$P_s + w = P_m = P_b - u \tag{4}$$

Which leads to:

$$P_s + u = P_m + u - w = P_b - w \tag{5}$$

Combining this with the hedonic pricing function in (1) leads to:

$$P_m + u - w = h(z) + v \;\; => P_m = h(z) + v - u + w \tag{6}$$

Therefore, the price of a good in a market, P_m, can be described as a function of the vector of product characteristics and their influence on the price, a random error v, and the costs for being uninformed u and w for sellers and buyers, respectively. With perfect information w = 0 and u = 0 or with $w - u = 0$, the price should equal the hedonic price (Kumbhakar and Parmeter, 2010). The components v, u and w can be combined into a single error term ε:

$$P_m = h(z) + v - u + w = h(z) + \varepsilon \tag{7}$$

In their original work, Kumbhakar and Parmeter (2010) apply their approach to the housing market and empirically test which characteristics affect house prices (e.g., size), and which buyer/seller characteristics (e.g., education and gender) influence the deviation from the optimal price. Bonanno *et al.* (2019) apply the model to the Italian yogurt market to test whether producers are able to reduce the information asymmetry for consumers and hence achieve higher prices based on credence attribute labels. In doing so, they assume that w equals 0, meaning that only the loss that a seller may incur for not being able to target those consumers with the highest WTP is considered. In our study, we follow this approach. Verteramo Chiu, Tauer and Gröhn (2022) use the approach to model the price efficiency of livestock in the non-dairy cattle market in Canandaigua, New York.

2.3 Data and econometrical implementation

2.3.1 Data sources

To estimate the price premiums associated with product characteristics in the German sausage market, we use a hedonic pricing model that also accounts for the effects of information asymmetry. As the base for the estimation, we compiled a comprehensive data set on product prices and respective attributes. Sales data are from the IRI database (IRI, 2023) that includes information on products sold, points-of-sale (two-digit zip code level), anonymous store id, prices (per 100g) and discounts. The data are available on a weekly basis, but were aggregated to a monthly level, using the European Article Number (EAN), the barcode that uniquely identifies each individual product. The EAN barcode-level price data were combined with the respective product-related attributes obtained from Mintel's Global New Product Database (Mintel, 2023), producers' websites, and other sources such as 'openfoodfacts.com'. The product data were coded by two authors of this paper and six student assistants and then cross-checked. The coding included a set of 89 different product attributes ranging from the main ingredients and nutritional facts to packaging and credence attribute labeling. To adequately code the product, it was necessary to have images of all sides of the packaging. If those images could not be obtained, the products could not be considered in the analysis. For the retail brands, the barcodes are not included in the IRI database for confidentiality reasons, so they cannot be identified. Therefore, they also had to be removed from the analysis.

The final data set covers two years, i.e., 24 months, from the first month of 2020 to the last month of 2021, and includes 183,717 product-price observations, which account for a sales value of 103.3 million Euro. Note that the sales volume of retail brands that were not included is 115 million Euro (49.8%) while the sales volume of products excluded due to missing information is 13 million Euro (5.5%). Hence, the final sales volume of the products included represents 44.7% of the total sales volume in the initial dataset and 89% of the branded products available.

2.3.2 Empirical implementation and variables

Our empirical model is based on the hedonic pricing model revealed in equation (7) and allows us to estimate the influence of a large number of product characteristics on the price while considering the effect of information asymmetry on the price. The model includes the following five vectors: $Z^{MI}, Z^{NF}, Z^{CA}, Z^{PA}$and Z^{MC}. In line with previous literature on price differences in the meat market (Staudigel and Trubnikov, 2022), we include a vector Main Ingredients Z^{MI}

that contains s=1,..,S different main ingredients. In the case of meat, we distinguish between pork-based, beef-based, pork-beef-based, poultry-based, and other meat-based products, which may be, for example, a combination of pork and turkey. For meat substitutes (MS), we differentiate between egg-based, soy-based, wheat-based, pea-based and other/multi-ingredient-based products, which can be, for example, a combination of soy and eggs or mushrooms only.

Z^{NF} is a vector of f=1,…,F different nutritional values. The vector contains information about the protein content in g/100g and thus enables to estimate the market valuation of protein in the sausage market. In addition, Z^{NF} takes into account the negative points from the Ofcom-score[5], the so-called A-Score, which includes saturated fat, salt, sugar and energy content. The higher the A-Score, the more nutrients to limit in the product (Poon *et al.*, 2018). Products that receive a lower A-score are considered healthier and can therefore be expected to achieve a price premium.

Z^{CA} is a vector of a=1,…,A different dummy variables covering the presence of credence attribute labels related to product and process attributes of the sausages. André, Chandon and Haws (2019) argue that some labels target product healthiness through the presence or absence of certain attributes associated with either a scientific or a natural aspect. We follow their categorization of labels and include the following four dummy variables: i) *Natural & Presence* for products labeled, for example, as fresh, ii) *Natural & Absence* for products labeled as, for example, without flavor enhancers. iii) *Science & Presence* for products labeled, for example, as being high in protein, and iv) *Science & Absence* for products labeled as, for example, being low in fat. Organic is included in the *Natural & Presence* category in the study of André, Chandon and Haws (2019). However, we consider organic as a separate variable because of its high relevance in the market. It also allows us to compare our results with previous studies that have exclusively investigated the impact of the credence attribute "organic" on the price (Staudigel and Trubnikov, 2022). Z^{CA} also includes information on whether a product is gluten- or lactose-free, which is captured by dummy variables. Since the criticism of meat also includes the sustainability dimension, we include as a dummy variable whether a product carries a label on the general topic of sustainability, recycling, or renewable energy. In addition, we capture the topic of animal welfare with a dummy variable equal to one if the product has a corresponding label. This includes products that, for example, carry a label from an animal

[5] The Ofcom-score is a well-known nutritional profile. As such it categorizes foods according to their nutritional composition (Scarborough, Rayner and Stockley , 2007, p.330)

welfare initiative or have a reference to the husbandry conditions. For meat sausages, we include four additional dummy variables in Z^{CA}, which were found to be relevant only for the meat market: We include two regional dummy variables, one of which captures whether there is a specific reference to the origin of the product, such as a claim that the sausage is a special product from the city of Frankfurt. The other regional variable captures certified regional products with the EU label protected geographical indication (PGI). An example of this would be the "Thüringer" sausage. Furthermore, we include two dummies for labeling related to the product's quality (e.g. the label for superior product quality from the German agricultural society (DLG)) and for referring to tradition (e.g. since 1908).

Z^{PA} is a vector of dummies controlling for k=1,…,K other product attributes. It contains a dummy for the type of sausage, i.e., whether it is primarily for roasting or whether it is primarily for cooking and/or direct consumption. It also includes a dummy capturing whether the product belongs to a national brand. Here, we define a national brand if its products are sold in at least 80 of the 95 German two-digit postal code areas. In addition, the vector contains dummy variables for the packaging material: plastic, can, glass, and the combination of plastic and paper. Finally, Z^{PA} also contains information on the weight of the product in 100g to capture the effect of packaging size.

Finally, Z^{MC} is a vector with information about r=1,…,R different retail and sales characteristics. It contains three dummies for the type of store where the price was observed, i.e., discounter, supermarket and hypermarket. The vector also includes information on whether a product was sold under a discount in the given period. The corresponding dummy is equal to one if within the respective month, the price is at least once 20% lower than in the previous week. Finally, we include market and time-fixed effects B_m and G_t, respectively. The full list of variable definitions can be found in Table A.1 in the Appendix.

The final model is defined as follows:

$$P_{imt} = \beta_0 + \sum^{S} Z^{MI}_{smt}\beta_s + \sum^{F} Z^{NF}_{fmt}\beta_f + \sum^{A} Z^{CA}_{amt}\beta_a + \sum^{K} Z^{PA}_{kmt}\beta_k + \sum^{R} Z^{MC}_{rmt}\beta_r + \sum^{T} G_t\beta_t + \sum^{M} B_m\beta_m + \varepsilon_{imt} \quad (8)$$

Whereby P_{imt} reflects the observed market price of product i in market m at time t. $\varepsilon_{imt} = v_{imt} - u_{imt} + w_{imt}$.

Estimation

For the estimation of the hedonic pricing model defined by (8), we assume that $w = 0$, similar to Bonanno *et al.* (2019). Therefore, in our analysis, we focus on the cost that a seller may incur for not being able to target those consumers with the highest WTP and attempt to explain these costs by seller characteristics. The stochastic frontier model can be estimated using maximum likelihood estimation with the following distributional assumptions for the error term (Kumbhakar and Parmeter, 2010):

$$v_i \sim i.i.d.N(0, \sigma_v^2\ ), \tag{10}$$

$$u_i \sim i.i.d.N^+(0, \sigma_u^2) \tag{11}$$

To account for the heterogeneity in the costs of incomplete information, u_i can be described by a vector of exogenous variables. Consequently, σ_u can be described as a function of the seller's characteristics Z^U (Kumbhakar and Parmeter, 2010).

$$\sigma_u = e^{\psi_u{}' Z^U} \tag{12}$$

We assume that the information deficit and the corresponding loss that a seller may incur for not being able to target those consumers with the highest WTP can be reduced by credence attribute labels. We, therefore, attempt to explain the variance in u_i by the number of different credence attributes on a given product:

$$\sigma_u^2 = \exp\left(\psi_0 + \psi_{NCA} * Number\ of\ Credence\ Label\right) \tag{13}$$

The corresponding likelihood function can be written as (Bonanno *et al.*, 2019):

$$L = \prod_i \prod_m \prod_t \frac{2}{\sigma} \phi\left(\frac{\varepsilon_{\text{jmt}}}{\sigma}\right) \Phi\left(\delta \frac{\varepsilon_{\text{jmt}}}{\sigma}\right) \tag{14}$$

where, $\sigma = \sigma_u^2 + \sigma_v^2$; $\delta = \frac{\sigma_u}{\sigma_v}$ and $\phi\ and\ \Phi$ are the standard normal pdf and CDF, respectively (Bonanno *et al.*, 2019). We estimate equation (14) separately for meat and meat substitute sausages.

2.4 Results

2.4.1 Descriptive statistics of the sample

Figure 1 presents the kernel density estimates of the prices of meat sausages, meat substitute sausages, and the combined sausage market. The average price of sausages in the German meat market is 1.14 €/100g. From the distributions, it can be observed that prices of meat substitute sausages are, on average, significantly higher (1.53€/100g, p<0.001) than that of meat sausages (1.01€/100g). However, there is overlap, showing that the low-priced meat substitute sausages are in the range of high-priced meat sausages.

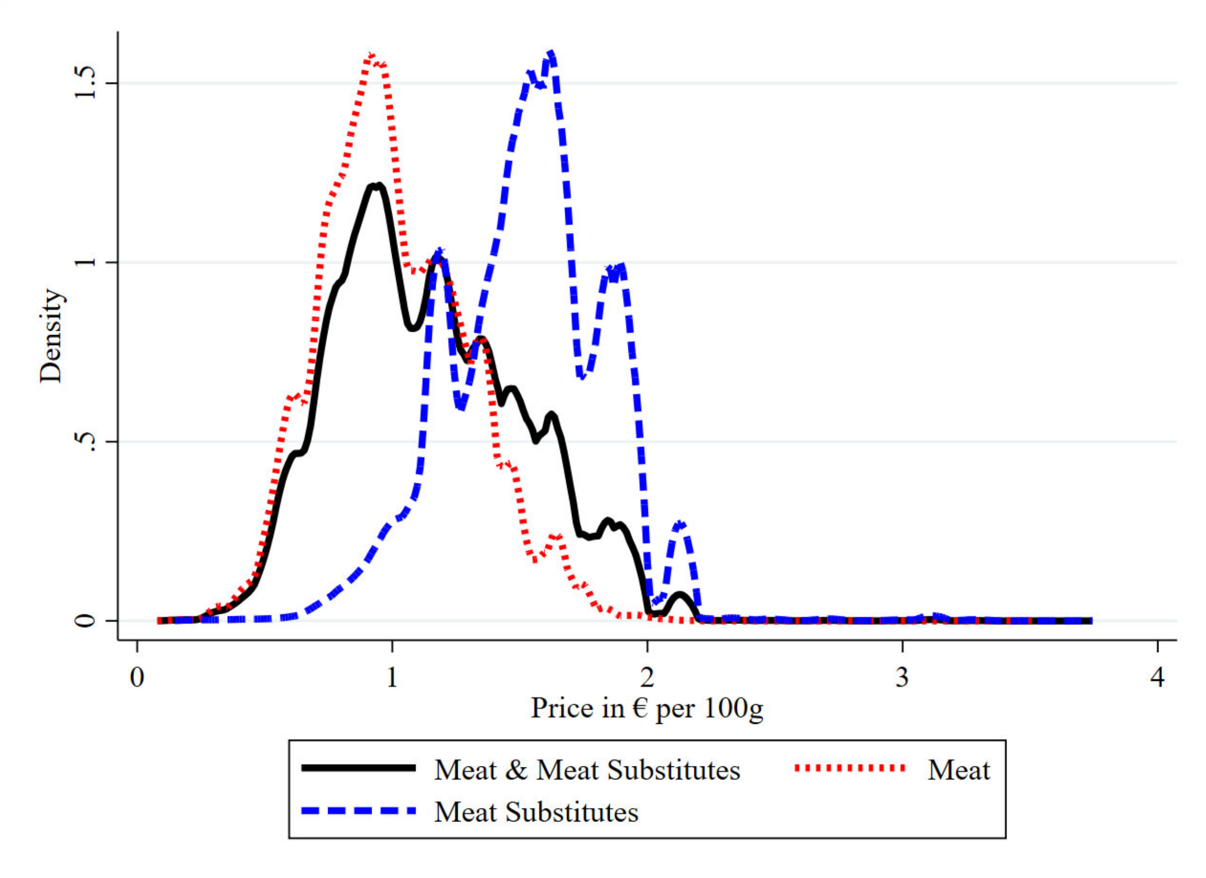

Figure 2-1 - Kernal density estimates of the price in €/100g

Note: The kernel function used to estimate the kernel density is the Epanechnikov kernel.

Sample descriptive statistics are shown in Table 1. Regarding ingredients, the substitute sausages are mainly soy-based (38%) or based on other ingredients or multiple ingredients (32%), highlighting the predominant role of soy as an ingredient in the meat substitute market. Pork is a dominant ingredient in the German meat sausage market (67.3%), followed at a considerable distance by poultry (21%) and the mix of pork & beef (7%).

Most credence attribute labels that are related to the product's healthiness (Nature & Presence, Science & Absence, No gluten, and Science & Presence) are more frequently observed on meat substitute sausages than on meat sausages. However, the opposite holds for health-related claims related to Nature & Absence (e.g., 'without flavor enhancers') and products being lactose-free. 18.7% of meat substitute sausages are labeled organic, while only 5% of meat sausages are labeled organic. It can also be observed that more than three-quarters of meat substitute products are labeled with "Science & Presence" (e.g., 'High in protein'). Animal welfare claims and sustainability labels are also more common on meat substitute sausages than on meat sausages. Labels related to the Origin, Tradition and Quality of the products are used only on meat products and are found on about 20% of meat sausage products. Meat substitutes have a significantly lower A-score on average ($p<0.001$) and thus contain less of the unfavorable nutrients energy, salt (sodium), saturated fat and sugar. In addition, the protein content of meat substitutes is significantly higher ($p<0.001$) at 16.4g/100g compared to 14.3g/100g for meat sausages.

Generally, the sausages in our sample are mostly sausages for roasting, with the share of roasting sausages for meat substitutes being higher (84.4%) than for meat sausages (42.6%). Furthermore, two-thirds of the sausages in our sample are from national brands (61%). Meat substitute sausages are either packed in Paper & Plastic (64.7%) or to a lesser extent just in Plastic (35.3%). In contrast, meat sausages are most often packed in Plastic (73.7%) followed by Glass (15.4%). Paper & Plastic and Cans are only of marginal importance due to their small share in the meat market.

Table 2-1 - Descriptive Statistics of the sample from the German sausage market (2020-2021)

Variable	Mean (standard deviation)		
		Individual markets	
	Total market	Meat	Meat substitutes
Observations	183,717	136,545	47,172
Price	1.144 (0.369)	1.012 (0.228)	1.526[a] (0.306)
Main ingredients (Z^{MI})			
Pork-based	0.5	0.673	
Beef-based	0.019	0.025	
Beef & Pork-based	0.051	0.069	
Poultry-based	0.159	0.214	
Other meats	0.014	0.019	
Egg-based	0.031		0.121
Soy-based	0.097		0.379
Wheat-based	0.015		0.057
Pea-based	0.032		0.126
Other/Multi-ingredient-based	0.081		0.317
Credence attributes (Z^{CA})			
Nature & Absence	0.188	0.207	0.133
Nature & Presence	0.158	0.115	0.283
Organic	0.085	0.05	0.187
Science & Absence	0.03	0.026	0.045
Lactose-free	0.185	0.216	0.098
Gluten-free	0.265	0.262	0.273
Science & Presence	0.227	0.036	0.778
Ethical Animal	0.057	0.038	0.111
Sustainability	0.26	0.111	0.688
Origin	0.197	0.26	
PGI label	0.051	0.068	
Traditional claim	0.204	0.262	
Quality claim	0.188	0.241	
Nutrition and diet (Z^{NF})			
A-score	17.256 (4.824)	19.773[a] (3.167)	11.021 (-2.159)
Protein content	14.858 (3.552)	14.309 (2.209)	16.447[a] (-5.623)
Product attributes (Z^{PA})			
Weight in 100g	2.859 (1.551)	3.197[a] (1.665)	1.894 (-0.289)
Roasting sausage	0.533	0.426	0.844
National brand	0.61	0.582	0.692
Plastic packaging	0.638	0.737	0.353
Plastic and paper packaging	0.181	0.021	0.647
Glass packaging	0.115	0.154	
Can	0.066	0.089	
Retail characteristics (Z^{RC})			
Discounter	0.182	0.235	0.03
Supermarket	0.087	0.09	0.079
Hypermarket	0.731	0.675	0.892
Discounted observations	0.551	0.565	0.513

Notes: [a] Indicates significant difference between the meat and meat substitute group at the 0.001 level. Variable descriptions are in Appendix 1 Table 1.

Finally, most of the observed prices in our sample are from sales in Hypermarkets (73.1%). The share of prices originating from Discounters is considerably lower for meat substitute sausages (3.0%) than for meat sausages (23.5%). More than 50% of the observations have been on a discount in a given month.

2.4.2 Results of the hedonic pricing model

In Figure 2, we present the results of the hedonic pricing model for the German meat sausage market. The underlying regression results of the hedonic pricing functions are presented in Table A. 2 in the Appendix. Note that we estimate separate models for the meat sausage market and the meat substitute sausage market. Figure 2 shows the marginal effects of product and retail characteristics along with their confidence intervals in red for the meat market and in blue for the meat substitute market. Regarding the main ingredients, the estimation results indicate a lower market valuation for sausages based on beef, beef & pork, poultry or other ingredients compared to the reference ingredient, pork. Thus, pork-based meat sausages command significantly higher prices by 0.03 to 0.14€/100g, ceteris paribus. For meat substitutes, soy-based products are the reference category. While there is no difference in market valuation for the main ingredient categories egg-based (p=0.811) and wheat-based (p=0.214), the market valuation for meat substitute sausages based on peas (0.29€/100g) and other/multi-ingredients (0.05€/100g) is significantly higher than for soy-based products.

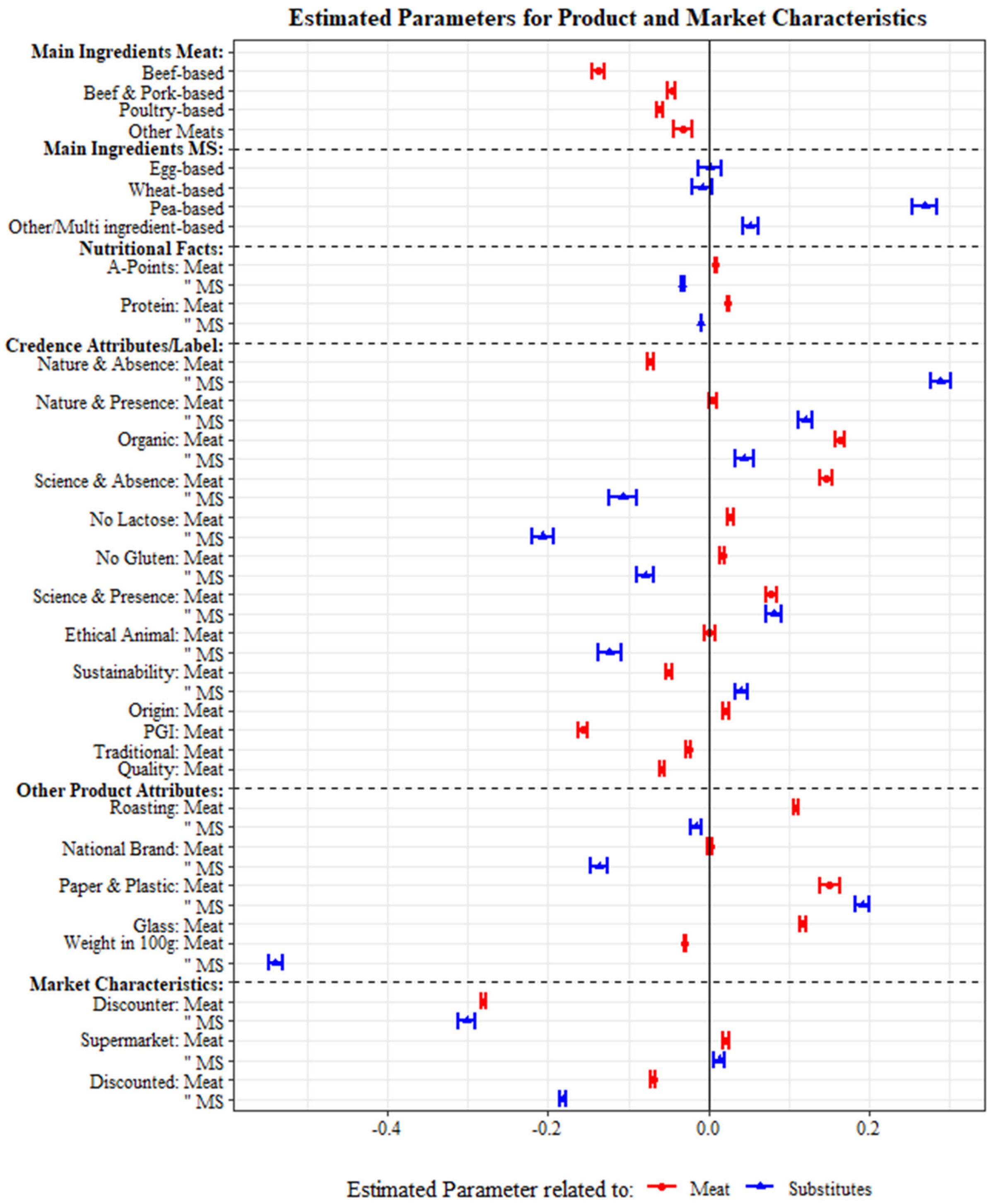

Figure 2-2 - Estimation results from the hedonic pricing models for the German sausage market

Note: The dependent variable is the price in €/100g. MS indicates meat substitutes. Pork, canned or in plastic and sold in hypermarkets is the reference category for the meat market. Soy-based products in plastic packaging, sold in hypermarkets are the reference category for the meat substitute market. The respective table with the underlying regression results is presented in the appendix Table A. 2. Month & region dummies are omitted for brevity. Observations: Meat= 136,545 and Meat substitutes= 47,172.

Turning attention to the nutritional facts, we observe that the marginal effect of the A-Points on the price is positive for meat sausages (0.009 €/100g) and negative for meat substitute sausages (-0.032 €/100g). Since higher A-score values indicate that the products contain more nutrients to limit, this suggests that there is a market valuation for unhealthy sausages in the meat market, but a valuation for healthier sausages in the meat substitute market. While a higher protein content per 100g is associated with a higher price in the meat market (0.024 €/100g), a higher protein content is associated with a lower price in the meat substitute market (-0.009 €/100g).

Market valuation for credence attribute labeling shows more differences than similarities between meat and meat substitutes. While the effect of Nature & Absence (e.g., 'Without flavor enhancers') is negative in the meat market (-0.073 €/100g), it is positive in the meat substitute market (0.289 €/100g). The association of Nature & Presence (e.g., 'Natural Product') with the price is positive for both markets, but not significant for the meat market at a 1% significance level (0.005 €/100g; p=0.02). The effect of organic labeling on the price is positive for both markets, though the estimated value is significantly lower (cf. Table A.2) for meat substitute sausages (0.044 €/100g) than for the meat market sausages (0.163 €/100g). Focusing on the Science & Absence (e.g. 'Reduced in fat') dimension, a contrasting picture emerges. On the one hand, products with a Science & Absence claim (0.146 €/100g), No Lactose (0.027 €/100g) and No Gluten (0.017 €/100g) receive a higher price in the meat market, ceteris paribus. On the other hand, products with such claims receive a -0.107 €, -0.208 €, -0.079 € lower price per 100g in the meat substitute market, respectively. Science & Presence (e.g. 'High in protein') labels are associated with higher prices in both markets. Surprisingly, claims about the ethical aspects of livestock farming are not associated with prices in the meat market (p=0.806) and are negatively associated with prices in the meat substitute market (-0.124 €/100g). Finally, the estimated parameter of Sustainability is positively associated with prices in the meat substitute market (0.040 €/100g) and negatively associated with the price in the meat market (-0.050 €/100g).

Regarding the estimated parameters for those product and process characteristics almost exclusively present in the meat market model, and thus only included in the meat market model, we find heterogeneous results. For products with the indication of a specific origin, a positive market valuation can be observed (0.021 €/100g) while products with the official EU-protected geographical indication (PGI) label receive a lower price (-0.156 €/100g). The same holds for products labeled as Traditional (-0.024 €/100g) or with respect to Quality (with e.g., the golden DLG label) (-0.058 €/100g).

Turning to the other product attributes reveals that roasting sausages are associated with a slightly lower price (-0.016 €/100g) in the meat substitute market and with a higher price (0.108 €/100g) in the meat market. Thereby sausages for cooking, sausages that can be consumed cold or sausages that combine these characteristics with being a sausage for roasting are the reference category. The relationship of the national brand dummy with the price is not significantly different from zero in the meat market (p=0.179) and negative in the meat substitute market (-0.136 €/100g). The packaging material Paper & Plastic is associated with a higher price in both markets, and Glass is also associated with a higher price in the meat market. Note that products packaged in plastic are the reference category for meat substitutes, while canned products and products packaged in plastic form the reference category for meat sausages. Finally, a higher weight of products in 100g is associated with lower prices per 100g in both markets.

The results on the market characteristics also reveal that prices per 100g are -0.281 € and -0.301 € lower in discounters for meat sausages and meat substitute sausages, and 0.022 € and 0.013 € higher in supermarkets than in the reference category hypermarket, respectively. Finally, products that were sold under discount in a given time period have lower prices, as expected.

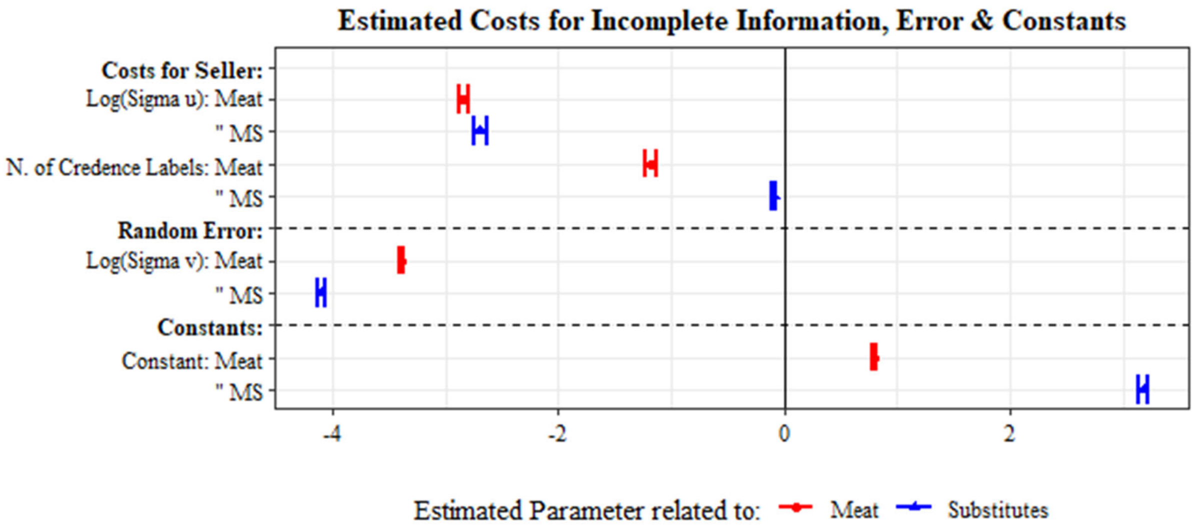

Figure 2-3 - Estimation results for the error terms and the constants

Note: The log(Sigma u) = $\log(\sigma_u^2)$ represents the variance of the half-normally distributed costs for producers for being unable to reach the consumers with the highest WTP. N. of Credence Labels represents a count variable for the number of different credence labels on a product. The log(Sigma v) = $\log(\sigma_v^2)$ represents the variance of the normally distributed error and the constants are related to the overall model. The results are presented in Table A. 2.

Figure 3 shows the estimated results for the market inefficiencies. In our specification, we test whether the number of credence attributes with which sellers tag a product can systematically reduce consumers' deviation from their highest WTP. First, we can observe from the estimated log (σ_u^2) which is -2.939 for the meat market and -2.690 for the meat substitute market that there is a systematic deviation from the highest willingness to pay of consumers in the German sausage market. This divergence appears to be greater in the emerging market for meat substitutes than in the mature market for meat products. Thus, producers are unable to reach consumers with the highest willingness to pay. This shows that it is important to take information asymmetry into account when estimating the hedonic price function. The calculation of $\frac{\sigma_u}{\sigma_v}$ shows that the variance of the half-normal error is two times larger than that of the normally distributed error in the meat substitute market and 1.2 times larger than that of the normally distributed error in the meat market (Bonanno *et al.*, 2019). However, this deviation can be reduced in both markets by the number of different credence labels on the products, as shown by the estimated parameters for the Number of Credence Labels for both the meat and the meat substitute market. This is an indication that the use of credence attribute labels can help to reduce information asymmetries and help sellers reach consumers with the highest willingness to pay. When running the stochastic frontiers without the specifications of σ_u the $\frac{\sigma_u}{\sigma_v}$ is 1.8 for the meat substitute market, however, the log(σ_u^2) turns out not to be significantly different from 0 (p=0.748).

2.5 Discussion

2.5.1 Prices of meat and meat substitutes and the role of main ingredients

Meat prices, when considered in the context of environmental issues and health costs, are arguably too low because they do not internalize the social costs they generate (Funke *et al.*, 2022; Siegrist and Hartmann, 2023). Therefore, several studies model the impact of meat taxes as a tool to reduce meat consumption and, thus, to (partly) internalize the negative external effects (Springmann *et al.*, 2018; Roosen, Staudigel and Rahbauer, 2022). Moreover, lower prices for meat substitutes could reduce meat consumption (Apostolidis and McLeay, 2016), thereby mitigating the associated external costs. Our data, however, show that the price for meat substitute sausages is 50% higher per 100g than the one for meat sausages. These higher prices could act like a "vegan-tax" (Kerslake, Kemper and Conroy, 2022), confirming consumer preconceptions that meat substitutes are very expensive (Peschel *et al.*, 2019), and ultimately acting as a barrier to adoption (Carlsson, Kataria and Lampi, 2022). Recent findings by Zhao *et al.* (2022) challenge the notion of a substitution relationship between meat and meat alternatives, observing a complementary relationship instead. Therefore, a meat tax would not necessarily lead to a higher substitution of meat by meat substitutes. Therefore, the own prices of meat substitutes are particularly relevant, and they would therefore need to be lowered (e.g., through subsidies) to increase their consumption. However, more research is necessary to conclude on this relationship.

Similar to previous literature on the German meat market, our results show that prices differ with respect to the main ingredients. More specifically, Staudigel and Trubnikov (2022), find in a recent hedonic pricing study that the price premium is higher for beef and the mix of beef and pork than for pork. Though, we find that the price of pork is the highest in the meat market, the difference has to be attributed to the different product categories. While Staudigel and Trubnikov (2022) focus on fresh meat, this study investigates sausages, for which traditionally pork is the main ingredient. van Loo, Caputo and Lusk (2020) find a higher willingness to pay for pea-based meat substitutes than for cultured meat and yeast-based meat substitutes in a choice-experiment setting. Our study based on scanner data shows a high market valuation as well for pea-based meat substitutes. More specifically, those products receive a higher price compared to the reference category soybean-based meat substitutes. One reason for this could be that consumers associate soy for meat substitute products with soy mainly produced for feeding animals and grown in deforested areas of the Amazon rainforest (Marin *et al.*, 2022), while some pea-based products are evaluated as more environmentally friendly than soy-based products (Hartmann, Furtwaengler and Siegrist, 2022). Peas could also be perceived as regionally grown inducing a higher market value. In addition, the difference between soy-based and pea-based meat substitutes might be explained by the potential association of consumers of soy with tofu-based meat substitutes, i.e., first-generation meat substitutes. Kim, Caputo and Kilders (2023) found first-generation tofu-based seafood alternatives are less popular than second-generation seafood alternatives, which more closely resemble seafood and are therefore more popular.

2.5.2 Nutrients and their relationship to the price

In general, our results on the sausage market that meat substitutes have a lower A-Score and, hence, contain fewer nutrients to limit (sodium, salt, saturated fats, and calories) per 100g are consistent with the findings of Petersen, Hartmann and Hirsch (2021) who use a sample consisting of 5,842 meat and meat substitute innovations from the German market. Also, the findings of the hedonic pricing model for the meat market are in line with the ones of Petersen, Hartmann and Hirsch (2021), revealing that products with a higher A-score obtain higher prices.

However, the results of this study differ for the meat substitute market. While Petersen, Hartmann and Hirsch (2021) find a positive relationship between the price per 100g and the A-score for the meat substitute market, our results reveal a negative relationship, suggesting that sausage substitutes with fewer 'nutrients to limit' have a higher valuation. Similar to Yang and Dharmasena’s (2020) study on consumer preferences for the nutritional values of dairy and alternative dairy products, who find a positive effect of milk's protein content on the price, we find a positive market valuation of protein for the meat sausage market. However, they report the same relationship for the alternative milk, while our results suggest a negative relationship between protein content and the price in the meat substitute market.

2.5.3 The relevance of credence attributes and marketing for the price premium

The information on credence attributes of products has a distinct role in product pricing in the German meat market. Martin, Lange and Marette (2021) showed that information complementary to the information on packages increases consumers' WTP for meat substitutes. We observe that the share of products labeled with credence attributes is larger for meat substitute sausages than meat sausages. Thereby, there is an emphasis on the aspect Science & Presence which indicates that producers try to inform consumers that the products are nutritionally adequate. This might be because consumers (Weinrich, 2018) and some nutritional experts perceive deficits regarding the nutritional quality of meat substitutes, especially regarding the protein quality (Estell, Hughes and Grafenauer, 2021). This holds despite the fact that research points to a generally preferable composition of meat substitutes when compared to (processed) meats (Petersen, Hartmann and Hirsch, 2021; Alessandrini *et al.*, 2021).

Science Absence claims ('low in fat' and 'low in sugar') are generally less common but still present in both markets, showing a negative relationship with meat substitute prices but a positive relationship with meat sausage prices. Consumers may assume that meat substitutes carrying that claim may lack something. As there are general concerns about dryness and product texture, this could reduce the economic value of meat substitutes (Kerslake et al. 2020), In contrast, interest in fat avoidance is reported among meat consumers and might be especially of relevance in the case of sausages (Apostolidis and McLeay, 2016; Araújo *et al.*, 2022).

Yang and Renwick's (2019) meta-analysis of consumers' willingness to pay for credence attributes in livestock products shows a willingness to pay a premium for animal-friendly production claims and organic claims. Focusing on the organic label, our study also reveals that organic products receive a price premium, which is similar to Staudigel and Trubnikov (2022) findings for the German fresh meat market and the findings of Edenbrandt, Smed and Jansen

(2018), who cover a range of products focusing on Denmark and The Netherlands. Interestingly, the market valuation for organic labeling differs between meat and meat substitute sausages, with the latter receiving a smaller price premium. Organic is a multidimensional construct that encompasses many dimensions of sustainability, such as healthiness and animal welfare (Katt and Meixner, 2020). Consumers might consider that those domains are already per se covered by meat substitutes, leading to a lower market valuation of organic labeling for meat substitute sausages.

Concerning the animal welfare findings, on the one side, a recent choice experiment from the Swedish market on ready-to-eat meals with meat showed that there is a high willingness to pay a price premium for animal welfare (Carlsson *et al.*, 2022). On the other side, insights from Kerslake, Kemper and Conroy (2022) showed that consumers consider animal (welfare) indications on meat substitutes as redundant and even “funny”, which provides an explanation for the negative price effect of this claim in our study. Since this claim is found on 11.1% of products in the meat substitute segment, manufacturers should reconsider whether and how they can credibly communicate this claim.

In the meat substitute market, there are some established brands that are (were) mainly meat producers (e.g. Rügenwalder Mühle). However, Kerslake, Kemper and Conroy (2022) identified that meat substitute consumers tend to distrust products from already established meat producers, which corresponds to our findings, where national brands of meat substitutes receive lower prices on the market. An implication could be that the established meat producers, although more capable of investing in R&D and absorbing the cost of entering the new market, are likely to encounter an “image penalty”. In contrast, value-driven companies could avoid such a penalty, if perceived as credible by consumers. Finally, in contrast to the results of the meta-analysis by Yang and Renwick (2019), we find a lower market valuation per 100g for the EU PGI label. The selected product category might explain this, as sausages are not considered premium products and hence, this type of claim is less relevant.

The type of retail outlet the products are sold can play an important role in price building and the price barrier for consumers. Consumers shopping in discounters are known to be highly price-sensitive (Gottschalk and Leistner, 2013). Our findings show that the market price for meat substitutes are 30 Cents lower in discounters compared to hypermarkets, thereby reducing the potential price barrier for purchasing these products in the former compared to the latter retail outlet. However, since meat sausages are also cheaper in the discounters, the relative price difference remains, which could lead to a price barrier for consumers.

Finally, the stochastic frontier results shed light on the cost to sellers of not being able to reach consumers with the highest willingness to pay, suggesting a systematic deviation from the producer's optimal price. This deviation appears to be greater in the emerging market for meat substitutes than in the mature market for meat products. Similar to the results of Bonanno *et al.* (2019), we find that producers can reduce the deviation from buyers' price frontier by using credence attribute labels on products. This highlights the importance of signaling information in the market. Therefore, product differentiation, through the labeling of credence attributes, can be a competitive strategy (Marchi *et al.*, 2023). This is true because product and process information and respective quality labels can – if credible – induce a higher willingness to pay, as they transform credence attributes into search characteristics, thus reducing information asymmetry and allowing consumers to choose according to their preferences (Karstens and Belz, 2006; Jahn, Schramm and Spiller, 2005; Unnevehr *et al.*, 2010).

2.6 Limitations and conclusion

Although the present analysis has several strengths, such as the large sample size, it is not without limitations. First, there are some limitations related to the sample. While retail brands play an important role in the meat market in general and in the sausage market in particular (Braun, 2023), only producer-branded sausages on the German market for meat and meat substitutes could be considered in the hedonic price model. This limits the transferability of our results to the overall German sausage market, as the analyzed product attributes could have different effects on the prices of private labeled versus producer-branded products. However, the recent trend where retail brands are also aiming at the high-quality market segment may lower those potential differences (Gielens *et al.*, 2021). Nevertheless, further research is needed to investigate whether the relationships differ between branded products and private labels. In addition, our sample considers only pre-packaged sausages, as the provision of information at the fresh counter is unknown, specific to each store, and generally much lower compared to pre-packaged products.

Second, we do not consider the visibility of the information provided. As Grunert and Wills (2007) note, consumers have limited time to process information when grocery shopping. This leads to a similar problem as the attribute non-attendance problem of stated preference methods (Scarpa *et al.*, 2013). Hence, a label on the front of the product might be easier recognized, thereby having a higher influence on the price than a label on the back. Third, we categorize the labels in our model and assume that, for example, credence attribute labels related to the product's healthiness affect the price in a similar direction. However, based on our estimation, it is not possible to determine the extent to which, for example, ‘without GMO’ or ‘without flavor enhancers’ labels contribute to the overall effect of the “natural and absence” category. In addition, we cannot control for the quality of individual labels or whether consumers perceive one label as more trustworthy than others. Fourth, though Caputo, Sogari and van Loo (2023) show that taste is an important product characteristic in the meat and meat substitute market for consumers’ WTP our method and data, do not allow us to include this attribute in the analysis. Nevertheless, it would be interesting to see whether the results of Caputo, Sogari and van Loo (2023) could be replicated in the context of highly processed products like sausages in the German market. Finally, we assume a hedonic price function that holds for the whole of Germany. Although we control for general price differences across regions by market fixed-effects, there could be differences in consumers’ valuations for specific attributes by region. Future studies could therefore estimate geographically differentiated hedonic price models and analyze the differences that might exist across regions.

In summary, our research aimed to understand the factors that influence the market prices of meats and meat substitutes. Based on a sample of 183,717 observations from the German sausage market, we found that meat substitutes are significantly more expensive than meat sausages, which can be a barrier for consumers to adopt them. Here, differences within the market of meat sausages and meat substitute sausages can be explained by the main ingredients, with pork in the case of meat and peas in the case of meat substitutes achieving the highest market valuation. In addition, credence attributes are important factors explaining the price differences. However, the direction of the effects strongly depends on the credence attribute. Thereby, for some credence attributes, there are significant differences in valuation between meat and meat substitute sausages. In addition, the greater use of credence attribute claims on meat substitute packaging suggests that manufacturers are attempting to reduce information asymmetry with consumers. Finally, our results suggest that there is no one-size-fits-all approach to credence attributes and that different marketing strategies are required for meat sausage and meat substitute sausages.

2.7 Appendix

Table 2-A1 Variable descriptions

Variable	Variable description
Price	Price per €/100g
Main ingredients (Z^{MI})	
Pork-based	1 if sausage is based on pork meat, 0 otherwise
Beef-based	1 if sausage is based on beef meat, 0 otherwise
Beef & Pork-based	1 if sausage is based on a mixture of pork and beef meat, 0 otherwise
Poultry-based	1 if sausage is based on chicken, turkey or a mixture of chicken and turkey meat, 0 otherwise
Other meats	1 if sausage is based on other types of meat, 0 otherwise
Egg-based	1 if sausage is based on eggs, 0 otherwise
Soy-based	1 if sausage is based on soya, 0 otherwise
Wheat-based	1 if sausage is based on wheat, 0 otherwise
Pea-based	1 if sausage is based on peas, 0 otherwise
Other/Multi-ingredient-based	1 if sausage is based on other ingredients (e.g. mushrooms) or mixtures, 0 otherwise
Credence attributes (Z^{CA})	
Nature & Absence	1 if any of the following claims are present: “no flavor enhancers”, “no artificial colorings”, “no yeast extracts”, “no phosphates”, “no preserving agents”, “no palm oil” or “no GMO”, 0 otherwise
Nature & Presence	1 if any of the following claims are present: “fresh”, “all natural”, 0 otherwise
Organic	1 if organic, 0 otherwise
Science & Absence	1 if any of the following claims are present: “low in sugar”, “low in fat”, 0 otherwise.
Lactose-free	1 if the sausage has a “lactose-free” claim, 0 otherwise
Gluten-free	1 if the sausage has a “gluten-free” claim, 0 otherwise
Science & Presence	1 if any of the following claims are present: “rich in calcium”, “rich in protein”, “rich in unsaturated fats”, “with added vitamins”, “rich in fiber”, “with iodine”, 0 otherwise.
Ethical Animal	1 if a claim about benefits for animal welfare is present (e.g. any type of animal welfare label or claim for meat products or production of egg-based meat substitutes from cage-free eggs only), 0 otherwise
Sustainability	1 if any claims related to sustainability of the product, its packaging, or renewable energies are present, 0 otherwise
Origin	1 if a reference to a specific geographic location in Germany, 0 otherwise
PGI label	1 if EU PGI (Protected Geographical Indication) label is present, 0 otherwise
Traditional claim	1 if a traditional claim is present (e.g. company with a long, family tradition, or traditional production methods), 0 otherwise
Quality claim	1 if any of the following labels are present: “DLG”, “Institut Fresenius”, “QS”, “Stiftung Warentest”, “Öko-test”, “LZ Top-Marke”,0 otherwise
Nutrition and diet (Z^{NF})	
A-score	The A-Score from the Food Standards Agency (FSA) is calculated by the sum of points for the energy content/100g, saturated fat g/100g, sugar in g/100g and sodium in mg/100g. Each nutrient has a possible range from zero to ten and hence, the overall from 0 to 40. The higher the value is, the worse the nutritional composition. (DH / Department of Health, 2011)
Protein content	Protein content in g per 100g of product

Variable	Variable description
Product attributes (Z^{PA})	
Weight in 100g	Sausage weight in 100g
Roasting sausage	1 if it is a roasting sausage, 0 otherwise
National brand	1 if a product is from a brand that sells products in at least 80 of the German two-digit postal code areas, 0 otherwise
Plastic packaging	1 if packed in plastic, 0 otherwise
Plastic and paper packaging	1 if packed in a combination of plastic and paper, 0 otherwise
Glass packaging	1 if packed in glass, 0 otherwise
Can	1 if packed in can, 0 otherwise
Retail characteristics (Z^{RC})	
Discounter	1 if the observation comes from a discounter, as defined by IRI, 0 otherwise
Supermarket	1 if the observation comes from a supermarket, as defined by IRI, 0 otherwise
Hypermarket	1 if the observation comes from a hypermarket, as defined by IRI, 0 otherwise
Discounted observations	1 if for specific product, in a given store, in a given month, any discount measured by an at least 20% price reduction to the previous week was offered, 0 otherwise

Table 2-A2 - Estimation Results of the Stochastic Frontier Hedonic-Pricing Model

Variables	Meat	Meat Substitutes	Difference: $\hat{\beta}_{meat} - \hat{\beta}_{ms}$
Main ingredients			
Beef-based	-0.138		
	(0.004)		
'Beef & Pork-based'	-0.046		
	(0.003)		
Poultry-based	-0.060		
	(0.002)		
Other Meats	-0.032		
	(0.006)		
MS Main Ingredients			
Egg-based		0.002	
		(0.008)	
Wheat-based		-0.008	
		(0.006)	
Pea-based		0.269	
		(0.008)	
Other/Multi ingredient-based		0.052	
		(0.005)	
Nutritional facts			
A-Points	0.009	-0.032	0.041
	(2.7E-04)	(0.001)	[36.280]
Protein in g/100g	0.024	-0.009	0.033
	(3.3E-04)	(0.007)	[62.014]
Credence Attributes/Label			
Nature & Absence	-0.073	0.289	-0.361
	(0.002)	(0.007)	[-51.925]
Nature & Presence	0.005	0.121	-0.116
	(0.002)	(0.004)	[-23.970]
Organic	0.163	0.044	0.119
	(0.003)	(0.006)	[17.535]
Science & Absence	0.146	-0.107	0.253
	(0.004)	(0.009)	[25.253]
No Lactose	0.027	-0.208	0.235
	(0.002)	(0.007)	[32.452]
No Gluten	0.017	-0.079	0.096
	(0.002)	(0.005)	[17.465]
Science & Presence	0.078	0.081	-0.003
	(0.003)	(0.005)	[-0.561]
Ethical Animal	0.001	-0.124	0.124
	(0.003)	(0.007)	[15.253]
Sustainability	-0.050	0.040	-0.090
	(0.002)	(0.004)	[-20.001]
Origin	0.022		
	(0.002)		
PGI	-0.156		
	(0.003)		

Variables	Meat	Meat Substitutes	Difference: $\hat{\beta}_{meat} - \hat{\beta}_{ms}$
Traditional	-0.025		
	(0.001)		
Quality	-0.058		
	(0.002)		
Other Product Attributes			
Roasting	0.108	-0.016	0.124
	(0.002)	(0.004)	[30.693]
National Brand	0.002	-0.136	0.138
	(0.001)	(0.005)	[24.558]
Paper & Plastic	0.151	0.192	-0.041
	(0.006)	(0.004)	[-5.369]
Glass	0.117		
	(0.002)		
Weight	-0.029	-0.540	0.511
	(3.9E-04)	(0.004)	[114.4]
Market Characteristics			
Discounter	-0.281	-0.301	0.021
	(0.002)	(0.005)	[3.716]
Supermarket	0.022	0.013	0.008
	(0.002)	(0.003)	[2.191]
Discounted	-0.070	-0.182	0.113
	(0.001)	(0.002)	[49.571]
Constant	0.790	3.178	
	(0.009)	(0.019)	
Costs of Incomplete Information			
$log(\sigma_v^2)$	-3.383	-4.101	
	(0.007)	0.017	
$log(\sigma_u^2)$	-2.939	-2.690	
	(0.021)	(0.028)	
N. of Credence Labels	-1.033	-0.092	
	(0.028)	(0.010)	
Time and Market Dummies			
Month Dummies included	Yes	Yes	
Market Dummies included	Yes	Yes	

Note: The dependent variable is the price in €/100g. MS indicates meat substitute. Pork, canned in plastic and sold in hypermarkets is the reference category for the meat market. Soy-based products with plastic package, sold in hypermarkets is the reference category for the meat substitute (MS) market. The numbers in parentheses are the standard errors of the respective coefficients. The numbers in the square brackets are the z-values from the z-statistic calculated based on the following formula: $z =$

$\frac{\hat{\beta}_{meat} - \hat{\beta}_{ms}}{\sqrt{se^2_{\hat{\beta}_{meat}} + se^2_{\hat{\beta}_{ms}}}}$ (Paternoster *et al.*, 1998). The critical z-value to accept or to reject the null hypotheses of the difference being 0 at a significance level of 0.01 is +-2.576.

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3 Which Meat (Substitute) to Buy? Is Front of Package Information Reliable to Identify the Healthier and More Natural Choice?

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Abstract:

Environmental, ethical and health concerns have damaged the image of meat products for some consumer groups. As a result, the relevance of meat substitutes (*MS*) and the labelling of credence attributes has increased. However, it is unclear whether *MS* do indeed make the grade regarding nutritional quality when compared to meat and whether the Front-of-package (FOP) labelling provides reliable information for consumers. Therefore, in this article, we analyse the nutritional quality of different meat products and assess whether the FOP information is a reliable indication of nutritional quality and naturalness. Based on Mintel's Global New Product Database, we analysed a sample of 5,482 innovations from the German meat market, covering a time-span of 9 years (2010-2018). We find an increasing number of MS entering the meat market, with a high-point in 2015. Further, we use Ofcom's A-score to show that *MS* contain fewer 'nutrients to limit' than red meat (*RM*) and poultry meat (*PM*) innovations. In addition, *PM* and *MS* contain fewer food additives than *RM*. Finally, the FOP information is not always consistently related to superior nutritional quality and fewer food additives.

Keywords: Meat innovation, meat substitute innovation, nutritional quality, food additive, front-of-package labelling

3.1 Introduction

Due to GDP growth and associated increases in individual incomes, plus productivity and efficiency gains in livestock farming, a wider population can now afford to buy meat products in large quantities (Godfray *et al.*, 2018; Tilman and Clark, 2014). This has led to a change in the role of meat in humans' diet with overconsumption in most high-income countries (Godfray *et al.*, 2018). In particular, it has been suggested that there is a relationship between excessive intakes of red and processed meat and adverse health effects (Yip, Lam and Fielding, 2018; Wolk, 2017). These potentially adverse health consequences are a major driver curbing the long term rise in meat consumption in high-income countries. Indeed, recently there have even been marginal reductions in meat consumption, despite the high preference most consumers exhibit for the taste of meat (Derbyshire, 2016; Weinrich, 2018; Godfray *et al.*, 2018; Hagmann, Siegrist and Hartmann, 2019; Finder UK, 2021). Consumers' decision to reduce meat consumption is further strengthened by their environmental and animal welfare concerns as meat products are associated with high negative environmental effects (e.g. higher greenhouse gas emissions) (Nijdam, Rood and Westhoek, 2012; Tilman and Clark, 2014) and modern animal husbandry practices are seen to compromise animal welfare (Weinrich, 2018; Simons *et al.*, 2018).

Food producers reacted to these developments and started to reformulate parts of their product ranges and innovate in meat substitutes (MS). In our article, we follow Rödl (2018) and consider MS as products that imitate meat for the smell, texture, taste and appearance or replace meat's function as a protein supply in a meal context. Examples are soy-based burgers, vegetarian salami and tofu, which can either be plant-based (e.g. soy, peas or jackfruit), animal-based (e.g. milk, eggs or insects) or mixtures of both (van der Weele *et al.*, 2019). Further, we follow Hoek *et al.* (2011: 666) and do not consider "*fish, eggs, cheese, nuts or legumes*" as MS. Using this categorisation, Mintel's (2019) product innovation data reveals that the share of MS in all meat innovations in Germany, the case study of our article, increased from 4% in 2010 to 20% in 2015 and declined again to 10% in 2018. Although the MS market can still be considered a niche market, it is expected to exhibit high growth rates in the coming years and, hence, to compete increasingly with meat products in the market (Kyriakopoulou, Dekkers and van der Goot, 2019). The MS segment accounted for 1% of the global meat market in 2019, but it is estimated that its share will rise to 10% by 2029 (Barclays, 2019).

Another option for producers to better reach consumers in the highly competitive meat market, is intensifying the marketing via front-of-package (FOP) labels and claims on the products.

These FOP labels and claims, like the “reduced in fat” claim or the “organic” label, are often related to the nutritional quality or the naturalness of the products (Grasso *et al.*, 2014; Bonny *et al.*, 2015). It has been shown that the organic label for example influences the perception of the products nutritional quality (Schuldt and Schwarz, 2010).

However, up to now, the findings are inconclusive with regard to the actual nutritional quality of MS compared to meat products. Furthermore, it is unclear whether health-related FOP information, like claims and labels, do indeed reflect the nutritional quality of products. Therefore, in this paper, we use the German meat market as a case study to compare the nutritional quality between meat and MS and to assess the reliability of FOP information as an indicator for nutritional quality.

3.1.1 Nutritional aspects of meat and meat substitute consumption

The average annual per capita meat consumption in our case study region, Germany, amounts to 60 kg (Statista, 2018) and thus exceeds the recommendation of the World Cancer Research Fund of 26 kg per person and year by a factor greater than two (WCRF, 2018). While it is acknowledged that the presence of meat in a diet can be beneficial (McAfee *et al.*, 2010), excessive consumption, especially of red meat (beef, pork and lamb) and processed meat, (preserved by smoking, curing, salting or by adding preservatives) has been identified as a cause of colorectal cancer. Despite the general criticism on the overall methodological quality of studies analysing the relationship between meat consumption and health issues (Johnston *et al.*, 2019), there is evidence that excessive meat consumption is linked to obesity, a higher risk of type 2 diabetes and cardiovascular diseases (CVDs) such as high blood pressure (Inguglia *et al.*, 2017; Springmann *et al.*, 2018; Wolk, 2017; Yip, Lam and Fielding, 2018). Several mechanisms may lead to these detrimental health impacts, one of which is linked to the high levels of saturated fat in red and processed meat and another to its high sodium (salt) content (Lim *et al.*, 2012; Inguglia *et al.*, 2017).

While there is considerable scientific evidence relating to the nutritional quality and health impact of meat consumption, little research has been devoted to analysing the nutritional quality and health aspects of meat substitute consumption. Previous literature focused primarily on comparing different types of diets and found that vegan diets include lower amounts of protein, sodium, fat and saturated fat than the diets of vegetarians and omnivores (Clarys *et al.*, 2014). There is also evidence that the consumption of plant-based MS dishes compared with normal meat dishes reduces the serum trimethylamine N-oxide levels, which is a risk factor for CVDs (Crimarco *et al.*, 2020). However, plant-based diets, in contrast, include fewer (bio-available) proteins than animal-based diets (Key, Appleby and Rosell, 2006). These proteins, however, are vital for humans, as they deliver essential amino acids that are irreplaceable in the metabolism of living organisms (Moughan, 2009). Besides, plant-based proteins are less digestible for the human body than animal-based proteins due to e.g., anti-nutritional factors like trypsin inhibitors (Gilani, Wu Xiao and Cockell, 2012; Bohrer, 2017). However, plant-based protein's digestibility increases significantly with thermal processing (e.g., cooking) (Gilani et al., 2012) and the consumption of a balanced variety of plant-based proteins can supply the human body with sufficient essential amino acids (Lynch, Johnston and Wharton, 2018; Day, 2013).

Up till now, there have only been a few studies explicitly comparing the nutritional value of meat versus meat substitutes. In their analysis of the Canadian food market, Arcand *et al.* (2014), found that the salt content of both processed meat products and MS tends to exceed the amount recommended by Canadian governmental department for public health. However, their analysis lacks any comparison between the meat categories, thus inhibiting conclusions on the differences between MS and meat. Ritchie, Reay and Higgins (2018) provide an overview of specific nutritional values for beef, pork, poultry and lamb and compare them with the MS, Quorn's ™ Mycoprotein. They conclude that MS are lower in fat and calories but high in fibre and rich in protein and, hence, of superior nutritional quality. Similar, the fat content of meat products and substitutes differs significantly, with plant-based MS having a lower saturated fat content than meat products (Song *et al.*, 2016). However, these findings contradict partly those of Bohrer (2019), who compares the nutritional values of seven MS with their original meat counterparts from four different product categories (burgers, meatballs, ham and nuggets). While MS nuggets and MS meatballs are found to be healthier compared to their meat counterparts, MS ham has only one nutritional advantage, it is lower in sodium. Finally, MS burgers are found to be very high in sodium and similarly high in saturated fats. Hence, Bohrer (2019) infers that one cannot make general conclusions on the differences in the healthiness between MS and meat products.

3.1.2 The relevance of food additives

Together with nutritional values, food additives also play an important role in the debate on the healthiness of foods, as consumers perceive the consumption of food additives as unhealthy, risky and less natural (Siegrist and Sütterlin, 2017; Aschemann-Witzel, Varela and Peschel, 2019). In the European Union, food additives are indicated on the list of ingredients either by a certain E-number or by the chemical name (Siegrist and Sütterlin, 2017). Furthermore, the

European Food Safety Authority (EFSA) evaluates the safety of food additives and provides recommendations for their legislation, indicating whether additives are safe to consume, must be limited to a certain amount, or even prohibited (Carocho, Morales and Ferreira, 2015). Food additives are used in meat and meat substitute products for various reasons and fulfil particular technological functions, like preservation, flavour enhancement or improving a product's texture (Carocho *et al.*, 2014; EFSA, 2020). Examples of additives are the preservative sodium nitrite (E250) (Alahakoon *et al.*, 2015) and the flavour enhancer monosodium glutamate (E631), which are applied in many processed meat products and MS, respectively. While the flavour enhancers in MS are used to imitate the taste of real meat more closely (Kyriakopoulou, Dekkers and van der Goot, 2019), at the same time, they are likely to lower the perceived naturalness of the meat substitutes (Hartmann and Siegrist, 2017). Up to now, there is no scientific evidence indicating that additives are generally harmful (Cao *et al.*, 2020; Laudisi, Stolfi and Monteleone, 2019). Despite the evaluation of the EFSA, some consumers in high-income countries, nevertheless, actively look for products with a zero food additive content as they perceive products containing additives to be less natural and view their consumption as hazardous (Bearth, Cousin and Siegrist, 2014; Di Vita *et al.*, 2019; Aschemann-Witzel, Varela and Peschel, 2019). Still, no previous study has investigated whether MS more often contain (several) additives than meat products and can, therefore, be considered as less natural.

3.1.3 Marketing influencing the perceived healthiness

Product marketing plays an important role, especially in saturated sectors like the German meat market. In particular, increasing use has been made of FOP claims and labels such as "low in fat" or "organic" to highlight products' nutritional quality, healthiness or naturalness. These claims and labels can help overcome the information asymmetry between consumers and producers, especially regarding credence attributes such as products' nutritional content or the production method, and thereby enable consumers to make an informed choice (Bernués, Olaizola and Corcoran, 2003; Yeh, Hartmann and Hirsch, 2018). It has been shown that these claims and labels influence consumers' perception of the product's healthiness and naturalness (Schuldt and Schwarz, 2010; Apostolidis and McLeay, 2019; Fernan, Schuldt and Niederdeppe, 2018). Further, research using choice experiments showed that this information as well as sustainability information is important as it influences the purchase decisions and the willingness to pay of some consumer groups for MS (Apostolidis and McLeay, 2019; e.g. Apostolidis and McLeay, 2016; Martin, Lange and Marette, 2021). A recent meta-analysis on the effects of FOP nutritional labelling on consumers' behaviour points to the fact that the presence of FOP labels, such as "reduced in fat", decreases the time consumers spend on actually evaluating the nutritional facts of the product and rather base their nutritional evaluation of the product on the label, only (Ikonen *et al.*, 2020). Thereby, the framing of claims also plays a distinct role (Levin and Gaeth, 1988). For the example of ground beef, claims framed positively ("75% lean") have been shown to improve the consumers' perception of the products more than negatively framed claims ("25% fat"), though the magnitude of the effect decreases when consumers are more familiar with the products and have already tried them (Levin and Gaeth, 1988). Further, consumers perceive products to be healthier when a claim focuses on the presence of a certain attribute than when a claim is focusing on the absence of an attribute (André, Chandon and Haws, 2019). Moreover, a considerable stream of research points to the Halo effect of nutritional claims and sustainability labels where the positive perception of a specific attribute caused e.g. by the presence of a FOP organic label also positively influences the perception of other unrelated product attributes such as the nutritional quality in terms of lower calories (Schuldt and Schwarz, 2010). At the same time, there is evidence for the cereal market that those labels and claims are not consistently related to a superior nutritional quality of products (André, Chandon and Haws, 2019; Maschkowski, Hartmann and Hoffmann, 2014). Thus, FOP information has the potential to mislead consumers and cause them to perceive the product more positively than it actually warrants (André, Chandon and Haws, 2019). However, up till now no comparable research has investigated the meat sector. Hence, it is unclear whether meat products and MS that claim to be beneficial, e.g., with respect to their nutritional quality, are indeed superior or whether those claims and labels potentially mislead consumers.

3.1.4 Contribution and study case

We make two contributions to the existing literature:

i) we use nutritional quality and utilisation of food additives as proxies for healthiness and perceived naturalness and determine the differences in these proxies when comparing meat products (red meat and poultry) and MS (vegan and non-vegan);

ii) we investigate whether products' FOP claims and labels relating to health and naturalness are linked to an aggregated nutrient score and the number of additives. This allows an assessment of whether FOP provides a reliable basis for consumers to perceive a products' nutritional value and naturalness. In addition, we also evaluate whether this reliability varies between different kinds of meat and meat substitutes.

Germany represents an interesting case study as it is the largest market for meat and meat substitutes in the European Union (EU 27) (Statista, 2019). Our analysis is based on Mintel's

Global New Product Database (GNPD) which contains detailed information on food product innovations (Mintel Group Ltd., 2019). This enables us to obtain a holistic overview of the German meat market based on 5,482 product innovations, whereby we focus on the 9-year time horizon between 2010 and 2018.

3.2 Data and method

3.2.1 Data source and variables

We use Mintel's Global New Product Database (GNPD) (Mintel Group Ltd., 2019), which was used before by, e.g. van Camp, Souza Monteiro and Hooker (2012) who have analysed the drivers of adoption of front-of-pack nutrition labels for food products in the UK. The GNPD provides information from over 86 countries on more than 5 million product innovations entering the market for fast-moving consumer goods (Mintel Group Ltd., 2019). Information on more than 204 thousand products is available for Germany. New products and product extensions are identified and added to the database by shoppers at point-of-purchase, which includes all relevant supermarkets and discounters as well as food product fairs, e.g., the Anuga (Mintel Group Ltd., 2019). This provides a holistic overview of the German market for meat products and MS. The data available for each product comprises detailed information on the main nutrients content, main ingredients, type of innovation, price, producer, labels and claims as well as pictures of all sides of the products' packaging. The innovations added to the database include entirely new products and products with new packaging or reformulation. Therefore, we define the term (product) innovation as the set of entirely new products entering the market, brand extensions, reformulated products, or products with new packaging. Although a change of the packaging does not affect a product's nutritional values, it might be associated with a change in its FOP marketing.

We differentiate between the following product groups using dummy variables to appraise potential systematic differences in the nutritional quality between meat and MS: red meat (*RM*), which includes beef, pork and lamb, poultry *(PM)* and meat substitutes (*MS*). Moreover, to account for the differences in the nutritional quality between vegan and vegetarian diets (Clarys *et al.*, 2014) and to analyse whether this translates to the food innovations, we further distinguish between vegan (*VMS*) and non-vegan (*NVMS*) meat substitutes. Hence, we capture systematic differences in *MS* dependent on whether they are exclusively from plant-based origins or also include animal products (e.g. eggs). We created the product group dummies for *VMS* and *NVMS,* using the individual product's list of ingredients and Python dictionaries, to count the number of occurrences of each ingredient. We rechecked the results again by visually inspecting the list of ingredients of all *NVMS* and *VMS* to rule out potential misallocations[6].

The nutritional quality of the innovations was analysed using the A-score from the Ofcom-score as this is the most researched, valid nutritional profile available (Poon *et al.*, 2018). Nutritional profiles categorise foods according to their nutritional composition (Scarborough, Rayner and Stockley, 2007: 330). Initially, the Ofcom model was developed by the UK's Food Standards Agency to regulate TV advertising for products targeted at children (Ofcom, 2009; Poon *et al.*, 2018). The model obtains an overall score by calculating 'nutrients to limit' points (energy, saturated fat, sugar, sodium), the so-called A-score, for each product. The A-score has a possible range between 0 and 40, whereby higher values indicate elevated contents of saturated fat, sodium, sugar and/or energy per 100 g and are thus less beneficial from a nutritional viewpoint. These points can be offset by points for 'nutrients to encourage' (protein, fibre, fruit, vegetable or nut content), termed C-score, that can have values between 0 and 15. Thus, the higher the C-score of a food product, the better it is from a nutritional point of view. The higher the overall Ofcom score, the lower the nutritional quality of a product. Due to a lack of data on the product's fibre and fruits/vegetables contents, we base our analysis on the A-score as a proxy for the nutritional quality. However, since it includes energy, saturated fat and salt, this part of the Ofcom model supplies the information most relevant for the debate on the healthiness of meat vs. meat alternatives (Inguglia *et al.*, 2017; Desmond, 2006; Godfray *et al.*, 2018; Wolk, 2017). Nevertheless, the omission of the C-score could be a drawback since the products' protein is not included in the analysis. However, as shown above, plant-based diets deliver sufficient amounts of protein and recent literature indicates that protein deficiency is mainly a problem in lower-income countries (Ritchie, Reay and Higgins, 2018). Therefore, we assume that the A-score is an adequate proxy of products' nutritional quality, particularly when comparing meat and meat substitute innovations in high-income countries such as Germany.

We not only apply the *A-score* as a nutritional quality indicator, but also use the prevalence of food additives as a proxy for the degree of a product's artificialness. This is based on the rationale that the presence of food additives lowers the (perceived) naturalness of a product and the likelihood of its consumption (Siegrist and Sütterlin, 2017). Therefore, we consulted the list of ingredients to identify all the additives present in each innovation, for which we used the EU

[6] We identified the following key-terms for *NVMS*: egg, milk, cheese, butter, mozzarella, cream, chicken protein powder, pork gelatine and rennet. These terms had to be adjusted for the terms palm butter, shea butter, rice milk and cashew cream as they are vegan but contain some of the key-terms for non-vegan ingredients. Products without such ingredients were coded as *VMS*.

database of approved food additives[7]. Since we assume that the perceived naturalness of innovations declines with the number of additives as ingredients, we calculated the sum of the number of additives present in each product (*#Additives*). Therefore, an innovation with added E250 and E300 would score a two, whereas a product without any additives would score a zero. The shortcoming of this procedure is that it does not distinguish between different additives and thus, no conclusions can be drawn regarding the effects of food additives on human health. Moreover, it is not possible to account for the amount of each additive present in the innovations. However, if ingredients are unknown, which is likely the case for food additives, consumers tend to move in their evaluation from the "unknown" status to an "unhealthy" status of the ingredient (Aschemann-Witzel, Varela and Peschel, 2019). Hence, in their evaluation of several food additives consumers are likely to defer to a "more=worse" heuristic. Our approach allows the systematic description of the application of food additives in the German meat market and we use this as a proxy for the degree of products' artificialness and relate it to the products' FOP information.

Information on products' FOP labelling was acquired by introducing dummy variables to capture the presence of *Science_absence*, *Science_presence*, as well as *Natural_absence* and *Natural_presence* claims on the products' package. According to André, Chandon and Haws (2019), health-related labels can be divided into two main categories: "*Healthy by Presence or Absence*" and "*Healthy by Nature or Science*" (cf. Appendix I, Figure 1). Consequently, FOP information can aim at either the presence or absence of certain product characteristics whereby this can be associated with either natural or scientific attributes. *Science_absence* claims relate to innovations that fall in the "absence and science" category as the amount of a nutrient with a negative image, such as fat, is reduced. *Science_presence* claims belong to the category "presence and science" and indicate the addition of an ingredient with a positive image, e.g., that the product contains added minerals. Accordingly, *Science_absence* and *Science_presence* claims relate directly to the products' health and nutritional quality characteristics (Henchion *et al.*, 2014; Fernqvist and Ekelund, 2014). We also cover the "nature and absence" and "nature and presence" sectors (André, Chandon and Haws, 2019), whereby "free of additives" would be an "absence and nature" claim as ingredients that diminish naturalness are not added to a product. A "whole grain" claim belongs to the category "presence and nature" as a positive attribute remains in its original form in the product (André, Chandon and Haws, 2019). The full list of claims and labels included in each of the four FOP categories (*Science_absence,*

[7] https://webgate.ec.europa.eu/foods_system/main/?sector=FAD&auth=SANCAS Last access: 17.05.2021

Science_presence and Natural_absence and *Natural_presence*) is presented in Appendix II, Table 1. Equation 2 in section 3.3 shows a sensitivity analysis for which we split the *Natural_absence* variable into *Natural_absence_GMO* [genetically modified organisms] and *Natural_absence_addit* [addit] to account for the fact that the latter is directly related to the dependent variable (number of additives) in model 2. Finally, we added information on the year the innovation was introduced and the products' price per 100g to control for a potential time trend, the quality and the degree of processing of the products. The full list of variables and their descriptions is included in Table 1.

Table 3-1. Variable description

Variable name	Variable description
A-Score	The aggregated negative points from the UK Ofcom score including information about: fat, energy, salt and sugar content per 100g.
#Additives	Count variable for the number of different additives present in an innovation.
Red Meat (RM)[a]	Dummy variable (DV); 1 if an innovation is based on red meat, 0 otherwise.
Poultry (PM)[a]	DV; 1 if an innovation is based on poultry, 0 otherwise.
Substitute (MS)	DV; 1 if an innovation is a meat substitute, 0 otherwise.
Non-Vegan MS (NVMS)	DV; 1 if an innovation is a non-vegan *MS*, 0 otherwise.
Vegan MS (VMS)	DV; 1 if an innovation is a vegan *MS*, 0 otherwise.
Natural_presence	DV; 1 if an innovation has claim/label aiming at natural and presence, 0 otherwise.
Natural_absence	DV; 1 if an innovation has a claim/label related to natural and absence, 0 otherwise.
Natural_absence_GMO[b]	DV; 1 if an innovation has a claim/label aiming at absence of GMO, 0 otherwise.
Natural_absence_addit[b]	DV; 1 if an innovation has a claim/label aiming at absence of additives, 0 otherwise.
Science_presence	DV; 1 if an innovation has a claim/label related to science and presence, 0 otherwise.
Science_absence	DV; 1 if an innovation has a claim/label "related to science and absence, 0 otherwise.
Time	Year of product introduction-2010.
Price (€/100g)	Price of the product in €/100g

Notes: The A-score is the sub-sub score of the Ofcom score. The more energy, saturated fat, sodium and/or sugar a product contains, the higher the A-score. See footnote 12 for the exact calculation of the A-score.

[a]: If innovations contained both red meat and poultry they were assigned to the specific category based on the predominant ingredient. In one case, although a product marketed as poultry contained mainly pork, we still assign it to the poultry category [b]: We split the "Nature and absence" category further, as this includes a claim (absence of additives) that is directly related to the dependent variable analysed in equation 2, while the other claim in that category (absence of GMO) is not.

3.2.2 Data processing

We generated our sample by using Mintel's GNPD to select all innovations in the meat category during 2010-2018, as the data availability before that period is low, including red meat, poultry and meat substitutes, but excluding fish products. This led to a sample of 6,900 products, comprising 4,624 *RM*, 1,395 *PM*, and 881 *MS* innovations.

In some cases, information was only available regarding either the salt or sodium content of a product. In accordance with van Camp, Souza Monteiro and Hooker (2012), we calculated the missing values for sodium or salt based on the molecular weight of sodium and chlorine. In addition, if values for a product's energy content were provided in kilojoules/100g they were converted to kcal/100g.

In cases where nutritional facts for individual innovations were incomplete, we checked the product's picture and the long list of nutritional values provided to obtain the missing information. Nevertheless, 1,405 innovations (21%) had to be excluded from further analysis due to a lack of information on at least one of the relevant nutritional variables. Furthermore, we screened the data for potential outliers and unreasonable values by excluding observations where the sum of the nutritional content per 100g (*sugar, salt, fat* and *protein*) exceeded the total value of 100g. Secondly, we checked whether the maximum and the minimum amounts of the nutritional values observed in our sample were reasonable, and if not, the value was adjusted manually using information from the package picture. However, the observations had to be dropped if we could not find the correct information, for example, an innovation where the salt content per 100 g equalled 36 g. Finally, multivariate outliers were identified using the BACON algorithm, which identifies outliers based on Mahalanobis distances (Weber, 2010). The sample size was reduced by 13 products that were identified by the algorithm. The final sample includes 5,482 different products with 3,601 *RM*, 1,141 *PM* and 740 *MS* innovations and thus provides a comprehensive sample of products for our analysis of the German meat market. The *MS* innovations include 232 *NVMS* and 508 *VMS*.

3.2.3 Econometric framework

Previous empirical research on the relationship of health-related product information and the actual nutritional quality of products has used regression models of nutritional profiles on FOP claims (e.g. Maschkowski, Hartmann and Hoffmann, 2014). Furthermore, André, Chandon and Haws (2019) showed that labels influence how consumers perceive the healthiness of products. Accordingly, we estimate several regression models that allow us to i) uncover differences in the nutritional quality (*A-score*) and artificialness (*#Additives*) between product categories (*RM, PM, and MS* including *VMS* and *NVMS*) and ii) to evaluate the relationship between FOP claims and labels and the two variables of interest (*A-score* and *#Additives*). Consequently, the first group of models with the *A-score* as the dependent variable is specified as follows:

$$Ascore_i = \beta_o + \beta_{RM} * RM_i + \beta_{PM} * PM_i + \sum_{c=1}^{4} \beta_c * x_{c_i} + \beta_t * time_i + \beta_p * price_i + \varepsilon_i \qquad (1)$$

where *i* reflects the individual innovation. RM_i and PM_i are dummy variables that capture the differences between the product categories, whereby *MS* is used as the reference category. We extend equation (1) in a subsequent step by adding the dummy for $NVMS_i$ whereby *VMS* becomes the reference category. We then estimate equation (1) for each product category (*RM, PM, MS, NVMS, VMS*) separately, leading to a total of 7 estimated models. The vector x comprises dummy variables that capture the existence of FOP claims and labels for a product related to the four categories *Science_absence, Science_presence* and *Natural_presence* and *Natural_absence*. Furthermore, we control for product price per 100g and include a linear time variable to capture the evolution of the nutritional quality of the innovations in the meat market. Finally, ε_i represents a classical i.i.d. error term. We estimate equation (1) using OLS.

Secondly, based on equation (2) we estimate a negative binomial regression model for the count variable *#Additives* using the same explanatory variables as in (1). Note that in a sensitivity analysis of equation (2), we split the category *Natural_absence* as it includes a claim "free of additives/without certain additives" which is directly related to the number of additives in an innovation. Therefore, we included the dummies for *Natural_absence_addit* and *Natural_absence_GMO,* as there were only two groups of claims in the *Natural_absence* classification. Due to the non-zero condition of the counts, it would be inappropriate to estimate (2) with OLS. The basic count data model is the Poisson regression model, with its equidispersion assumption on the dependent variable. Whereby, equidispersion implies that the mean value of a variable is equal to the variance of the variable (Long and Freese, 2014). In turn, if the variance is greater than the mean value, this is referred to as overdispersion However, as this condition is likely to be violated in real count data (Long and Freese, 2014), we adopt a negative binomial regression model (NBREG) as it considers the unobserved heterogeneity (Long and Freese, 2014). As in equation (1), we again assume differences between the meat product categories and estimate a total of 7 models. In addition, we assume a relationship between the FOP claims and the number of additives. Finally, we control for the time effect and the price. Thus, the NBREG model is specified as follows:

$$\#Additives_i = \exp\,(\alpha_o + \alpha_{RM} * RM_i + \alpha_{PM} * PM + \sum_{c=1}^{4} \alpha_c * x_{c_i} + \alpha_t * time_i + \alpha_p * price_i + \gamma_i) \tag{2}$$

whereby, exp (γ_i) represents a gamma-distributed error term. The model is estimated using pseudo-maximum likelihood. For better interpretation, we present the estimated coefficients as incidence-rate ratios (IRR), which are estimated as follows (Long and Freese, 2014):

$$\frac{E(y|x, x_k + 1)}{E(y|x, x_k)} = e^{\alpha_k} \tag{3}$$

this implies that the expected counts of the dependent variable (*#Additives*) change by a factor of e^{α_k} in response to a unit change in x_k (Long and Freese, 2014).

3.3 Results

3.3.1 Descriptive statistics of the German meat market

Figure 1 illustrates the shares of *RM, PM, NVMS* and *VMS* over time thereby providing a first impression of developments in the German meat market over the period 2010 to 2018.

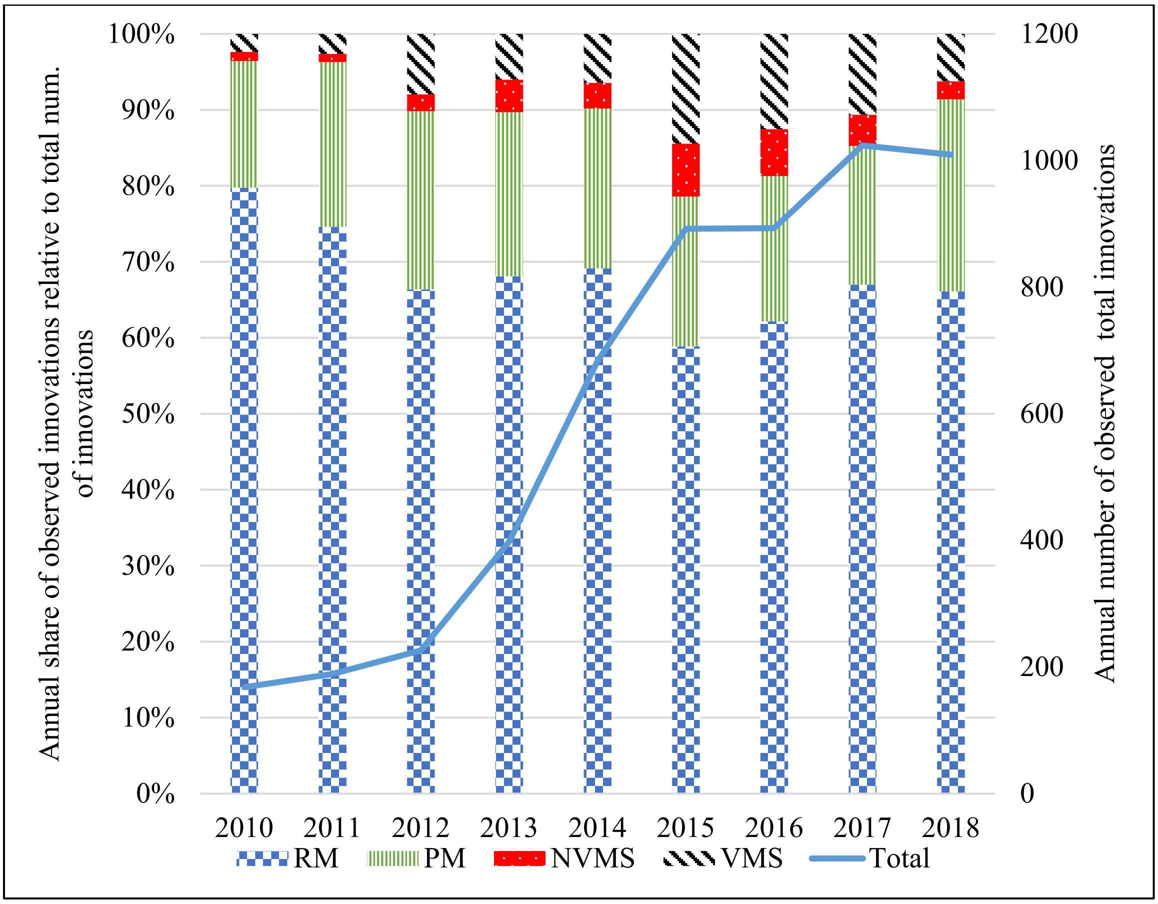

Figure 3-1: Yearly shares of meat categories in total meat market product innovations (Germany, 2010 to 2018).

Source: Own illustration based on Mintel's GNPD.

Figure 1 reveals that the number of innovations recorded in the database has increased rapidly over the period analysed. Furthermore, the figure shows dynamics with respect to the composition of product innovations in the German meat market over the period 2010 to 2018. The share of *RM* in all meat innovations started at 80% in 2010, subsequently showed a declining trend up to 2015 (below 60%) and has slightly increased again in the following years (about 65% in 2018). At the same time, the share of PM rises with some yearly fluctuations. Furthermore, it can be observed that the percentage of *MS* in the German meat market has increased from only 4% in 2010 to over 20% in 2015 and levelled off at around 10% in 2018, whereby *VMS* account for the major share of *MS*. Similar to the relative (percentage) importance of MS in the meat market, which decreased between 2015 and 2018, also the absolute number of MS innovations has decreased from 191 in 2015 to 87 in 2018. Still, the absolute number of MS is higher in 2018 (87) than before the sharp increase in 2014 (67).

In Table 2, we present the descriptive statistics of our data for the whole sample (left panel) and individual product categories (right panel). The mean *A-score* of the whole sample of meat and meat substitute products is 14.5, which is above the threshold of 10 A-points. In the overall calculation of the Ofcom score this threshold marks the level at which the points for protein can no longer be subtracted unconditionally. Furthermore, on average products contain 2.2 different additives. The composition of the sample in terms of product categories reveals that 65.7% of the products are *RM* innovations, 20.8% *PM* and 13.5% *MS,* again underlining the predominant role of red meat in the German market. Note that 68,6% of the *MS* are vegan. The most prevalent and, therefore, most relevant FOP claims and labels used are *Natural_absence* and *Natural_presence,* which appear on 18.5% and 13.0% of the products, respectively. This indicates that producers of meat and meat substitutes seem to attach some importance to highlighting the naturalness of their products. The two other labelling areas, "scientific and added" and "scientific and reduced" prove to be less relevant in the German meat market as only 7.2% and 3.0% of products are labelled with a *Science_absence* or *Science_presence* claim/label, respectively.

Comparing the different product categories reveals that *RM* innovations have an *A-score* of around 16.5 points, while at 9.8, that of *MS* is almost 7 points lower. Differences between the *A-score* of *MS* and *PM* are smaller with 1.2 points. Furthermore, the *A-score* of *VMS* (9.4 points) tends to be slightly lower than that of *NVMS* (10.7 points). The indicator for the product's artificialness (*#Additives*) also reveals differences between the product categories. On average, *RM* innovations contain 2.4 different additives, while at 1.9, the additive content of *PM* innovations is somewhat lower. Interestingly, there are differences in the usage of additives in *MS*. While the aggregate of all *MS* innovations contain on average 1.7 additives, *NVMS* products contain over twice as many additives as *VMS* products (2.8 vs. 1.3).

Finally, the presence of FOP labels and claims differs between the product categories. While 8% of *RM* innovations (4% of *PM* innovations) carry a *Natural_presence* claim or label, at 50% that share is over five (12) times higher in the *MS* category. Again, differences can be observed between *VMS* and *NVMS* with respect to *Natural* claims. While 13% of the *NVMS* are labelled in this way, almost 67% of the *VMS* in our sample exhibit a *Natural_presence* claim or label. The share of products labelled with a *Natural_absence* claim varies less between the meat categories. As indicated above, *Science_absence* and *Science_presence* claims play a comparatively minor role in the meat market. In particular, there are almost no *Science_presence* claims (below 1%) for *RM* and *PM,* and *Science_absence* claims are of little relevance (7%). These claims are more prevalent on *MS* innovations, with 18% in the case of *Science_presence* claims and 10% in the case of *Science_absence* claims. While few differences exist between *NVMS* (19%) and *VMS* (17%) with respect to *Science_presence* claims, the share of products bearing *Science_absence* claims is higher for *NVMS* (15%) compared to *VMS* (8%).

To summarise, when the *A-score* is used as an indicator for the nutritional quality of the products, the descriptive analysis reveals that during the period analysed, *RM* innovations have the lowest nutritional quality, while differences between *PM, NVMS and VMS* are less pronounced. The products' naturalness measured by the number of additives it contains seems to be lowest for *RM* and *NVMS* and highest for *VMS*, with *PM* in between. Furthermore, *Natural* claims are much more prevalent than *Scientific* claims on the front of a product's package and the former are of greater relevance on *MS* than on *RM* or *PM* innovations.

Table 3-2. Descriptive statistics of the sample of German meat market innovations from Mintel's GNPD (2010-2018)

	Whole sample				*RM*		*PM*		*MS*		*NVMS*		*VMS*	
VARIABLES	mean	sd	min	max	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
A-Score	14.458	6.547	0.000	28.000	16.530	6.521	10.947	4.708	9.786	3.842	10.677	3.297	9.380	4.004
#Additives	2.180	1.829	0.000	13.000	2.357	1.764	1.902	1.764	1.746	1.919	2.763	2.352	1.281	1.468
RM	0.657		0	1	1		0		0		0		0	
PM	0.208		0	1	0		1		0		0		0	
MS	0.135		0	1	0		0		1		1		1	
NVMS	0.042		0	1	0		0		1		1		0	
VMS	0.093		0	1	0		0		1		0		1	
Natural_presence	0.130		0	1	0.082		0.039		0.504		0.134		0.673	
Natural_absence	0.185		0	1	0.140		0.257		0.295		0.319		0.283	
Natural_absence_GMO	0.137		0	1	0.125		0.136		0.191		0.316		0.134	
Natural_absence_addit	0.055		0	1	0.016		0.123		0.139		0.004		0.201	
Science_presence	0.030		0	1	0.009		0.005		0.176		0.194		0.167	
Science_absence	0.072		0	1	0.066		0.071		0.103		0.147		0.083	
Time	5	2.123	0	8	5.342	2.198	5.465	2.154	5.614	0.468	5.522	1.603	5.656	1.649
Price in (€/100g)	1.434	1.053	0.124	13.980	1.529	1.174	1.073	0.771	1.529	0.582	1.443	1.443	1.568	0.604
Number of observations	5,482				3,601		1,141		740		232		508	

Source: Own calculations based on Mintel (2019). *RM*: Red meat, *PM*: Poultry meat, *MS*: Meat substitutes, *NVMS*: Non-vegan *MS*, *VMS*: Vegan *MS*.

3.3.2 Results on the relationship between the *A-score* and product attributes

We now turn our attention to the results of the regression analysis based on equation (1). The results of the OLS estimation for the relationship between the *A-score*, product groups and FOP labels/claims are presented in Table 3. The first column includes all products using *MS* as the reference category. The estimated intercept for the first model indicates that the average *A-score* is 11 points for *MS*, given that all other variables are set equal to zero. Furthermore, the results reveal significant differences between the three product categories, with *RM* innovations having the worst score on the aggregated scale for nutritional quality (highest *A-score*). More precisely, the estimated coefficient is statistically significant and positive, indicating that the average *A-score* of *RM* products exceeds that of *MS* products by 6.6 points (assuming that values for all other variables equal zero). Moreover, the estimated coefficient for *PM* is significant and positive, but at 1.14 it is smaller than the estimated coefficient for *RM.* The relationship between FOP information and the *A-score* indicates that for products exhibiting a *Science_absence* it is about 2.7 points lower than that of products without such labelling. Therefore, this label seems to be a predictor for a product with a more favourable nutritional quality. On the other hand, there is no statistically significant relationship between either the *Science_presence claim* and the *A-score* nor the two *Natural* claims and the *A-score*. Finally, it can be observed that a higher product price is associated with lower nutritional quality and that there is a negative time trend which implies that product innovations in the meat market display a more favourable nutritional profile over time.

To distinguish between vegan and non-vegan *MS* products, the second column of the model contains *VMS* as the reference category, while *NVMS* is included as an additional dummy variable. The estimated coefficient for *NVMS* indicates that the nutritional composition of the related products is lower than that of *VMS.* Otherwise, the distinction all MS or vegan *MS* as reference group only reveals minor changes in the remaining coefficients. Regarding the model fit, the F-test indicates the overall significance of both models. Furthermore, the adjusted-R^2s indicate that both models explain around 21% of the variance in the *A-score*. Further, multicollinearity was low with variance inflation factors (VIFs) below 2.5. Note that since the White test revealed the presence of heteroscedasticity in the residuals, we used heteroscedasticity robust standard errors in our estimation.

We estimated equation (1) separately for the five product categories to assess whether the information reliability of FOP claims/labels regarding the nutritional quality of meat products differs between meat categories. The results are presented in columns 3-7 of Table 3. The estimated intercepts, which reveal the *A-score,* assuming that all other variables are set equal to zero, vary across categories. While the estimated coefficient for *RM* is 17.7, it is around 6 (8) points lower for *PM (MS),* confirming the initial descriptive analysis. Therefore, based on the *A-score*, *PM* and *MS* contain fewer unfavourable nutrients than *RM*. Furthermore, differentiation between *NVMS* and *VMS* shows an intercept that is 2.6 points lower for the former than for the latter. A study of the relationship between FOP claims and the nutritional value of the product as measured by the *A-score* reveals similarities and differences between meat categories. There is a negative relationship between the use of *Natural_presence* claims and the *A-score* for the aggregate and the two subcategories of meat substitutes though the link is only significant for the *MS* aggregate and the subcategory NVMS. The FOP claim category *Natural_absence* is associated with lower *A-scores* on *PM*, *MS* and *VMS*, while the opposite is revealed for *RM*. For NVMS this finding is not significant. In the case of *Science_presence* claims, we observe differences between *RM* and *PM* innovations on the one hand and *MS* innovations, including the subgroups *NVMS* and *VMS,* on the other hand. While *RM* and *PM* innovations with *Science_presence* claims have a higher *A-score* and thus a lower nutritional quality, the opposite is true for *MS*, *NVMS* and *VMS*. Note that these findings are only significant for *RM, MS* and *NVMS*.

Table 3-3. OLS-Regression of product categories, FOP information and controls on the *A-score*

	(All products)	(All products)	(*RM*)	(*PM*)	(*MS*)	(*NVMS*)	(*VMS*)
VARIABLES	*A-score*	*A-score*	*A-score*	*A-score*	*A-score*	*A-score*	*A-score*
RM	6.598***	7.173***					
	(0.211)	(0.260)					
PM	1.140***	1.723***					
	(0.236)	(0.283)					
NVMS		1.500***					
		(0.302)					
Natural_presence	-0.169	0.094	0.122	0.509	-1.098***	-1.531***	-0.199
	(0.249)	(0.265)	(0.397)	(0.856)	(0.275)	(0.428)	(0.360)
Natural_absence	0.255	0.249	1.256***	-1.239***	-0.487*	-0.120	-0.631*
	(0.186)	(0.185)	(0.274)	(0.330)	(0.285)	(0.471)	(0.362)
Science_presence	0.320	0.293	1.665**	0.733	-0.780**	-1.604***	-0.493
	(0.335)	(0.333)	(0.730)	(2.437)	(0.344)	(0.529)	(0.435)
Science_absence	-2.670***	-2.691***	-4.050***	0.048	-1.345***	-1.018	-1.539***
	(0.256)	(0.255)	(0.336)	(0.475)	(0.456)	(0.647)	(0.594)
Time	-0.254***	-0.255***	-0.216***	-0.304***	-0.203**	-0.295**	-0.138
	(0.039)	(0.039)	(0.050)	(0.067)	(0.084)	(0.142)	(0.105)
Price in €/100g	0.255***	0.246***	0.021	1.083***	1.562***	1.559***	1.632***
	(0.076)	(0.076)	(0.087)	(0.205)	(0.268)	(0.460)	(0.313)
Constant	11.053***	10.474***	17.718***	11.735***	9.507***	10.761***	8.125***
	(0.305)	(0.342)	(0.302)	(0.440)	(0.638)	(1.018)	(0.815)

	(All products)	(All products)	(*RM*)	(*PM*)	(*MS*)	(*NVMS*)	(*VMS*)
VARIABLES	*A-score*	*A-score*	*A-score*	*A-score*	*A-score*	*A-score*	*A-score*
Observations	5,482	5,482	3,601	1,141	740	232	508
R^2	0.211	0.212	0.030	0.072	0.090	0.133	0.093
adjusted-R^2	0.210	0.211	0.029	0.067	0.082	0.109	0.082
F-value	243.8	218.5	28.87	12.68	10.19	6.68	8.48
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Heteroskedasticity robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. *MS* is the reference category in column 1 while *VMS* serves as the reference category in column 2. *RM*: Red meat, *PM*: Poultry meat, *MS*: Meat substitutes, *NVMS*: Non-vegan *MS*, *VMS*: Vegan *MS*.

Furthermore, it must be borne in mind that these claims are rarely present on *RM* and *PM* innovations (less than 1%). Finally, a FOP *Science_absence* claim is related to a lower *A-score* across all meat categories but poultry meat and, therefore, to superior nutritional quality, although the findings are not significant for *NVMS* products.

All models reveal a negative time trend, indicating that the nutritional quality of products has improved (lower *A-score*) over time across all categories, although the time coefficient does not differ significantly from zero for *VMS.* In addition, the findings reveal that higher prices are an indication of lower nutritional quality for all meat categories with the exception of *RM*.

As regards model diagnosis, the F-test reveals overall significance for all subcategory models. The models explain between 3.0% (*RM*) and 13.3% (*NVMS*) of the variance in the *A-score*. Further, multicollinearity was low with VIFs below 2.5. Once again, we apply heteroscedasticity robust standard errors in all subgroup estimations as the White test indicated that the models suffered from heteroscedasticity.

As robustness check, we re-run the estimation, omitting the control variables *Time* and *Price*, to separate their effect from the overall effect of the credence attributes and meat categories. The results are presented in Appendix III, Table 2. It can be observed that the estimated results of Table 3 are generally, with the exception of the PM model, robust towards the inclusion of control variables. However, the model performance as measured by the adjusted-R^2 decreases in the subcategory estimations (columns 3-7, Appendix III, Table 2).

3.3.3 Results on the relationship between the number of additives and product attributes

The results of the NBREG with the *#Additives* as the dependent variable are reported in Table 4. Note that our interpretation focuses on the incidence rate ratios (IRR) (cf. equation 3) for all coefficients except the constant. The latter reveals the number of additives in the reference category, given that all other variables are set equal to zero. The IRRs must be interpreted as a factor change of the dependent variable in response to a unit change in the respective independent variable (Long and Freese, 2014). In the case of the first model, Table 4 reveals a constant of 2.7. This indicates that the number of additives for the reference category *MS* is equal to 2.7, assuming all other variables are set equal to zero. The significant IRR of 0.8 (1.1) for *PM (RM)* indicates that the number of additives in this category is lower (higher) by a factor of 0.8 (1.1) compared to *MS*. As regards FOP information, the labels *Natural_presence* and *Natural_absence* seem to be in line with fewer additives in meat and meat substitute innovations, although the IRR is not significant for the latter. The opposite applies to *Science_absence* claims. Thus, products claiming to have reduced their amounts of negatively associated ingredients seem to compensate this with an increase in additives. There is no significant relationship between *Science_presence* and the number of additives. Finally, the IRRs for time is below one, indicating that the number of additives used in the German meat market per innovation has decreased over time. There is no association between price and the number of additives.

If the *MS* category is split and the *NVMS* dummy added to the original model we obtain a lower value for the constant (2.2) which now refers to the reference category *VMS*. The IRRs for *NVMS* reveal that meat substitute innovations in this category have a higher number of additives than *VMS*. The use of additives does not differ between *PM* and *VMS.* All other findings mirror those of the first model. The estimated alpha values, which reflect the dispersion parameter, indicate that the NBREG is preferred over the Poisson regression approach for both models as the latter model suffers from overdispersion. Furthermore, the Wald tests indicate the overall significance of both models.

Table 3-4. NBREG of product categories, FOP information and controls on the #Additives (IRRs)

	(All products)	(All products)	(*RM*)	(*PM*)	(*MS*)	(*NVMS*)	(*VMS*)
VARIABLES	*#Additives*	*#Additives*	*#Additives*	*#Additives*	*#Additives*	*#Additives*	*#Additives*
RM	1.076*	1.310***					
	(0.046)	(0.072)					
PM	0.849***	1.036					
	(0.043)	(0.064)					
NVMS		1.523***					
		(0.111)					
Natural_presence	0.470***	0.510***	0.640***	0.428***	0.270***	0.272***	0.314***
	(0.021)	(0.024)	(0.033)	(0.077)	(0.020)	(0.062)	(0.027)
Natural_absence	0.985	0.985	1.072**	0.814***	0.822***	0.885	0.830*
	(0.029)	(0.027)	(0.034)	(0.060)	(0.062)	(0.101)	(0.087)
Science_presence	1.118	1.097	1.304**	1.039	0.994	1.311*	0.791
	(0.081)	(0.078)	(0.144)	(0.441)	(0.098)	(0.206)	(0.113)
Science_absence	1.136***	1.127***	1.053	1.292***	1.103	0.919	1.059
	(0.044)	(0.043)	(0.049)	(0.097)	(0.133)	(0.164)	(0.210)
Time	0.972***	0.972***	0.980***	0.963***	0.933***	0.912***	0.979
	(0.005)	(0.005)	(0.006)	(0.013)	(0.020)	(0.032)	(0.031)
Price in €/100g	1.000	0.998	0.943***	1.390***	1.288***	1.430***	1.236***
	(0.010)	(0.010)	(0.012)	(0.084)	(0.080)	(0.198)	(0.082)
Constant	2.653***	2.170***	2.905***	1.696***	2.883***	2.942***	2.091***
	(0.140)	(0.136)	(0.102)	(0.172)	(0.459)	(0.799)	(0.467)

VARIABLES	(All products) *#Additives*	(All products) *#Additives*	(*RM*) *#Additives*	(*PM*) *#Additives*	(*MS*) *#Additives*	(*NVMS*) *#Additives*	(*VMS*) *#Additives*
alpha	0.226***	0.221***	0.130***	0.515***	0.250***	0.305***	0.146***
	(0.017)	(0.017)	(0.017)	(0.053)	(0.046)	(0.077)	(0.054)
Observations	5,482	5,482	3,601	1,141	740	232	508
pseudo-R^2	0.022	0.024	0.011	0.019	0.101	0.055	0.097
Log pseudo-likelihood	-10253	-10235	-6840	-2076	-1194	-470.7	-711.5
Wald chi^2	496.1	551.6	154.2	86.08	337.3	57.72	196.7
p	0.000	0.000	0.000	0.000	0.000	0.000	0.000

The values reported are the IRRs. Transformed robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. *MS* is the reference category in column 1, while *VMS* serves as the reference category in column 2. *RM*: Red meat, *PM*: Poultry meat, *MS*: Meat substitutes, *NVMS*: Non-vegan *MS*, *VMS*: Vegan *MS*.

A comparison of the estimations for the different meat categories reveals similarities and differences in results again. *Natural_presence* seems to be a consistent predictor for fewer additives across all categories. The results for *Natural_absence* are inconsistent; it is associated with more additives in *RM* products and with less additives in *PM, MS* and *VMS.* The *Science_absence* claim is associated with a higher number of additives in *PM* while *RM* and *NVMS* tend to have more additives when labelled with *Science_presence.* We find that the usage of additives decreases over time for all product categories, though not significantly for *VMS.* Finally, a higher price is associated with more additives across all meat categories, with the exception of *RM* innovations where the opposite holds. Again, the estimates for the alphas across all categories indicate that the NBREG is to be preferred over the Poisson regression. Furthermore, the Wald tests reveal the overall significance of all subcategory models.

We re-run the estimations to assess the effect of the control variables *Time* and *Price* and to distinguish between *Natural_absence_GMO* and *Natural_absence_addit.* The latter allows determining the drivers of the results of the *Natural_absence* variable as *Natural_absence_addit* is directly related to the dependent variable. The results are presented in Appendix IV, Table 3 and Appendix V, Table 4 and indicate that our results for credence attributes and the meat categories are mostly robust regarding the inclusion of control variables and that *Natural_absence_addit* is associated with fewer additives, while the results for *Natural_absence_GMO* labelled products are mixed across categories.

3.4 Discussion

This study aims to add to the ongoing discussion about sustainable and healthy food consumption by investigating the extent to which meat and meat substitute innovations differ regarding their nutritional quality and naturalness. We use the *A-score* of the Ofcom nutritional profile to measure nutritional quality. This includes saturated fats, sodium, sugar, and the energy content of products, while naturalness is quantified through the number of different additives applied in product innovations.

3.4.1 Nutritional quality of different meat and meat substitute categories

High levels of meat consumption can have negative effects on human health, despite the superior nutritional quality of protein from meat sources compared to plant-based sources. We found that especially red meat products but also poultry meat contain more 'nutrients to limit' per 100g of product weight than meat substitutes. This result differs from the findings of Bohrer (2019), who could not derive unambiguous results on whether meat substitutes are indeed of better nutritional quality than meat products. However, as Bohrer's (2019) analyses are based on a limited sample of 13 products, of which 7 are MS, our findings are likely more robust as we consider the nutritional facts of 5,482 different products. In addition, we not only found differences in the nutritional quality between meat substitutes and meat products, but also detected differences between vegan and non-vegan substitutes, whereby the latter tend to contain higher amounts of the 'nutrients to limit'. Hence, given the fact that obesity and diet-related diseases are of great concern in high-income countries like Germany, meat substitutes together with poultry products are an option to reduce the intake of 'nutrients to limit' while still providing sufficient amounts of protein.

However, the measure we chose as a proxy for the nutritional quality does not allow conclusions to be reached on general health effects. Although the A-score includes the relevant nutrients, previous literature presents mixed results on the validity of this measure when discussing the nutritional risks associated with meat. While Julia *et al.* (2015) found a positive association between the intake of products classified as unhealthy by the Ofcom score and the risk of metabolic diseases, Mytton *et al.* (2018) detected no relationship between the intake of products classified as unhealthy and cardiovascular diseases. In spite of these mixed results, the Ofcom A-score allows the nutritional facts for different products to be compared on a single aggregated scale and to conclude on a product's nutritional quality.

3.4.2 Usage of food additives in different meat categories

Previous literature highlights potential barriers which prevent consumers from adopting meat substitutes in their diet. In addition to the expected taste, these include the artificialness of the products (Siegrist and Sütterlin, 2017; Hoek *et al.*, 2011). More specifically, some consumers are not only wary of highly processed products but also of the excessive presence of food additives which detract from the perceived naturalness of the products (Siegrist and Sütterlin, 2017). Furthermore, there are health-related issues associated with food additives. However, a comparison of the usage of food additives across meat categories shows that vegan meat substitutes, as well as poultry meat products, contain fewer additives than red meat products and non-vegan *MS*. However, based on our sample of 740 *MS* of which 232 (31%) are *NVMS* we conclude that the relevance of non-vegan *MS* in the German meat market is lower compared to *VMS* (cf. Figure 1). Consequently, due to the lower relevance of NVMS and the fewer additives in VMS, there might be a misconception in the mind-set of consumers regarding the degree of artificialness of meat substitutes compared to meat products.

3.4.3 Relationship of nutritional quality and food additives with FOP information

In supermarkets with large product ranges, consumers face an excess of information. Therefore, producers in the meat market use FOP information to close the information gap between themselves and consumers and to advertise their product's superiority. Rödl (2018) found that meat products are advertised with claims and labels designed to support the idea that "*eating meat is normal, natural, and necessary*" (Rödl, 2018: 330). Furthermore, *MS* copy this marketing strategy. Although we did not include "normal" and "necessary" as specific FOP information, we found an even greater use of FOP information on meat substitutes than on meat products, whereby it focuses specifically on the natural dimension. This includes labels such as organic (*Natural* and *Presence)* or GMO-free (*Natural* and *Absence)*. Consumers tend to perceive MS as more artificial and less natural than red and poultry meat products (Michel, Hartmann and Siegrist, 2021). The higher degree of concentration on natural claims in *MS* could thus aim at overcoming this. Furthermore, especially *Science_presence* (e.g. "high in protein") but also *Science_absence* (e.g. "reduced/low in fat") claims and labels seem to be of little relevance in the meat market and though more prevalent also seldom applied in the meat substitute market. However, *Science_absence* claims and labels can be interpreted as the producers' reaction to criticism regarding the nutritional quality of meat products.

Finally, the FOP information is not consistently related to the products' nutritional quality and the number of additives they contain. Previous literature indicates that consumers perceive products with a natural label to be healthier, even though these two product characteristics are unrelated (Schuldt and Schwarz, 2010). We find no unambiguous relationship between the natural dimension of the FOP classification by André, Chandon and Haws (2019) and the nutritional quality of the products. Therefore, consumers cannot rely on natural FOP information to make assumptions about the nutritional quality of products. However, according to our findings *Natural* and *Presence* labels indicate over all product categories that a product is less artificial as measured by the number of additives used. For that, it is important to stress that not all additives approved for conventional products are also approved for EU-certified organic products (EU Commission Regulation (EC) No 889/2008). This means that the organic label is in general a reliable indication for fewer additives. Despite the low relevance of the *Science_presence* labels, there is a noticeable relationship with nutritional quality and artificialness in red meat innovations. Products labelled in this way tend to have a higher *A-score* and contain more additives and thus can mislead consumers in their perception of the healthiness and naturalness of RM. Taking into account that positively framed claims might further foster that perception (André et al., 2019) indicates that this might be an interesting area for future research. We also find that while *RM* and *MS* products bearing a *Science_absence* claim contain fewer nutrients to limit, this claim is associated with more food additives in *PM* products. This shows that a single FOP information area is not a reliable cue for consumers seeking products with both better nutritional quality and fewer food additives.

3.4.4 Limitations

Our analyses have several drawbacks and limitations. First, we did not distinguish between different product types commonly available on the meat market, for example, sausages and raw fillets. This would allow to consider the fact that the market is very heterogeneous concerning the types of product available. However, we believe that this issue is covered, at least partly, by assuming that the whole range of different product types is available in the different categories of meat (*RM*, *PM* and *MS*) that we included in our analysis. Nonetheless, future research should consider analysing the differences between meat and meat substitutes based on more disaggregated product groups. Moreover, our analyses rely on secondary data with no information on the reliability of the data. Therefore, it is impossible to infer representativeness for the German meat market from the used data. However, based on the large number of different products included, we are confident that our findings provide a solid starting point for future research on the debate about the nutritional quality of meat and meat substitute innovations.

A second limitation is that we conclude on the nutritional quality of products although we did not include the C-score of the Ofcom score. This was due to the fact that information on elements necessary for the calculation of the C-score, such as fibre and fruit and vegetable content, is not available in the Mintel database for each product. However, this also implies that we omit products’ protein content in our proxy for nutritional quality. The protein content, however, is important when evaluating the overall nutritional quality of food products. This holds especially in the case of meat as this product category is one of the major sources for high-value proteins (Bohrer, 2017). In low-income countries foods from animal sources have a crucial role in e.g. the challenge to reduce child stunting (Headey, Hirvonen and Hoddinott, 2018). However, given our focus on Germany, where a lack of protein in the diet is usually not the case this limitation is likely less relevant. Nevertheless, it would be desirable if future research could evaluate the nutritional value of meat and meat substitutes on the A and C-score of the Ofcom nutrient profile or consider other holistic nutritional profiles.

Third, the chosen proxy for the artificialness of products only considers the number of different additives. We, therefore, cannot distinguish between different kinds of food additives such as flavour enhancers or preservatives, though they might be perceived differently by consumers (Aschemann-Witzel, Varela and Peschel, 2019). Further, we did not consider other factors that might influence the degree of perceived artificialness of a product, like the processing level, the number of different ingredients, consumers’ familiarity with the product, or the novelty of the innovation. However, consumers do perceive food additives as a factor that lowers the naturalness of the product (Siegrist and Sütterlin, 2017). Nevertheless, including additional drivers of perceived artificialness might be an avenue of future research.

Fourth, we did not conduct a survey and, therefore, cannot conclude that the products with a *Natural* claim are indeed perceived as healthier or not. We can only assume that there is a Halo-effect where some consumers might assume that products are generally healthier when they bear a *Natural* claim/label (Verain, Sijtsema and Antonides, 2016). However, this would require further research involving a comparison of products with and without a *Natural* claim and exhibiting different nutritional values to determine how healthy these products are perceived by consumers.

Finally, our analysis solely focuses on the nutritional components of meat and meat substitute despite the wide and complex range of other product and process attributes of relevance in consumers’ decisions to consume meat or meat substitutes such as animal welfare or the environmental impact.

3.4.5 Conclusion

To summarise, meat substitutes contain fewer nutrients to limit, such as salt and saturated fats, than red and poultry meat. Therefore, consumers who are looking for alternative products with fewer of these potentially adverse nutrients might consider adopting meat substitutes. Non-vegan meat substitutes tend to contain the highest amount of food additives while the use of additives is lowest for poultry meat followed by vegan meat substitutes. Furthermore, our analysis revealed a relationship between the nutritional quality and the usage of food additives on the one hand and FOP claims and labels used on products in the meat market on the other hand. While *Science_absence* labelling, such as "reduced in fat", is for some categories related to higher nutritional quality, it is also associated in the case of poultry meat with a greater number of additives. Finally, *Natural* labelling, such as "organic", is associated across meat and meat substitute categories with fewer additives, but it is not consistently related to a better nutritional quality. Hence, FOP information in the meat market is not a reliable cue for jointly predicting the naturalness and the nutritional quality of a product.

3.5 Appendix

Appendix I

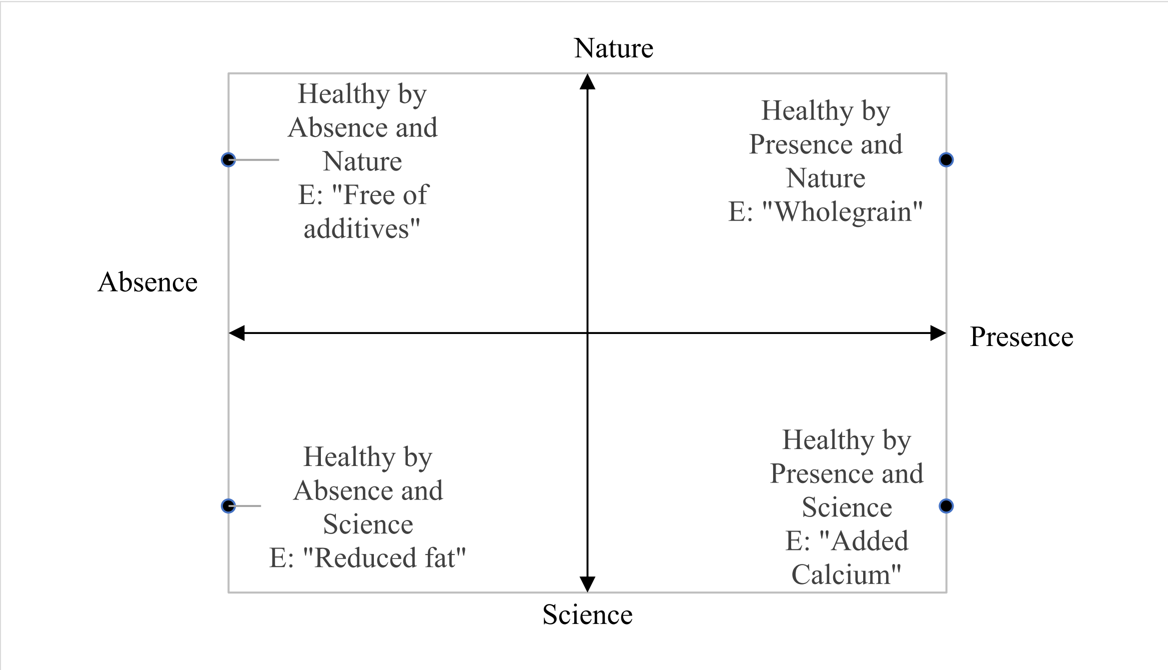

Figure 3-2A. Dimensions of health information

Source: (André, Chandon and Haws, 2019: 176; Fig. 1).

Illustration of the two dimensions “nature and science” and “absence and presence” with examples (E:) for the meat market.

Table 3-A1 – Overview on Labels

Natural_presence	*Natural_absence*	*Science_presence*	*Science_absence*
Whole-grain	GMO-free	High in protein content	Low/free of cholesterol
Natural product	Free of (certain) additives	Added fibre	Low in/free of calories
Organic		Added vitamins and minerals	Low/free of sugar
		Added calcium	Low/free of sodium
			Low/free of trans fats
			Low/free of fat

Appendix II, Table 1. FOP information in terms of claims and labels assigned to the overall FOP information categories: *Natural_presence, Natural_absence*, *Science_absence* and *Science_presence*.

Table 3-A2 - OLS-Regression of product categories and FOP information on the *A-score*

	(All products)	(All products)	(*RM*)	(*PM*)	(*MS*)	(*NVMS*)	(*VMS*)
VARIABLES	*A-score*	*A-score*	*A-score*	*A-score*	*A-score*	*A-score*	*A-score*
RM	6.708***	7.297***					
	(0.211)	(0.260)					
PM	1.102***	1.703***					
	(0.238)	(0.284)					
NVMS		1.543***					
		(0.305)					
Natural_absence	0.287	0.280	1.332***	-1.431***	-0.280	0.411	-0.586
	(0.187)	(0.187)	(0.272)	(0.348)	(0.290)	(0.450)	(0.372)
Natural_presence	-0.068	0.197	0.046	1.921**	-0.913***	-1.459***	-0.101
	(0.246)	(0.261)	(0.389)	(0.798)	(0.279)	(0.468)	(0.355)
Science_presence	0.224	0.195	1.530**	0.680	-0.567*	-1.073**	-0.300
	(0.331)	(0.328)	(0.723)	(2.426)	(0.344)	(0.491)	(0.432)
Science_absence	-2.407***	-2.430***	-3.871***	0.868**	-1.234***	-0.858	-1.571***
	(0.253)	(0.252)	(0.332)	(0.428)	(0.458)	(0.627)	(0.594)
Constant	9.944***	9.336***	16.582***	11.174***	10.555***	11.074***	9.794***
	(0.203)	(0.258)	(0.127)	(0.156)	(0.222)	(0.319)	(0.315)
Observations	5,482	5,482	3,601	1,141	740	232	508
R^2	0.203	0.205	0.025	0.027	0.030	0.062	0.022
adjusted-R^2	0.202	0.204	0.0240	0.023	0.025	0.045	0.015
F-value	311.2	269.4	38.83	6.127	6.404	4.359	3.368
p-value	0.000	0.000	0.000	0.000	0,000	0.002	0.010

Heteroskedasticity robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. *MS* is the reference category in column 1 while *VMS* serves as reference category in column 2. *RM*: Red meat, *PM*: Poultry meat, *MS*: Meat substitutes, *NVMS*: Non-vegan *MS*, *VMS*: Vegan *MS*

Table 3–A3 - NBREG of product categories and FOP information on the #Additives (IRRs)

VARIABLES	(All products) *#Additives*	(All products) *#Additives*	(*RM*) *#Additives*	(*PM*) *#Additives*	(*MS*) *#Additives*	(*NVMS*) *#Additives*	(*VMS*) *#Additives*
RM	1.082*	1.321***					
	(0.046)	(0.072)					
PM	0.852***	1.042					
	(0.043)	(0.064)					
NVMS		1.530***					
		(0.112)					
Natural_presence	0.467***	0.506***	0.606***	0.689***	0.281***	0.272***	0.319***
	(0.021)	(0.023)	(0.031)	(0.093)	(0.021)	(0.063)	(0.027)
Natural_absence	0.988	0.988	1.072**	0.846**	0.855**	0.971	0.843*
	(0.029)	(0.029)	(0.034)	(0.065)	(0.065)	(0.111)	(0.086)
Science_presence	1.103	1.083	1.292**	0.962	1.013	1.478**	0.796
	(0.080)	(0.077)	(0.142)	(0.402)	(0.104)	(0.235)	(0.112)
Science_absence	1.169***	1.159***	1.074	1.505***	1.156	0.944	1.061
	(0.045)	(0.044)	(0.050)	(0.109)	(0.143)	(0.175)	(0.208)
Constant	2.259***	1.845***	2.393***	1.937***	2.814***	2.859***	2.566***
	(0.097)	(0.101)	(0.034)	(0.066)	(0.138)	(0.207)	(0.173)
alpha	0.230***	0.225***	0.137***	0.576***	0.284***	0.355***	0.163***
	(0.017)	(0.017)	(0.017)	(0.056)	(0.048)	(0.082)	(0.056)
Observations	5,482	5,482	3,601	1,141	740	232	508
pseudo-R^2	0.021	0.023	0.008	0.005	0.092	0.041	0.091
Log pseudo-likelihood	-10267	-10250	-6861	-2105	-1206	-478.0	-716.0
Wald chi^2	463.0	516.5	110.0	44.71	312.3	42.01	182.5
p	0.000	0.000	0.000	0.000	0.000	0.000	0.000

The values reported are the IRRs. Transformed robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. *MS* is the reference category in column 1, while *VMS* serves as the reference category in column 2. *RM*: Red meat, *PM*: Poultry meat, *MS*: Meat substitutes, *NVMS*: Non-vegan *MS*, *VMS*: Vegan *MS*.

Table 3–A4 - NBREG of product categories, FOP information and controls on the #Additives (IRRs)

	(All products)	(All products)	(*RM*)	(*PM*)	(*MS*)	(*NVMS*)	(*VMS*)
VARIABLES	*#Additives*	*#Additives*	*#Additives*	*#Additives*	*#Additives*	*#Additives*	*#Additives*
RM	1.045	1.227***					
	(0.045)	(0.070)					
PM	0.852***	0.999					
	(0.043)	(0.062)					
NVMS		1.394***					
		(0.104)					
Natural_presence	0.488***	0.520***	0.635***	0.451***	0.269***	0.281***	0.302***
	(0.023)	(0.025)	(0.033)	(0.071)	(0.020)	(0.064)	(0.026)
Nat_absence_addit	0.608***	0.634***	1.153	0.323***	0.735***	0.000***	0.860
	(0.045)	(0.047)	(0.108)	(0.051)	(0.073)	(0.000)	(0.092)
Nat_absence_GMO	1.108***	1.098***	1.063*	1.275***	0.796**	0.892	0.652**
	(0.033)	(0.033)	(0.034)	(0.095)	(0.073)	(0.102)	(0.115)
Science_presence	1.111	1.095	1.310**	0.904	0.990	1.308*	0.817
	(0.080)	(0.077)	(0.145)	(0.311)	(0.097)	(0.205)	(0.113)
Science_absence	1.111***	1.106***	1.055	1.214***	1.118	0.921	1.139
	(0.043)	(0.042)	(0.049)	(0.089)	(0.134)	(0.165)	(0.220)
Time	0.977***	0.977***	0.979***	0.999	0.931***	0.910***	0.970
	(0.005)	(0.005)	(0.006)	(0.013)	(0.020)	(0.032)	(0.030)
Price in €/100g	0.995	0.994	0.943***	1.235***	1.306***	1.420**	1.256***
	(0.010)	(0.010)	(0.012)	(0.062)	(0.081)	(0.195)	(0.083)
Constant	2.643***	2.251***	2.911***	1.588***	2.928***	2.994***	2.233***
	(0.139)	(0.144)	(0.102)	(0.151)	(0.462)	(0.811)	(0.484)
alpha	0.214***	0.211***	0.130***	0.421***	0.236***	0.303***	0.127***
	(0.017)	(0.016)	(0.017)	(0.050)	(0.046)	(0.077)	(0.052)
Observations	5,482	5,482	3,601	1,141	740	232	508
pseudo-R^2	0.026	0.027	0.011	0.039	0.105	0.057	0.102
Log pseudo-likelihood	-10215	-10204	-6839	-2035	-1189	-470.0	-706.8
Wald chi^2	524.3	567.5	154.9	159.1	350.3	382.1	207.3
p	0.000	0.000	0.000	0.000	0.000	0.000	0.000

The values reported are the IRRs. Transformed robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. *MS* is the reference category in column 1, MS is the reference category, while *VMS* serves as the reference category in column 2. *RM*: Red meat, *PM*: Poultry meat, *MS*: Meat substitutes, *NVMS*: Non-vegan *MS*, *VMS*: Vegan

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4 Comparing Meat and Meat Alternatives: An Analysis of Nutrient Quality in 5 European Countries

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Abstract:

Objective: To assess and compare the (macro-)nutritional composition of red and poultry meat products with the emerging category of meat substitutes.
Design: We use information on nutritional values per 100g to estimate the differences in the nutritional composition between red meat, poultry meat, vegan and non-vegan meat substitutes and derive six unique meat product clusters to enhance the comparability.
Setting: Meat markets from five major European countries: France, Germany, United Kingdom, Italy, Spain.
Participants/Data: Product innovation data for 19,941 products from Mintel's Global New Product Database from 2010-2020.
Results: Most of the innovations in the sample are red meat products (55%), followed by poultry (30%), vegan meat substitutes (11 %) and non-vegan meat substitutes (5%). Red meat products exhibit a significantly higher energy content in kcal/100g as well as fat, saturated fat, protein, and salt all in g/100g than the meatless alternatives, while the latter contain significantly more carbohydrates and fiber than either poultry or red meat. However, results differ to a certain degree when products are grouped into more homogeneous clusters like sausages, cold cuts and burgers. This indicates that general conclusions regarding the health effects of substituting meat with plant-based alternatives should only be drawn in relation to comparable products.
Conclusions: Meat substitutes, both vegan and non-vegan, are rated as ultra-processed foods. However, compared to red meat products, they and also poultry products both can provide a diet that contains fewer nutrients-to-limit, like salt and saturated fats.

Keywords: meat substitute, red meat, poultry meat, nutritional composition, nutrients, nutritional comparison

4.1 Introduction

Meat provides a dense form of valuable macro- and micronutrients, but its environmental impact, e.g., carbon footprint, is worse than that of alternative plant-based protein sources such as peas(Nijdam, Rood and Westhoek, 2012; Saget *et al.*, 2021). Furthermore, there is growing ethical concern among consumers about the production methods within the meat industry and animal welfare(Birkle, Klink-Lehmann and Hartmann, 2022). Finally, ongoing research indicates that overconsumption of meat, particularly processed meat products, is associated with detrimental effects on health and increasing the incidence of non-communicable diseases (NCDs), such as hypertension(Cocking *et al.*, 2020; Chung, Li and Liu, 2021). The food industry has responded to these objections to meat products by developing meat substitutes. Meat substitutes are defined in this paper as products that mimic the taste, appearance, texture and smell of meat products such as steak or salami(Petersen, Hartmann and Hirsch, 2021). In addition, we consider products such as tofu as meat substitutes because they replace the function of meat in a meal(Petersen, Hartmann and Hirsch, 2021). In contrast, we do not consider products such as cheese, insects, peas, or fish as meat substitutes(Petersen, Hartmann and Hirsch, 2021; Hoek *et al.*, 2011). Although their environmental impact is lower(Clark *et al.*, 2022), meat substitutes are also considered unhealthy because most of them can be classified as ultra-processed foods(Wickramasinghe *et al.*, 2021). These are, like processed and red meats, associated with detrimental health effects(Lane *et al.*, 2021). For example, higher shares of calories originating from ultra-processed foods as classified by the NOVA system[(8)] in diets are, similar to meat, associated with adverse effects on cardiovascular health(Lane *et al.*, 2021). In this context, a study based on a large sample (n = 21,212) for the French market found a positive correlation between a higher avoidance of animal products in diets and the consumption of ultra-processed foods (Gehring *et al.*, 2021). In terms of public health, this raises the question of whether meat substitutes can improve the nutritional composition of diets compared to conventional meat products(Siegrist and Hartmann, 2023). Therefore, in this paper, we use a holistic and multinational sample of 19,941 product innovations from five major European countries over a period of 11 years to analyze the differences in the nutrient content of meat substitutes, poultry, and red meat products.

Although eating habits differ across European countries and regions, high meat consumption is common and usually exceeds the recommendation of the World Cancer Research Fund of 350-500 g/week(WCRF). The United Kingdom has the lowest annual consumption amongst the countries studied, with 71.6 kg/per capita, while it is highest in Spain at 105.8 kg/per capita(LfL

& LEL, 2022; DEFRA, 2022). The annual meat consumption in the EU 28 and the sample countries is presented in the supplemental Table 1.

The nutritional composition of meat and meat substitutes is a widely debated subject, particularly given the concerns regarding the overconsumption of certain nutrients, e.g., saturated fats and salt, found in both processed red meats and ultra-processed foods (Wickramasinghe *et al.*, 2021; Macdiarmid, 2022). Red meat products, and especially processed meat products, have a high salt content (Inguglia *et al.*, 2017). While sodium, as part of dietary salt, is an essential nutrient (Gharibzahedi and Jafari, 2017), excessive intake is associated with higher blood pressure and consequently a greater risk for cardiovascular diseases (He and MacGregor, 2018). Hence, the World Health Organization (WHO) recommends a maximum salt intake of 5 g per day for adults to reduce the problem of hypertension and other diet-related NCDs(WHO, 2022) . However, the actual intake of salt in Europe exceeds the amount recommended by the WHO, ranging from 8-12 g per day in most European countries (European Commission, 2012).

The overconsumption of energy-dense foods is associated with a higher risk of obesity(Hill, Wyatt and Peters, 2012), which in turn is a risk factor for several NCDs (Vandevijvere *et al.*, 2015). The WHO nutrition recommendation foresees an intake of under 30% of the total energy supply from fats and under 10% from saturated fats(WHO, 2022). However, actual consumption in Europe is higher, whereby meat is one of the major sources of total fats and saturated fats (Eilander, Harika and Zock, 2015). In addition, ultra-processed foods are usually characterized by high fat levels per 100g (Da Rocha *et al.*, 2021). The risk of cardiovascular diseases can be lowered by using polyunsaturated fats from plant-based products instead of animal-based saturated fats (Sacks *et al.*, 2017).

In Europe meat is one of the primary sources of high-quality protein(Cocking *et al.*, 2020; Bohrer, 2017). On the other hand, plant-based proteins are less digestible than those of animal origin(Bohrer, 2017). However, this can be improved by processing techniques like fermentation or cooking (Sá, Moreno and Carciofi, 2020). Furthermore, a meta-analysis suggests that the risk of cardiovascular diseases can be reduced by using plant-based proteins instead of animal-based proteins(Li *et al.*, 2017). While the WHO recommends for healthy adults, both men and women, a safe intake level of 0.83g/kg body weight(WHO, 2007), most adults in high-income countries exceed this recommendation (Mittendorfer, Klein and Fontana, 2020). Diets with a protein intake that exceeds the recommended amount can be related to a higher risk for type-2 diabetes (Mittendorfer, Klein and Fontana, 2020).

The previous literature on differences in the nutritional composition of meats and meat substitutes is limited, as it is often based on small sample sizes and presents mixed results. One study comparing the nutrient content of modern meat substitutes and meat products yields inconclusive results regarding which of the two options is healthier from a nutritional viewpoint(Bohrer, 2019). However, the study size is limited on a sample of just 13 individual products A second study, carried out in the market of the United Kingdom in 2020 involving a total of 207 meat substitutes and 226 red and poultry meat products reports that ~~in the main,~~ the nutrient composition of meat substitutes is beneficial, but thereby it does not examine the role of carbohydrates (2021). A third study based on 137 products for the Australian market reports mixed results for the differences in nutritional values when comparing the product groups of burger, sausages and minced meats (Curtain and Grafenauer, 2019). Moreover, a study for the German meat market found based on an aggregated score fewer 'nutrients to limit', i.e., salt, sugar, saturated fat and energy content, in meat substitutes than in red and poultry meat products(Petersen, Hartmann and Hirsch, 2021). Finally, a recent study of the Italian meat substitute market based on 269 products reports some nutritional benefits of meat substitutes, however, it does not recommend them as a wholesome replacement for meat(Cutroneo *et al.*, 2022).

Our research contributes to the literature as follows: We use a holistic sample of 19,941 individual products introduced between 2010 and 2020 in five major European countries, France, Germany, United Kingdom, Italy, and Spain, to compare and analyze the nutritional composition of meat substitutes and traditional meat products. Thereby, we provide data for the nutritional composition of products on a disaggregated scale. And finally, the comparability is enhanced by systematically grouping red meat products and poultry meat products and the corresponding meat substitutes into homogenous clusters, like burgers or sausages. To the best of our knowledge, our analysis provides the first holistic comparison of the nutritional characteristics of meat and meat substitutes across European countries. While meat consumption patterns differ perceptibly, there are similarities in the overall level of high meat overconsumption.

4.2 Materials and methods

We used data from Mintel's Global New Product Database (GNPD)(Mintel, 2022). This keeps abreast with the fast-moving consumer goods market and provides information and data about product innovations, which are being launched in supermarkets in countries worldwide. The product data is entered into the database by shoppers and offers a wide range of information about the products, such as the region where the product was introduced, the date of market introduction, the producer, the complete information provided on the product package, including the nutrients and ingredients, plus pictures of the product, its size, and price (Mintel, 2022). Our initial search for all red meat, poultry meat and meat substitutes introduced in the five European countries studied, France, Germany, United Kingdom, Italy and Spain over the time frame 2010-2020, resulted in 27,375 product-level observations.

Packaged food products in the EU must comply with legal requirements regarding the information provided on the packages(European Parliament & European Council, 2011 / 2011). As this includes detailed information on the ingredients and the nutritional values of the products(European Parliament & European Council, 2011 / 2011), we were able to conduct our nutritional comparison of products based on information for the following nutrients: energy content in kcal/100g, fat, saturated fats, carbohydrates, sugar, protein, fiber, and salt (all in g/100g). In cases where products indicated the sodium content instead of the salt content, we used the molecular weight of sodium and chloride to calculate the salt content. Since information on the fiber content is not mandatory on all products, it was calculated based on energy levels. In accordance with the literature (Menezes *et al.*, 2016) the calculation was carried out using the energy levels of protein (4 kcal/g), carbohydrates (4 kcal/g), and fat (9 kcal/g) in the product's total energy content without fiber. The calculated energy without fiber was then subtracted from the energy level indicated on the package and the number was divided by the energy level of fiber (2 kcal/g). Finally, we replaced the missing fiber values with the calculated values. The conversion factors applied are available in the EU legislation for nutritional information (European Parliament & European Council, 2011 / 2011). Although this approach is less accurate than an analytical detection of fiber levels, it allowed a larger number of observations to be compared, as only 8,598 of the 27,375 products reported the fiber content.

We commenced by checking the minimum and maximum values for each nutrient in each product to identify outliers and incorrect values and thus ensure data accuracy and mitigate potential biases caused by reporting errors in the data. Secondly, we checked for recording errors in the database, e.g., cases in which the saturated fats were reported to be higher than the total fat, which is impossible. In these cases, we used the images of the products to derive the correct values from the nutrition facts label. We corrected a total of 1,603 individual values based on the product images. In cases where the information was originally obtained from the product itself, but was obviously incorrect, we excluded the observation from our analysis. Note that this only applied to 155 products (0.5%). An estimated value for the calories was then calculated based on the information for fat, carbohydrates, fiber and protein, to identify those products with a large, i.e., > 10 kcal/100g, deviation between the estimated value and the caloric value indicated on the package. In these cases, we rechecked to confirm that the information entered in Mintel's GNPD matched the information on the packages and corrected the value in our database accordingly. In addition, we used STATA's Bacon algorithm, which is based on Mahalanobis distances, to detect multivariate outliers under consideration of all nutritional indicators and the values calculated for fiber(Weber, 2010). The algorithm detected 51 outliers, which were excluded from further analysis. These outliers are characterized by a high divergence between the calculated and the indicated calorie content.

4.2.1 Meat categories and meat cluster formation

The GNPD database only distinguishes between poultry meat, red meat and meat substitute products. However, previous literature has shown that there are nutritional differences between vegan and non-vegan meat substitutes(Petersen, Hartmann and Hirsch, 2021). Therefore, the ingredients listed for the meat substitutes included in our sample were used to verify whether a product is vegan or not. This resulted in two distinct groups: vegan meat substitutes and non-vegan meat substitutes.

Furthermore, as the meat market encompasses a wide range of heterogenous products, from minimally processed fillet to highly processed ham, which are not only consumed in different portion sizes but are also likely have different nutritional compositions, we applied a clustering mechanism to group products into more homogenous, more comparable product clusters. A study on the UK meat market grouped products into the following six distinct clusters: sausages, burgers, plain poultry, breaded poultry, mince and meatballs and compared the meat alternatives in each cluster with their traditional meat counterparts (2021). A second study applied four clusters: burgers, meatballs, ham and nuggets (2019). In line with the previous literature, we create six different clusters: burgers, coated meat, cold cuts, meatballs, meat for roasting and cooking, and sausages. These clusters represent major sectors of the total meat market and we believe that they duly reflect its heterogeneity, thus facilitating a better comparison of individual products. We created keywords for each cluster, e.g., quarter pounder for burgers, or nuggets for coated meats. Supplemental Table 3 presents a sample list of keywords for each cluster and the full list is available from the authors upon request. We then matched the names of the products with the keywords and assigned the products to the respective cluster. Our aim was to allocate each product in the sample to one specific cluster, but in some cases a product was placed in more than one cluster. One example of this is a product named 'burger bacon', which was not only allocated to the burger cluster but, due to the keyword “bacon”, was also to be found in the cold cuts cluster. In cases where the name did not tally specifically with one individual cluster, we checked the images of the products and allocated them manually to the best fitting cluster. Products which could not be assigned to one specific cluster were excluded from the whole study. This reduced our sample size by 1,582. In addition, we excluded 205 assortments from the analysis, e.g., packages containing a variety of different hams. In a last step, products with missing values for nutrients other than fiber were excluded.

4.2.2 Statistical analysis

The main objective of this study is to compare the nutritional values of products in the market for meat and meat substitutes. Hence, for our estimation, we first assumed that our observations apply to one meat market comprising the four broad product categories red meat (RM), poultry meat (PM), vegan meat substitute (VMS) and non-vegan meat substitute (NVMS) products. The differences in nutritional quality between these product groups were determined by estimating a set of eight linear equations with the individual nutrients (sugar, carbohydrates, fat, saturated fats, protein, salt and fiber each in g/100g) and the energy content (in kcal/100g) as the dependent variables and the meat categories (RM, PM, NVMS and VMS) are the independent variables. The multi-equation model is defined as follows and the full list of variable definitions is reported in the supplemental Table 1:

$$Y_{i\,(k)} = \beta_{0\,(k)} + \beta_{PM\,(k)} * PM_i + \beta_{NVMS\,(k)} * NVMS_i + \beta_{VMS\,(k)} * VMS_i + \varepsilon_{i\,(k)} \quad with\ k = 1, \dots, 8$$

where i indicates the 19,941 products and k indicates the eight different regressions with the nutrients and calorie content as dependent variables each reflected by $Y_{(k)}$. PM, $NVMS$ and VMS are dummy variables that take a value of one if product i belongs to the respective product category. Finally, ε_i is an error term. In the above model, we used red meat (RM) as our reference category. We assumed the common null hypothesis for all β that the differences in the nutritional values are zero. After estimating each regression model, we compared the β coefficients (i.e., the estimated marginal means) for the meat categories pairwise. We corrected the p-values for statistical significance with the approach proposed by Benjamini & Hochberg which corrects for the false discovery rate to avoid an alpha error for the rejection of a true null hypothesis, which can arise by random chance in a multiple comparison context(1995). This procedure reduces the risk of a beta error more effectively than alternative approaches like the

Bonferroni correction. In addition, we present the results with the correction proposed by Holm, which corrects for the familywise error rate (1979).

In the second stage of our analysis, we considered the differences between products available in the food market based on the defined clusters of meat product subgroups: burgers, coated meat, cold cuts, meatballs, meat for roasting and cooking, and sausages. We re-estimated the equations defined by (1) for the more homogenous product subgroups and subsequently the estimated marginal means are compared again for each meat category (RM, PM, NVMS and VMS) within the subgroups. Finally, the model was also estimated individually for the different countries to identify regional variations in nutrient quality. The results are presented graphically to illustrate the estimated marginal means and the respective 95 % confidence intervals for each nutrient and product subgroup.

4.3 Results

Table 1 presents the cross-tabulation of the meat category and meat cluster distribution. Our total sample of 19,941 products consists of 5.1% non-vegan meat substitutes, 10.5% vegan meat substitutes, 29.5% poultry products, and 54.9% red meat products. This implies the predominant role of traditional meat products in the market. Table 1. Cross table of meat categories and meat clusters across all five countries

Table 4-1 - Cross table of meat categories and meat clusters across all five countries

	Meat category				
Meat cluster	Non-vegan meat substitutes	Poultry meat	Red meat	Vegan meat substitutes	Total sample
	Number of observations (share cluster of the total meat category)				
Burger	227 (22.1%)	142 (2.4%)	797 (7.3%)	559 (26.8%)	1,725 (8.7%)
Coated meat	133 (13.0%)	751 (12.8%)	165 (1.5%)	153 (7.3%)	1,202 (6.0%)
Cold cuts	108 (10.5%)	1,001 (17.0%)	4,671 (42.6%)	113 (5.4%)	5,893 (29.6%)
Meatballs	155 (15.1%)	106 (1.8%)	466 (4.3%)	195 (9.3%)	922 (4.6%)
Roasting/ cooking	253 (24.7%)	3,402 (57.9%)	2,557 (23.3%)	874 (41.8%)	7,086 (35.5%)
Sausages	149 (14.5%)	473 (8.1%)	2,296 (21.0%)	195 (9.3%)	3,113 (15.6%)
Total sample	1,025	5,875	10,952	2,089	19,941
Cat. share of whole sample	5.1%	29.5%	54.9%	10.5%	

Source: Own calculations based on Mintel's GNPD. Note: Cat. Refers to the meat category.

Roasting/cooking represents the largest product cluster in our analysis (36% of the total sample) and the meatball cluster is the smallest with 992 products (5%). Tables 4-8 in the supplementary file show the distributions per country. In general, poultry products play a much greater role in diets in France and the United Kingdom(LfL & LEL, 2022; DEFRA, 2022), with shares amounting to 31% and 39%, respectively in the samples, which exceed the shares in Germany, Italy and Spain (23%, 27%, 27%). The share of vegan meat substitutes is lowest in the UK (8%), while it holds a share of at least 10 % in all other countries. Furthermore, product cluster sizes differ between the countries observed. While the cold cut category has the highest share in most countries, the roasting/cooking cluster is the largest in France and in the UK.

Table 2 reports the results of the pairwise comparison for each nutrient across the four broader meat and meat substitute categories. The results for the underlying regressions are reported in the supplementary file, Table 10. At 22.5 and 24.3 kcal/100g, the estimated mean energy content in kcal/100g of non-vegan meat substitutes and vegan meat substitutes is significantly higher ($p<0.001$) than the energy content of poultry meat. In contrast, both non-vegan and vegan meat substitutes have a significantly lower ($p<0.001$) energy content than red meat products, namely 41.2 and 39.4 kcal/100g, respectively. Finally, while there is no statistically significant difference between the energy contents of non-vegan and vegan meat substitutes, red meat products have a significantly higher energy content than poultry products.

4.3.1 Results of pairwise nutrient comparisons across meat categories

Table 4-2 - Pairwise comparisons of marginal linear predictions of the individual nutrients

Comparison	Energy kcal/100g	Fat g/100g	Saturated fat g/100g	Carbo-hydrates g/100g	Sugar g/100g	Fiber g/100g	Salt g/100g	Protein g/100g
Non-vegan MS vs. Poultry meat	22.5 (<.001)	1.85 (<.001)	-0.47 (<.001)	6.63 (<.001)	0.89 (<.001)	3.31 (<.001)	-0.02 (0.599)	-6.67 (<.001)
Non-vegan MS vs. Red meat	-41.2 (<.001)	-6.13 (<.001)	-4.57 (<.001)	10.17 (<.001)	1.28 (<.001)	3.28 (<.001)	-0.92 (<.001)	-8.33 (<.001)
Non-vegan MS Vegan MS	1.8 (0.582)	1.22 (0.001)	0.40 (0.004)	0.58 (0.006)	0.08 (0.183)	-0.64 (<.001)	0.15 (0.001)	-3.52 (<.001)
Vegan MS vs. Poultry meat	24.3 (<.001)	0.63 (0.007)	-0.87 (<.001)	6.05 (<.001)	0.82 (<.001)	3.75 (<.001)	-0.17 (<.001)	-3.15 (<.001)
Vegan MS vs. Red meat	-39.4 (<.001)	-7.34 (<.001)	-4.97 (<.001)	9.59 (<.001)	1.20 (<.001)	3.93 (<.001)	-1.07 (<.001)	-4.82 (<.001)
Red meat vs. Poultry meat	63.7 (<.001)	7.97 (<.001)	4.11 (<.001)	-3.55 (<.001)	-0.38 (<.001)	-0.18 (<.001)	0.90 (<.001)	1.66 (<.001)

Non-vegan MS: Non-vegan meat substitutes. Vegan MS: Vegan meat substitutes. Fiber: Calculated fiber content.

The numbers in parentheses are the Benjamini & Hochberg corrected p-values (1995).

The results are estimated based on the results of the linear models in the Supplementary file, Table 10.

The fat content in non-vegan meat substitutes and vegan meat substitutes is significantly higher than in poultry but lower than in red meat products. However, results are different when focus centers on saturated fats, as both meat substitute categories contain, on average, significantly lower levels of saturated fats than red meat and poultry meat products. We detected considerable differences when meat substitutes are compared to red meat products, with non-vegan and vegan meat substitutes undercutting the saturated fat value of red meat products by an average of 4.57 and 4.97 g/100g ($p<0.001$). We also found that red meat contains significantly higher amounts of fat and saturated fat than poultry meat. Finally, differences can also be detected across meat substitutes, with non-vegan alternatives containing on average both significantly more fat and saturated fats per 100g than vegan meat substitutes.

It can be observed, that both types of meat substitutes contain more carbohydrates and sugar than poultry and red meat products but, on the other hand, also higher amounts of fiber. Furthermore, vegan meat substitutes contain on average noticeably less carbohydrates and more fiber than non-vegan meat substitutes.

Although no statistically significant differences were detected between the salt content of non-vegan meat substitutes and poultry meat products ($p=0.599$), non-vegan meat substitutes contain less salt than red meat products and vegan meat substitutes contain less salt than either red or poultry meat products. In fact, vegan meat substitutes also contain on average less salt than non-vegan alternatives. Finally, red meat contains significantly higher amounts of salt than poultry meat products.

In general, both types of substitutes have a lower protein content than poultry and red meat products ($p<0.001$). In addition, we found that vegan meat substitutes contain more proteins than non-vegan products ($p<0.001$) and finally, red meat products contain more protein than poultry products($p<0.001$). In summary, the pairwise comparison results yielded a complex picture of the nutritional differences between emerging meat substitutes and traditional meat products. The implications of these findings are discussed in detail below.

4.3.2 Results of nutritional comparison based on meat product clusters

The plots in Figure 1 present the results of the nutritional comparison between the different meat categories (RM, PM, NVMS and VMS) for the individual homogenous meat clusters, i.e., burgers, cold cuts and meat balls, etc. To facilitate comparison, the first column of each plot recapitulates the results of the estimations reported in Table 2, i.e., relating to the four broader meat and meat substitute categories without consideration of the product clusters. The results confirm that red meat products tend to have the highest energy content across individual meat product clusters, apart from the coated meat cluster. In particular, the products in the red meat sausages cluster have a considerably higher energy content than any of the other products. In contrast, poultry products tend to have the lowest energy content levels in most clusters, except for coated meat and sausages. To a large extent, these results are due to the high/low fat contents of the respective meat clusters in the red meat and poultry meat categories, respectively. The fat content of vegan and non-vegan substitutes differs significantly if product clusters are disregarded, but it does not fluctuate within any of the individual clusters. In general, red meat also exhibits the highest levels of saturated fats across the meat clusters, though this not significantly higher than poultry meat and meat substitutes in the coated meat cluster.

There are only minor amounts of carbohydrates in red and poultry meat, except for the coated meat and, to some degree, the meatballs cluster. In contrast, the amounts of carbohydrates in vegan and non-vegan meat alternatives are higher across all product clusters and some differences between the carbohydrate content of both meat substitutes can be observed in the roasting/cooking and the meatballs clusters.

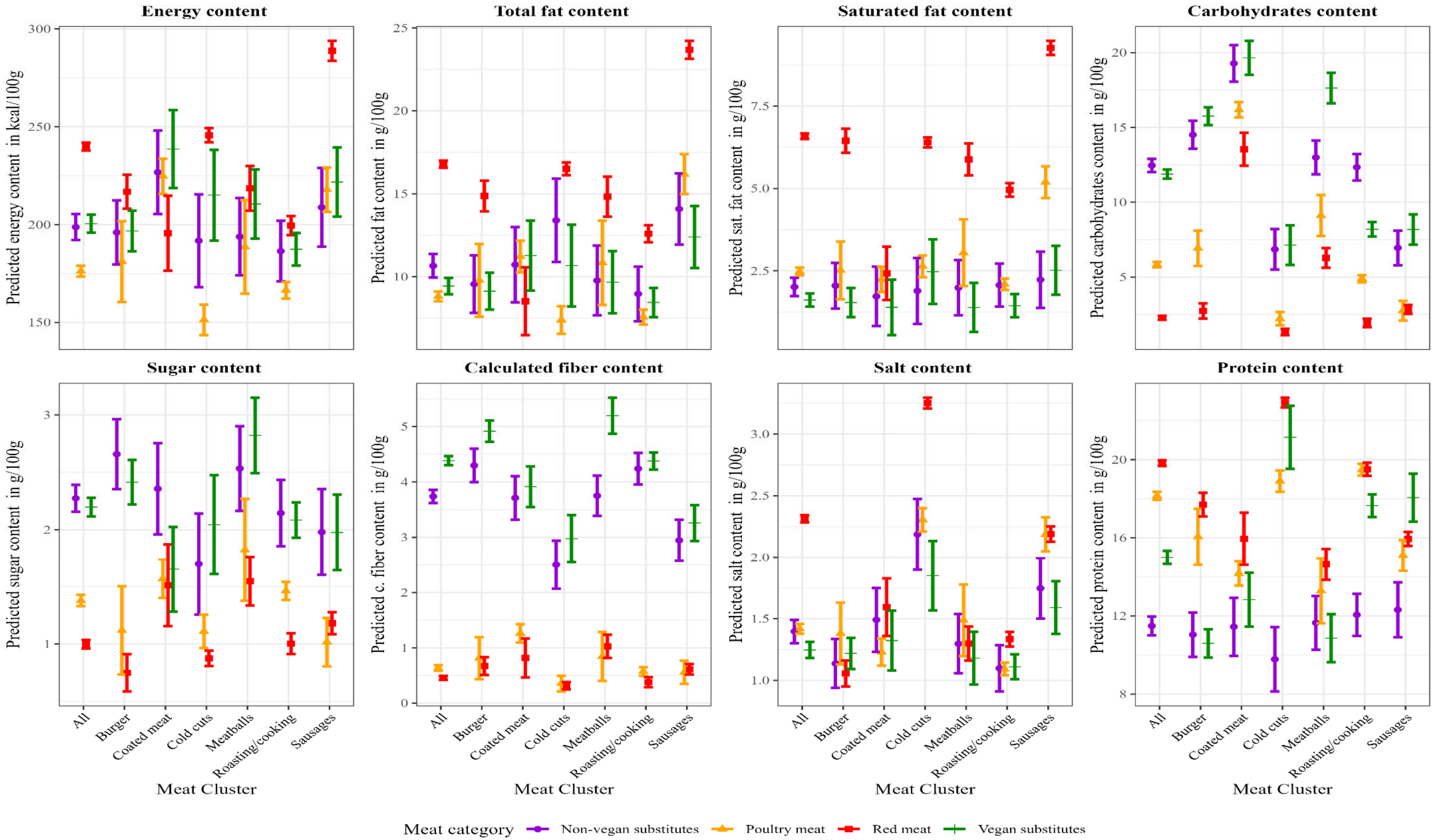

Figure 4-1 Comparison of predicted marginal mean values with 95% confidence intervals of observed

There are only minor amounts of carbohydrates in red and poultry meat, except for the coated meat and, to some degree, the meatballs cluster. In contrast, the amounts of carbohydrates in vegan and non-vegan meat alternatives are higher across all product clusters and some differences between the carbohydrate content of both meat substitutes can be observed in the roasting/cooking and the meatballs clusters.

A similar picture emerges for the sugar content of the products. While there are only marginal amounts in red meat and poultry meat, non-vegan and vegan meat alternatives contain considerably more sugar. However, it must be noted that in view of the WHO recommendation of less than 50 g per day(WHO, 2022), the general sugar levels are relatively low at <3g/100g.

Figure 1 shows that there is potential to enhance the amount of dietary fiber by substituting NVMS and VMS for poultry and red meat. Moreover, salt intake can be reduced by replacing red meat cold cuts with poultry, vegan or non-vegan meat substitutes. Finally, vegan and non-vegan meat substitutes have a lower protein level with the exception of vegan meat substitutes in the cold cuts and sausage clusters, which exhibit protein levels comparable to red and poultry meat products.

Figures 1-4 in the supplemental document present the country-wise comparison of the predicted marginal means for the individual product clusters with 95% confidence intervals. The results of the differences in the nutritional composition between the clusters seem to be robust across individual countries. However, it is noticeable that the average salt, energy, and saturated fat content of products in the UK is somewhat lower. In addition, the low number of observations within some country clusters leads to a pronounced increase in confidence intervals, leading to less significant results between country clusters.

4.4 Discussion

This study, compared the nutritional composition of red meat, poultry meat and (vegan and non-vegan) meat substitutes, was carried out against the background of the ongoing discussion of diet-related diseases due to excessive amounts of nutrients-to-limit inherent in meat and ultra-processed products. Based on a sample of 19,941 individual products from the European meat market, we found that red meat products are higher in energy, fat, saturated fats, and salt than poultry meat and both vegan and non-vegan meat substitutes. However, after grouping the products into more homogenous clusters, we found that the high salt content of red meat products is a specificity of the cold cut category. On the other hand, meat substitutes exhibit higher levels of carbohydrates, i.e., higher sugar and fiber content than red and poultry meat. It follows that dietary changes, such as opting for poultry and meat substitutes instead of red meat, which is so widely consumed in Europe(LfL & LEL, 2022), would reduce the intake of saturated fats, increase the intake of fiber, and could potentially lower the incidence of nutrition-related NCDs.

Our results indicate significantly higher amounts of saturated fats in red meat products compared to poultry meat products and meat substitutes, except for coated meat. For example, at ~9 g/100g, sausages contain three times more saturated fats than meat substitutes which represents 41% of the daily maximum intake recommended by the WHO. Therefore, meat substitutes have great potential in terms of the overall goal of reducing saturated fat intake in the diets which in turn could reduce the associated detrimental health effects(Sacks *et al.*, 2017).

The overall results indicate that meat substitutes and poultry meat products contain significantly less salt than red meat products ranging from 0.9g/100g to 1.02g/100g of salt. These values indicate that it would be highly recommendable to substitute red meat products. However, the results differ somewhat for the individual product clusters. It is noticeable that the average salt content of red meat cold cuts exceeds 3g per 100g of product, which is over 60% of the WHO recommendation and significantly more salt than found in the other meat categories. On the other hand, the differences and level seem to be less extreme in the burger cluster. Hence, these results underline the importance of considering product clusters when evaluating the health effects of products.

Meat is the major source of protein in Europe(Cocking *et al.*, 2020). Therefore, a high-quality source of protein would be lost if meat was eliminated completely. In general, meat substitutes provide less protein. However, there are large differences between the product clusters and between the vegan and non-vegan meat substitute categories. While both vegan and non-vegan meat substitutes contain fewer proteins than poultry and red meat in the burger and roasting/cooking clusters, the results are mixed in the other clusters. In addition, vegan meat substitutes in the sausage cluster contain, surprisingly, the highest amounts of protein while non-vegan meat substitutes have the lowest protein content. Therefore, it would be interesting to investigate which ingredients drive these protein content results which is beyond the scope of this study.

On average, meat substitutes contain more carbohydrates across all product clusters. We are unable compare the quality of these carbohydrates as our data only covers the sugar and fiber content. Low-quality carbohydrates might demand a more complex comparison and management of the blood sugar levels for people with diabetes(Reynolds *et al.*, 2019). Furthermore, our results regarding the higher fiber content in meat substitutes must be viewed with some caution, as they are not based on an analytical detection of fiber levels reported on the product packages, but on the manually calculated fiber content per 100g. However, the results do suggest higher amounts of fiber in meat substitutes than in red meat and poultry products. Therefore, given the higher amounts of fiber inherent in meat substitutes they can potentially reduce the risks for some NCDs if they are used to replace red meat products(Reynolds *et al.*, 2019).

Based on the NOVA classification, meat substitutes are mainly rated as ultra-processed foods(Wickramasinghe *et al.*, 2021). Thereby, consumers use the degree of processing as a heuristic to evaluate the healthiness of foods(Hässig *et al.*, 2023). However, when the UK nutritional profiling system is used, not all products classified as ultra-processed foods are rated as unhealthy(Derbyshire, 2019). Therefore, it might be more appropriate to evaluate the healthiness of products based on a detailed product cluster rather than on a processing level, thereby allowing for marginal improvements in nutrient uptake. For example, this could be achieved by replacing red meat sausages or cold cuts with poultry or meat substitute counterparts to reduce salt and saturated fat intake. This means that the adoption of mandatory food labelling schemes, like the Nutri-Score, that allow consumers to compare the products within a specific cluster, could promote healthier choices.

Traditional vegetarian diets consist of high shares of foods that are not highly processed, like legumes and vegetables(Macdiarmid, 2022). However, meat substitutes which conform to a vegetarian diet are highly processed products(Macdiarmid, 2022). Although our results suggest that meat substitutes contain lower levels of saturated fats and salt than red meat products, they are still likely to contain higher levels of these nutrients-to-limit than unprocessed vegetables. In any case, meat substitutes are probably of little relevance to traditional vegetarians for which a switch to meat substitutes might imply an increased intake of salt and saturated fats. However, most people in European countries include meat in their diets. Therefore, public health outcomes could benefit from a (partial) switch from the consumption of traditional red meat products to novel highly processed meat substitutes.

While many aspects of this study are sound, such as the comprehensive product sample, it also has limitations. Firstly, our sample is based on products which are sold in supermarkets, and therefore it provides no information about meat products sold at other points of sale, such as butcher's shops. However, most of the meat consumed, for example in Germany, is sold in discounters and supermarkets(LfL & LEL, 2022). Based on this fact and the large sample size involved, we assume that it is reasonable to draw conclusions about the population of meat products available on the markets analyzed. Secondly, even though the clustering mechanism is based on previous literature(Bohrer, 2019; Alessandrini *et al.*, 2021; Curtain and Grafenauer, 2019), there might well be more appropriate clusters to distinguish between the different meat products, e.g., a salami cluster or a minced meat cluster. However, our main goal was to explore the nutritional differences between meat and meat substitutes and our clustering mechanism adequately fulfils this purpose. Additionally, our research is based on nutritional values only, and thus neglects the role of important micronutrients, e.g., iron, zinc and vitamin B12 although meat is an important source of these nutrients(Biesalski, 2005). While plant-based diets can meet the requirements for micronutrient intake, this requires a higher level of food knowledge(Parlasca and Qaim, 2022). Therefore, for low-income and lower-educated groups, meat may be an easier way to meet the needs for these important micronutrients(Parlasca and Qaim, 2022). Thereby, although the excessive intake of certain nutrients, like saturated fats, is associated with NCDs(Sacks *et al.*, 2017), it is important to consider the food matrix of products as well. Foods having the identical nutritional compositions of macronutrients but with different food matrices could react differently during digestion (Fardet and Rock, 2022; Aguilera, 2019). Furthermore, the data did not allow us to consider whether a product is sold in more than one country, hence getting more weight in the overall analysis. Additionally, the data did not allow to assess the actual product sales and consumption patterns in the countries we investigated. Hence, it was not possible to derive the true uptakes of nutrients in the population based on the products weighted according to their actual sales. However, our study does allow us to assess the desirability of substituting certain products. For example, the intake of salt and/or saturated fats, which are both associated with detrimental health effects when overconsumed(He and MacGregor, 2018; Eilander, Harika and Zock, 2015), could be reduced by replacing red meat-based cold cuts and sausages with cold cuts and sausages from other sources. Finally, our study only focuses on the nutritional viewpoint of the meat and meat substitute debate. Thereby, it neglects the ethical aspects of meat production as well as the role of meat in the context of environmental sustainability. Thereby, meat consumption levels in high-income countries have a strong negative external effect on the environment(Godfray *et al.*, 2018). Though there is research on the environmental sustainability of meat substitutes, such as, a study on pea-based meat substitutes finding them to have a lower environmental footprint per nutrient than beef(Saget *et al.*, 2021), future research is needed to assess the environmental perspective holistically.

In view of the rising incidence of diet-related NCDs (Tilman and Clark, 2014), the results presented here should motivate policy makers to support strategies designed to increase the share of poultry products and meat substitutes in consumers' diets. Although the majority of the latter can be rated as ultra-processed foods, meat substitutes exhibit in cold cuts and sausages lower levels of salt, generally lower levels of saturated fats and a lower energy density while still providing adequate protein levels and significantly more fiber. Hence, the promotion of these meat alternatives could then lead to reduced public health costs by preventing diet-related NCDs. Furthermore, the promotion of meat substitutes could generate additional positive effects in European countries with intensive red meat consumption by help helping to reduce the associated carbon footprints.

4.5 Appendix

Table 4-3A - Annual meat and poultry consumption across Europe

Country/Region	Annual meat consumption in 2021 in kg/ per capita	Share of poultry meat in kg/ per capita	Source
France	89.0	28.6 (32.1%)	(LfL & LEL, 2022)
Germany	81.7	21.9 (26.8%)	(LfL & LEL, 2022)
United Kingdom	71.6	30.8 (43.0%)	(DEFRA, 2022)
Italy	87.1	21.7 (24.9%)	(LfL & LEL, 2022)
Spain	105.8	29.9 (28.3%)	(LfL & LEL, 2022)
EU-28	84.1	23.6 (28.1%)	(LfL & LEL, 2022)

Note: Meat consumption refers to the total meat supply (production + imports – exports) divided by the population.

Table 4-4A - Variable descriptions

Variables	Description
Sugar content	Sugar content in g/100g
Carbohydrate content	Carbohydrate content in g/100g
Energy content	Energy content in kcal/100g
Fat content	Fat content in g/100g
Saturated fat content	Saturated fat content in g/100g
Salt content	Salt content in g/100g
Calculated fiber content	Calculated fiber content in g/100g
Protein content	Protein content in g/100g
Red meat (RM)	Dummy: 1 if red meat
Poultry meat (PM)	Dummy: 1 if poultry meat
Vegan meat substitutes (VMS)	Dummy: 1 if vegan meat substitute
Non-vegan meat substitutes (VMS)	Dummy: 1 if non-vegan meat substitute
Germany	Dummy: 1 if product sold in Germany
United Kingdom	Dummy: 1 if product sold in the UK
France	Dummy: 1 if product sold in France
Spain	Dummy: 1 if product sold in Spain
Italy	Dummy: 1 if product sold in Italy
Burger	Dummy: 1 if burger, e.g., burger patties
Coated meat	Dummy: 1 if coated meat, e.g., schnitzel or nuggets
Cold cuts	Dummy: 1 if cold cuts, e.g., ham or salami
Meatballs	Dummy: 1 if meat balls, e.g., meat balls or burger
Roasting/ cooking	Dummy: 1 if roasting meat, e.g., filet or minced meat
Sausages	Dummy: 1 if sausages, e.g., frankfurter

Dummy: Dummy Variable

Table 4-5A - List of example keywords for clustering

Burgers	Coated meat	Cold cuts	Meatballs	Roasting/Cooking	Sausages	Excluded
Burger	Breaded	Ham	Meatball	Steak	Sausage	Pudding
Patty	Nugget	Salami	Kofta	Minced meat (beef/pork/chicken)	Viennese	Corned beef/pork
Quarter Pounder	Fingers	Bacon	Lentil balls	Schnitzel (plain)	Chorizo	Foie gras
	Sticks	Mortadella	Beef ball	Meatloaf	Hot dog	Products with sauce
	Schnitzel (ex. Plain)	Serrano	Köttbullar	Medallion	Frankfurter	Products with vegetables
	Escalopes (ex.plain)	Prosciutto		Goulash	Salsiccia	Chicken curry
		Aspic		Tofu	Merguez	Read-to-eat meals
		Pepperoni		Drumstick		
		Liver sausage		Cutlet		
		Sliced Chorizo		Soy granules		
		Lyoner				

Table 4-6A - Cross table of meat categories and meat clusters for France

	Meat category				
Meat cluster	Non-vegan meat substitutes	Poultry meat	Red meat	Vegan meat substitutes	Total sample
	Number of observations (share cluster of the total meat category)				
Burger	55 (21.8%)	23 (1.8%)	112 (5.2%)	75 (15.7%)	265 (6.3%)
Coated meat	57 (11.5%)	242 (18.6%)	12 (0.6%)	34 (7.1%)	317 (7.6%)
Cold cuts	13 (5.2%)	263 (20.2%)	989 (45.9%)	14 (2.9%)	1279 (30.5%)
Meatballs	71 (28.2%)	12 (0.9%)	65 (3.0%)	68 (14.2%)	216 (5.2%)
Roasting/ cooking	68 (27.0%)	660 (50.7%)	530 (24.6%)	261 (54.5%)	1519 (36.3%)
Sausages	16 (6.3%)	101 (7.8%)	449 (20.8%)	27 (5.6%)	593 (14.2%)
Total sample	280	1301	2157	479	4189
Cat. share of whole sample	6.0 %	31.1%	51.5%	11.4%	

Table 4-7A - Cross table of meat categories and meat clusters for Germany

	Meat category				
Meat cluster	Non-vegan meat substitutes	Poultry meat	Red meat	Vegan meat substitutes	Total sample
	Number of observations (share cluster of the total meat category)				
Burger	35 (12.6%)	15 (1.1%)	116 (3.1%)	100 (16.3%)	266 (4.4%)
Coated meat	57 (20.5%)	158 (11.7%)	82 (2.2%)	67 (10.9%)	364 (6%)
Cold cuts	56 (20.1%)	279 (20.6%)	1745 (46.2%)	50 (8.2%)	2130 (35.4%)
Meatballs	46 (16.5%)	42 (3.1%)	117 (3.1%)	50 (8.2%)	255 (4.2%)
Roasting/ cooking	33 (11.9%)	712 (52.6%)	870 (23.1%)	260 (42.5%)	1875 (31.2%)
Sausages	51 (18.3%)	148 (10.9%)	843 (22.3%)	85 (13.9%)	1127 (18.7%)
Total sample	278	1354	3773	612	6017
Cat. share of whole sample	4.6%	22.5%	62.7%	10.2%	

Table 4-8A - Cross table of meat categories and meat clusters for the UK

	Meat category				
Meat cluster	Non-vegan meat substitutes	Poultry meat	Red meat	Vegan meat substitutes	Total sample
	Number of observations (share cluster of the total meat category)				
Burger	62 (24.2%)	40 (2.0%)	266 (10.6%)	95 (23.6%)	463 (9.0%)
Coated meat	13 (5.1%)	173 (8.7%)	30 (1.2%)	20 (5.0%)	236 (4.6%)
Cold cuts	12 (4.7%)	115 (5.8%)	597 (23.8%)	16 (4.0%)	740 (14.4%)
Meatballs	13 (5.1%)	29 (1.5%)	209 (8.3%)	41 (10.2%)	292 (5.7%)
Roasting/ cooking	107 (41.8%)	1562 (78.7%)	798 (31.8%)	171 (42.4%)	2638 (51.2%)
Sausages	49 (19.1%)	66 (3.3%)	608 (24.2%)	60 (14.9%)	783 (15.2%)
Total sample	256	1985	2508	403	5152
Cat. share of whole sample	5.0%	38.5%	48.7%	7.8%	

Table 4-9A- Cross table of meat categories and meat clusters for Italy

	Meat category				
Meat cluster	Non-vegan meat substitutes	Poultry meat	Red meat	Vegan meat substitutes	Total sample
	Number of observations (share cluster of the total meat category)				
Burger	47 (36.4%)	22 (3.7%)	182 (16.1%)	157 (45.5%)	408 (18.6%)
Coated meat	23 (17.8%)	83 (14%)	13 (1.1%)	14 (4.1%)	133 (6.1%)
Cold cuts	11 (8.5%)	110 (18.6%)	668 (59%)	18 (5.2%)	807 (36.7%)
Meatballs	19 (14.7%)	13 (2.2%)	39 (3.4%)	13 (3.8%)	84 (3.8%)
Roasting/ cooking	23 (17.8%)	288 (48.7%)	164 (14.5%)	99 (28.7%)	574 (26.1%)
Sausages	6 (4.7%)	75 (12.7%)	66 (5.8%)	44 (12.8%)	191 (8.7%)
Total sample	129	591	1132	345	2197
Cat. share of whole sample	5.9%	26.9%	51.5%	15.7%	

Table 4-10A - Cross table of meat categories and meat clusters for Spain

	Meat category				
Meat cluster	Non-vegan meat substitutes	Poultry meat	Red meat	Vegan meat substitutes	Total sample
	Number of observations (share cluster of the total meat category)				
Burger	28 (25.5%)	42 (6.5%)	121 (8.8%)	132 (45.5%)	323 (13.3%)
Coated meat	11 (10.0%)	95 (14.8%)	28 (2.0%)	18 (6.2%)	152 (6.3%)
Cold cuts	16 (14.5%)	234 (36.3%)	672 (48.6%)	15 (5.2%)	937 (38.6%)
Meatballs	6 (5.5%)	10 (1.6%)	36 (2.6%)	23 (7.9%)	75 (3.1%)
Roasting/ cooking	22 (20.0%)	180 (28.0%)	195 (14.1%)	83 (28.6%)	480 (19.8%)
Sausages	27 (24.5%)	83 (12.9%)	330 (23.9%)	19 (6.6%)	459 (18.9%)
Total sample	110	644	1382	290	2426
Cat. share of whole sample	4.5%	26.5%	57.0%	12%	

Table 4-11A - Descriptive statistics by meat cluster

		Energy (kcal) (kcal / 100g)		Fat (g / 100g)		Saturated fat (g / 100g)		Salt (g / 100g)		Protein (g / 100g)		Carbohydrates (g / 100g)		Sugar (g / 100g)		Calculated fiber (g / 100g)		Obs.
Meat cluster	Meat category	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	N
Burger	NVMS	196.00	44.21	9.56	3.74	2.05	1.42	1.14	0.42	11.04	5.70	14.50	7.62	2.66	1.84	4.30	2.07	227
	PM	181.07	51.15	9.78	4.58	2.51	1.26	1.38	0.55	16.05	3.09	6.93	5.86	1.12	1.06	0.81	1.02	142
	RM	216.77	45.35	14.87	5.18	6.45	2.42	1.06	0.52	17.70	3.26	2.74	2.77	0.75	0.90	0.67	1.06	797
	VMS	196.73	49.56	9.13	4.56	1.54	1.68	1.22	0.52	10.59	5.94	15.75	8.95	2.41	1.71	4.92	2.83	559
	Total	204.60	48.57	11.89	5.51	3.95	3.07	1.15	0.52	14.38	5.73	8.85	8.78	1.57	1.60	2.54	2.80	1725
Coated meat	NVMS	226.74	29.59	10.73	2.60	1.73	0.94	1.49	0.89	11.44	4.38	19.28	5.20	2.36	1.59	3.71	2.68	133
	PM	224.64	38.61	11.22	3.93	2.24	1.26	1.23	0.46	14.17	2.87	16.18	4.45	1.57	1.43	1.26	1.26	751
	RM	195.57	51.29	8.52	4.98	2.42	1.76	1.59	0.77	15.95	4.27	13.54	7.46	1.51	1.27	0.82	1.07	165
	VMS	238.60	39.42	11.27	3.67	1.39	1.12	1.32	0.50	12.83	4.74	19.65	7.15	1.65	1.07	3.92	2.32	153
	Total	222.66	41.48	10.80	4.04	2.10	1.33	1.32	0.59	13.94	3.75	16.60	5.73	1.66	1.40	1.81	1.98	1202
Cold cuts	NVMS	191.73	49.45	13.40	5.36	1.89	1.82	2.19	0.72	9.78	4.18	6.85	6.61	1.70	1.01	2.50	2.18	108
	PM	151.31	79.19	7.39	8.69	2.64	3.41	2.30	0.86	18.90	4.54	2.22	2.22	1.11	1.13	0.35	0.69	1001
	RM	245.63	116.09	16.51	12.42	6.40	5.00	3.25	1.38	22.91	6.17	1.33	1.56	0.87	0.94	0.31	0.88	4671
	VMS	215.03	52.82	10.67	5.17	2.47	3.52	1.85	0.68	21.14	11.15	7.13	6.83	2.04	1.66	2.98	2.44	113
	Total	228.03	114.53	14.79	12.17	5.60	4.95	3.04	1.35	21.95	6.44	1.69	2.38	0.95	1.01	0.41	1.05	5893
Meatballs	NVMS	193.82	56.97	9.77	4.57	1.99	1.62	1.30	0.52	11.64	5.15	13.00	6.45	2.53	1.62	3.75	1.96	155
	PM	188.59	56.52	10.84	5.11	3.05	1.67	1.49	0.54	13.28	4.23	9.11	4.36	1.82	1.52	0.84	0.89	106
	RM	218.57	56.76	14.83	5.55	5.88	2.42	1.30	0.55	14.64	4.94	6.28	3.50	1.55	1.61	1.02	1.15	466
	VMS	210.50	57.33	9.67	4.49	1.39	1.16	1.18	0.48	10.86	5.46	17.63	10.32	2.82	1.62	5.20	2.68	195
	Total	209.26	57.96	12.43	5.68	3.95	2.83	1.29	0.53	13.18	5.26	10.14	7.66	2.01	1.69	2.34	2.47	922

		Energy (kcal) (kcal / 100g)		Fat (g / 100g)		Saturated fat (g / 100g)		Salt (g / 100g)		Protein (g / 100g)		Carbohydrates (g / 100g)		Sugar (g / 100g)		Calculated fiber (g / 100g)		Obs.
Meat cluster	Meat category	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	N
Roasting/ cooking	NVMS	186.42	58.52	8.97	5.09	2.07	1.85	1.10	0.51	12.05	5.67	12.34	7.78	2.14	1.76	4.24	2.06	253
	PM	166.46	54.31	7.57	5.71	2.09	1.83	1.09	0.69	19.48	4.78	4.89	5.82	1.46	1.93	0.57	0.87	3402
	RM	199.50	82.80	12.59	9.58	4.96	3.87	1.33	1.17	19.50	4.90	1.93	3.00	1.00	1.64	0.38	0.95	2557
	VMS	187.35	68.87	8.45	5.02	1.44	1.28	1.11	0.72	17.65	10.22	8.19	7.82	2.08	2.28	4.38	3.92	874
	Total	181.68	69.47	9.54	7.63	3.04	3.07	1.18	0.90	19.00	5.98	4.50	5.96	1.40	1.91	1.10	2.18	7086
Sausages	NVMS	208.80	50.73	14.08	6.55	2.23	2.22	1.75	0.68	12.31	4.34	6.95	6.62	1.98	2.06	2.95	2.08	149
	PM	217.81	51.94	16.18	6.11	5.19	2.36	2.19	0.76	15.10	4.48	2.75	2.90	1.02	0.85	0.56	1.47	473
	RM	288.83	79.00	23.68	8.13	9.27	3.50	2.19	0.93	15.94	5.21	2.84	3.50	1.18	1.35	0.61	1.19	2296
	VMS	221.75	50.43	12.39	5.04	2.52	2.63	1.59	0.48	18.06	8.31	8.18	6.22	1.98	1.84	3.26	2.61	195
	Total	270.00	79.33	21.37	8.58	7.89	4.05	2.13	0.89	15.77	5.41	3.36	4.14	1.24	1.39	0.88	1.62	3113
Whole sample	NVMS	239.91	99.83	16.78	10.96	6.59	4.46	2.31	1.46	19.82	6.21	2.28	3.27	1.00	1.27	0.46	1.01	10952
	PM	176.21	62.50	8.81	6.64	2.48	2.31	1.42	0.86	18.15	4.94	5.83	6.50	1.38	1.67	0.63	1.00	5875
	RM	198.71	51.64	10.66	5.13	2.01	1.70	1.40	0.70	11.49	5.16	12.46	7.94	2.27	1.75	3.74	2.24	1025
	VMS	200.48	60.74	9.44	4.93	1.61	1.76	1.25	0.64	15.00	9.14	11.88	9.30	2.20	1.96	4.38	3.31	2089
	Total	214.89	89.26	13.35	9.87	4.62	4.21	1.89	1.29	18.39	6.58	4.86	6.53	1.30	1.57	1.09	2.01	19941

NVMS: Non-vegan meat substitutes. PM: Poultry meat. RM: Red meat. VMS: Vegan meat substitutes.

Table 4-12A - Results of the Regression Analysis of Nutrients and meat categories

	Variables	(1) Sugar g/100g	(2) Carbohydrates g/100g	(3) Energy in kcal/100g	(4) Fat in g/100g	(5) Saturated fat in g/100g	(6) Salt in g/100g	(7) Protein in g/100g	(8) Calculated fiber in g/100g
Meat category	VMS	1.199***	9.593***	-39.43***	-7.344***	-4.972***	-1.068***	-4.816***	3.929***
		(0.0359)	(0.132)	(2.019)	(0.217)	(0.0859)	(0.0288)	(0.148)	(0.0359)
	PM	0.381***	3.547***	-63.71***	-7.973***	-4.106***	-0.896***	-1.664***	0.178***
		(0.0243)	(0.0895)	(1.367)	(0.147)	(0.0582)	(0.0195)	(0.100)	(0.0243)
	NVMS	1.275***	10.17***	-41.20***	-6.127***	-4.574***	-0.917***	-8.332***	3.284***
		(0.0492)	(0.181)	(2.762)	(0.297)	(0.118)	(0.0394)	(0.203)	(0.0492)
	Constant	0.998***	2.284***	239.9***	16.78***	6.586***	2.313***	19.82***	0.456***
		(0.0144)	(0.0529)	(0.808)	(0.0870)	(0.0344)	(0.0115)	(0.0593)	(0.0144)
	Observations	19,941	19,941	19,941	19,941	19,941	19,941	19,941	19,941
	R-squared	0.075	0.282	0.103	0.149	0.269	0.132	0.111	0.440

NVMS: Non-vegan meat substitutes. PM: Poultry meat. VMS: Vegan meat substitutes.

Standard errors in parentheses. Red meat products are the reference category in all models.

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

Table 4-13A - Pairwise comparisons of marginal linear predictions of the individual nutrients

Comparison	Energy kcal/100g	Fat in g/100g	Sat. fat g/100g	Carbo-hydrates g/100g	Sugar g/100g	Fiber g/100g	Salt g/100g	Protein g/100g
Non-vegan MS vs. Poultry meat	22.5 (<.001)	1.85 (<.001)	-0.47 (<.001)	6.63 (<.001)	0.89 (<.001)	3.31 (<.001)	-0.02 (0.599)	-6.67 (<.001)
Non-vegan MS vs. Red meat	-41.2 (<.001)	-6.13 (<.001)	-4.57 (<.001)	10.17 (<.001)	1.28 (<.001)	3.28 (<.001)	-0.92 (<.001)	-8.33 (<.001)
Non-vegan MS Vegan MS	1.8 (0.582)	1.22 (0.001)	0.40 (0.004)	0.58 (0.006)	0.08 (0.183)	-0.64 (<.001)	0.15 (0.002)	-3.52 (<.001)
Vegan MS vs. Poultry meat	24.3 (<.001)	0.63 (0.007)	-0.87 (<.001)	6.05 (<.001)	0.82 (<.001)	3.75 (<.001)	-0.17 (<.001)	-3.15 (<.001)
Vegan MS vs. Red meat	-39.4 (<.001)	-7.34 (<.001)	-4.97 (<.001)	-9.59 (<.001)	1.20 (<.001)	3.93 (<.001)	-1.07 (<.001)	-4.82 (<.001)
Red meat vs. Poultry meat	63.7 (<.001)	7.97 (<.001)	4.11 (<.001)	-3.55 (<.001)	-0.38 (<.001)	-0.18 (<.001)	0.90 (<.001)	1.66 (<.001)

Non-vegan MS: Non-vegan meat substitutes. Vegan MS: Vegan meat substitutes. Fiber: Calculated fiber content.
The numbers in parentheses are the (Holm, 1979) corrected p-values. The table is estimated based on the results of the linear models in Supplemental, Table 10.

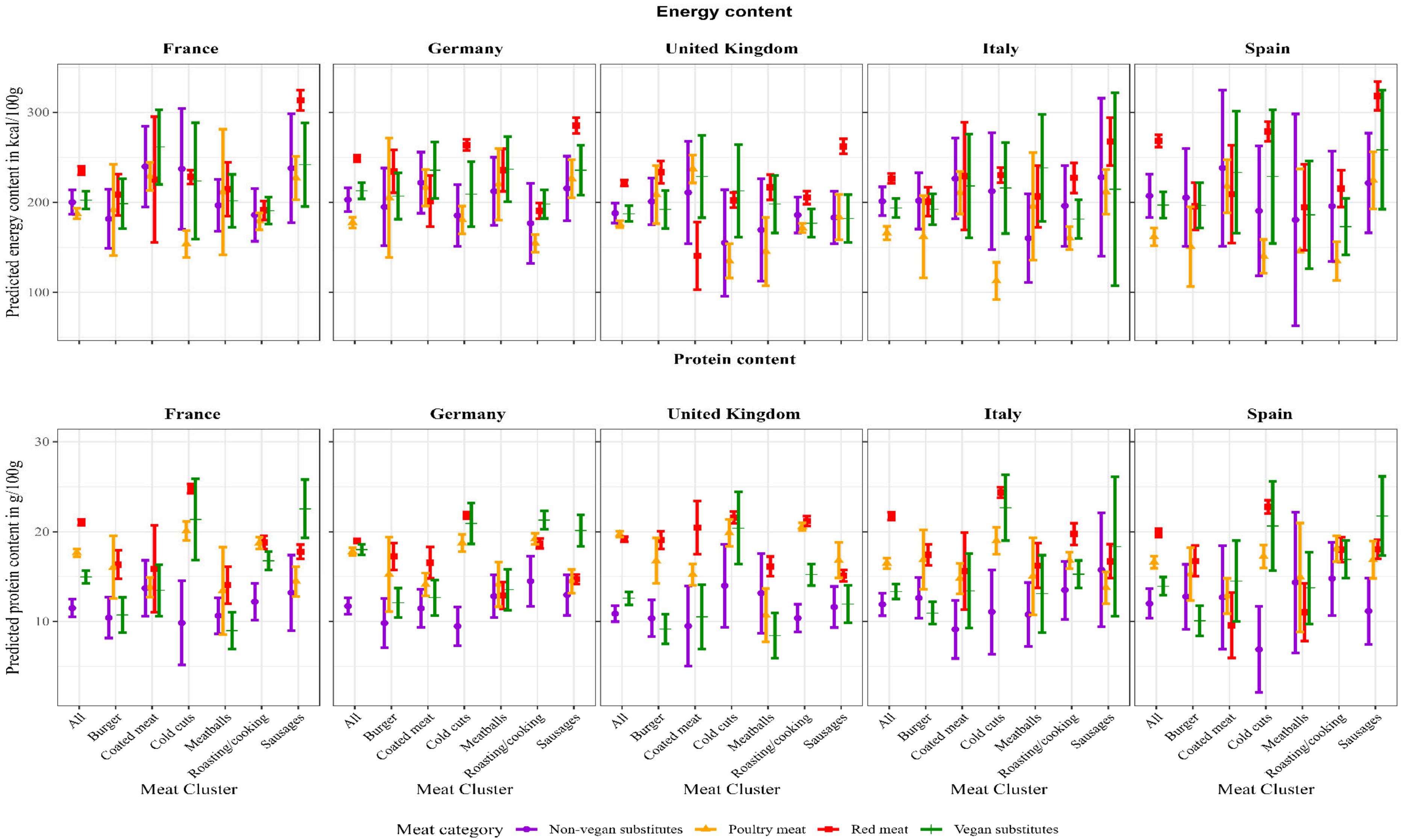

Figure 4-2A - Comparison of predicted marginal means of energy and protein content with 95% confidence intervals over clusters and countries

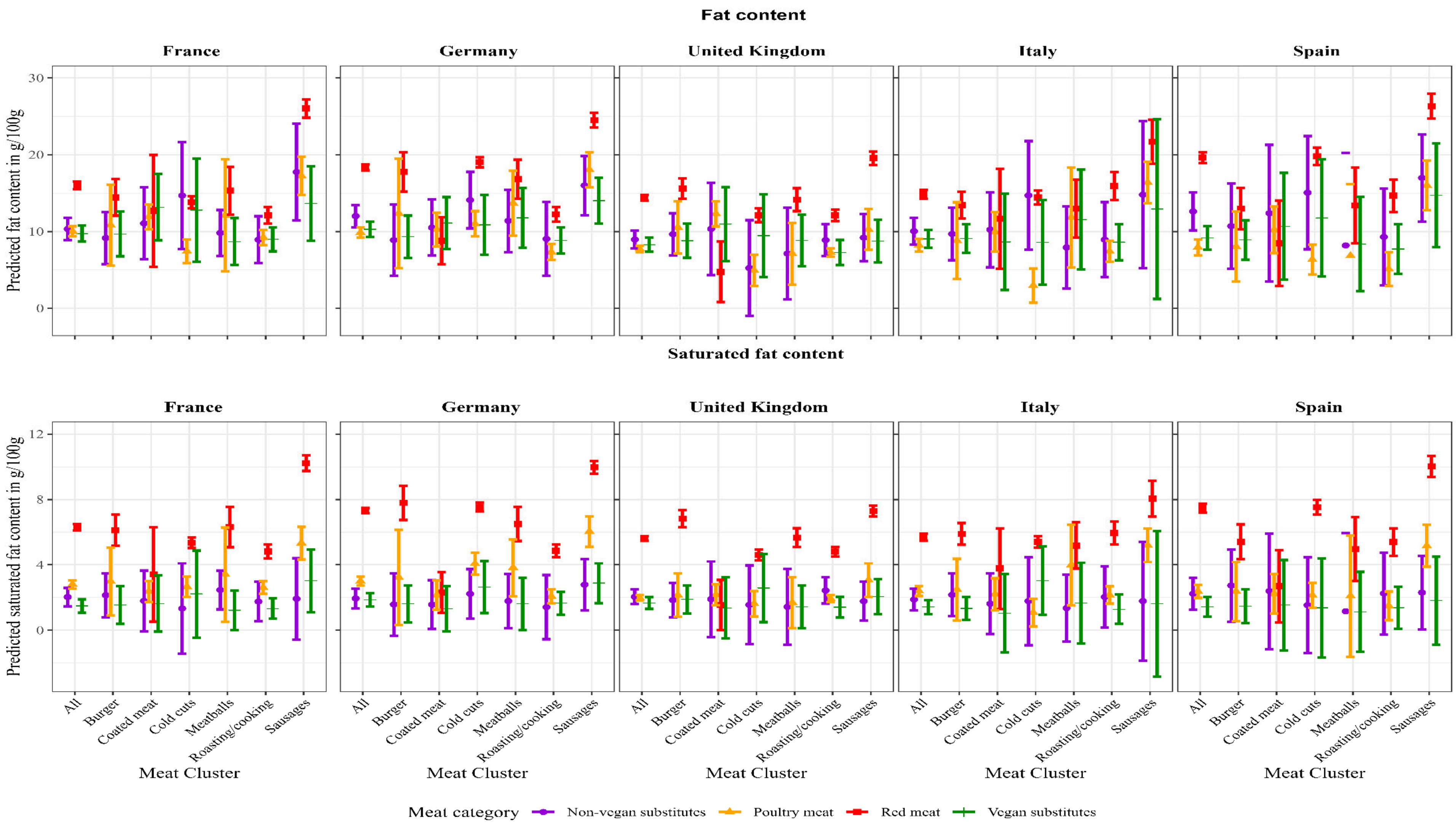

Figure 4-3A - Comparison of predicted marginal means of fat and saturated fat content with 95% confidence intervals over clusters and countries

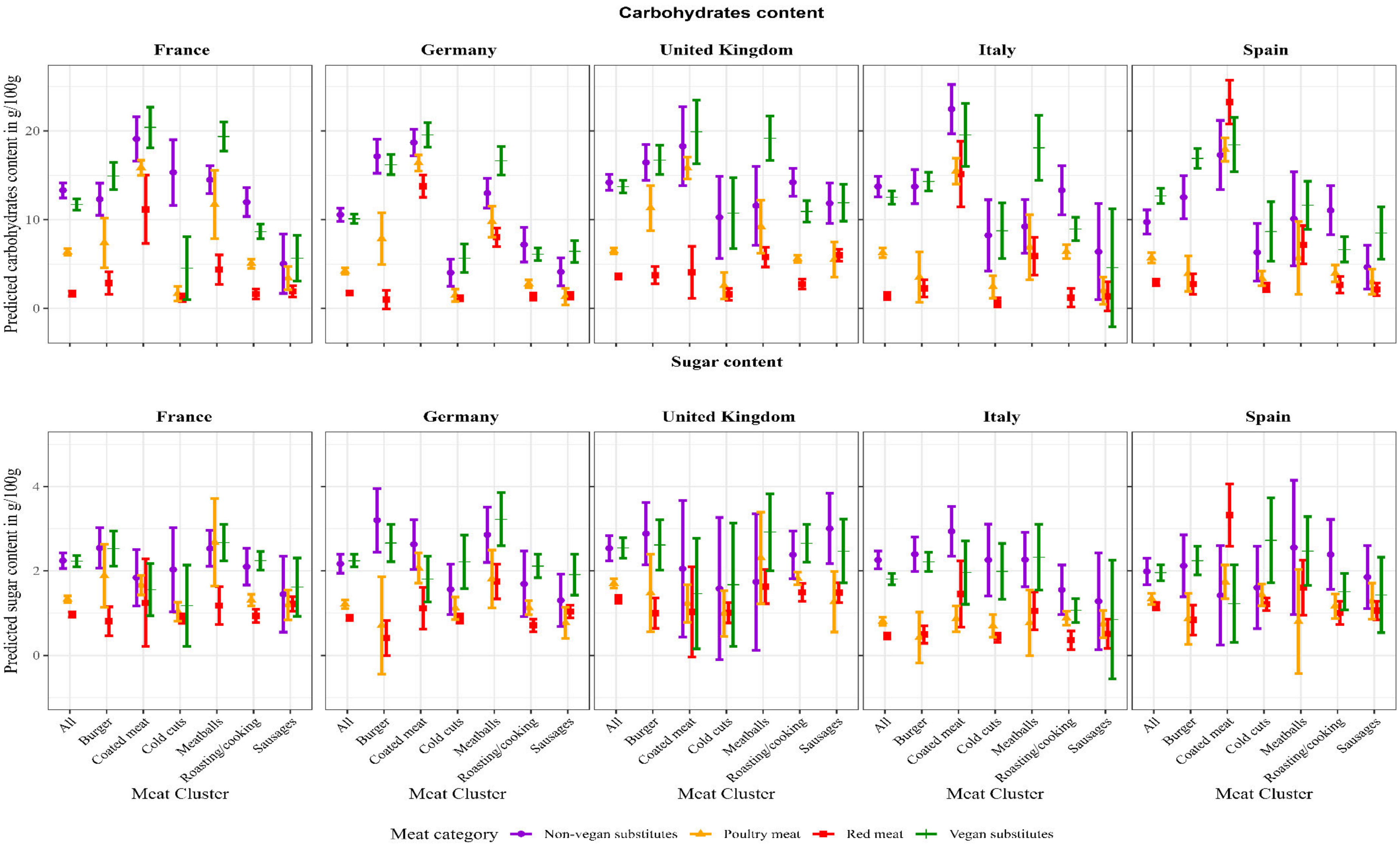

Figure 4-4A - Comparison of predicted marginal means of carbohydrate and sugar content with 95% confidence intervals over clusters and countries

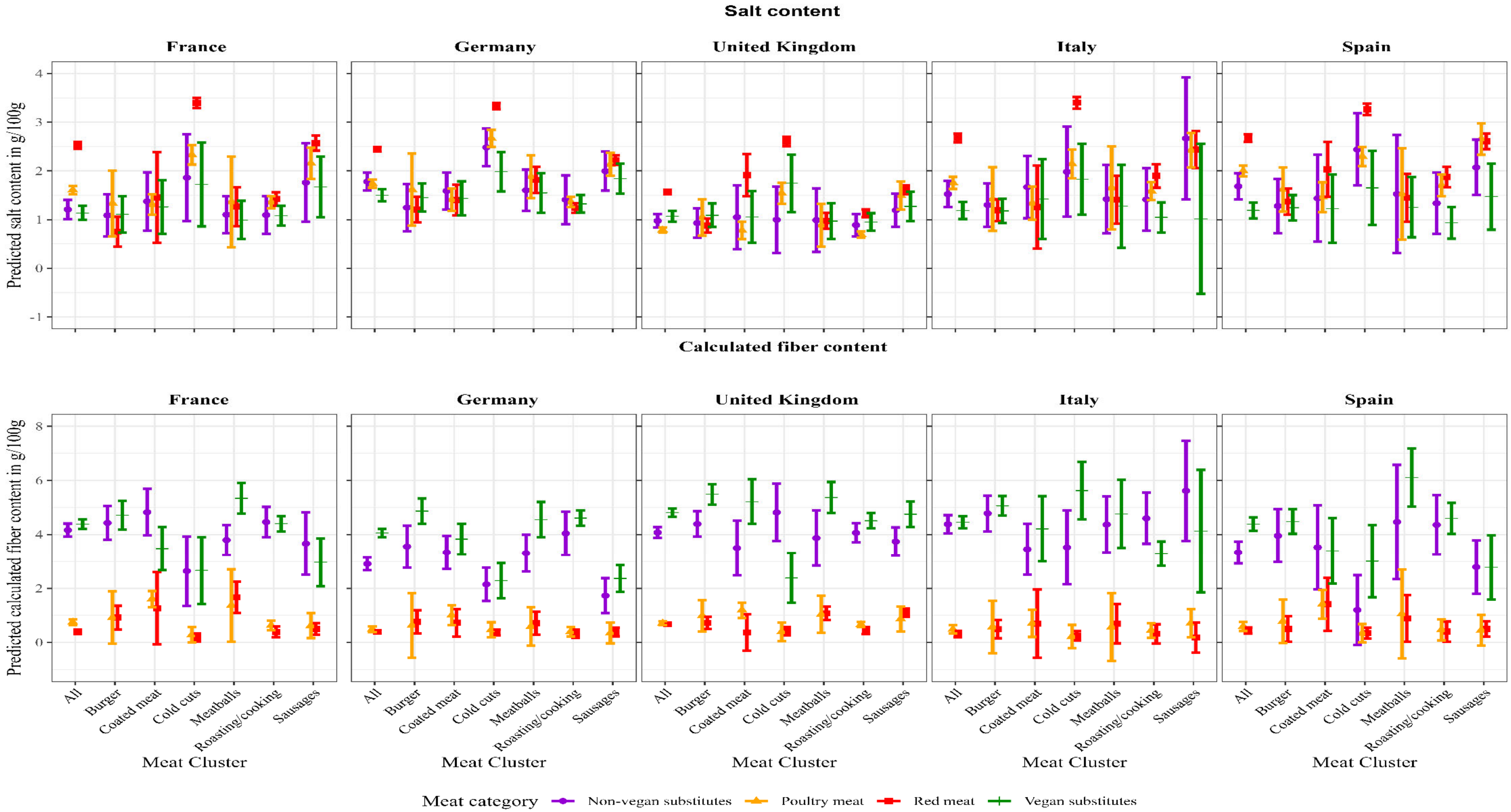

Figure 4-5A - Comparison of predicted marginal means of salt and calculated fiber content with 95% confidence intervals over clusters and countries

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5 Meat Substitute Consumption and Political Attitudes - Testing the Left-Right and Environmental Concerns Frameworks

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Authors' Contributions: Thies Petersen and Maximilian Koppenberg had the original idea for the research and developed the research questions. Tom Denker, Maximilian Koppenberg and Thies Petersen created the dataset. Thies Petersen led the formal analysis, wrote the manuscript, and created the visualizations. Tom Denker, Maximilian Koppenberg and Stefan Hirsch supervised the data analysis, and the writing of the final manuscript.

Abstract:

Promoting the consumption of meat substitutes to reduce meat consumption is a promising way to reduce the environmental and public health externalities of meat consumption while preserving the important role of flavor and taste in meat products. However, the market for meat substitutes in countries such as Germany is developing more slowly than expected. Therefore, in this article, we analyze the factors associated with the heterogeneity in meat substitute consumption in Germany, a country where meat consumption has a high cultural value. Using data on meat substitute sales, sociodemographic data and election results from 92 regions in Germany over the period 2017-2021, we analyze whether differences in meat substitute consumption are associated to consumers' political orientation (liberal/left or conservative/right). We also investigate whether differences in elected political parties' endorsement of climate protection goals can explain differences in meat substitute consumption across regions. Our results show that meat substitute consumption varies significantly across German regions and that these differences are related to differences in sociodemographic characteristics and voting behaviors across regions. In particular, voting for the Green Party and parties with strong climate protection ambitions is positively related to the market share of meat substitutes. In contrast, voting for the most conservative and least ambitious party in terms of climate protection targets in Germany is associated with lower meat substitute consumption. Therefore, to increase the market share of meat substitutes as alternatives to meat products, manufacturers could develop more tailored marketing strategies that better target these socio-demographic voter groups. Finally, measures to improve education on the benefits of meat substitutes in the context of climate change and public health could boost the market share of meat substitutes.

Keywords: meat; meat substitute consumption; sustainability; political preferences; green consumption

5.1 Introduction

Reducing meat consumption, particularly of red meat such as pork and beef, is of great importance to policymakers due to the adverse external effects of livestock farming and meat consumption on the environment and public health (IPCC, 2022). Accordingly, the 'EAT-Lancet Commission'[8] suggests to drastically reduce meat consumption and increase the intake of plant-based foods (Willett *et al.*, 2019). One way to reduce meat consumption is to increase green choices in meal settings (Meier *et al.*, 2022). Another option is to internalize the external effects of meat in its market price through policy measures, which could then reduce meat consumption (Funke *et al.*, 2022; Roosen, Staudigel and Rahbauer, 2022). Meat consumption could also be reduced by promoting the consumption of meat substitutes (Siegrist and Hartmann, 2023; IPCC, 2022). These products imitate meat in taste and appearance and/or replace it in a meal context[9] (Petersen, Hartmann and Hirsch, 2021). Meat substitutes tend to have lower carbon footprints than meat products (Clark *et al.*, 2022; Saget *et al.*, 2021; Bryant, 2022) and despite being ultra-processed products (Wickramasinghe et al., 2021), they can have favorable nutritional compositions (Petersen, Hartmann and Hirsch, 2021; Petersen and Hirsch, 2023). Another benefit of meat substitutes is that they can be used and prepared similarly to traditional meat products, which can simplify the transition from traditional meat (Siegrist and Hartmann, 2023). However, despite high estimated growth rates for meat substitutes (Barclays, 2019), their current market shares are relatively low in most Western countries (Siegrist and Hartmann, 2023). Given the environmental and health concerns connected to meat consumption, it is therefore crucial to understand the factors related to meat substitute demand.

When investigating these factors it is important to consider the characteristics of different segments and consumer groups that might be associated with different levels of adoption. Among these factors, young age, high education level and income are most likely positively related to the consumption of meat substitutes, although the related literature has not yet provided conclusive results in this regard (Onwezen *et al.*, 2021). Furthermore, factors such as the social and political environment of consumers have not yet been sufficiently researched (Onwezen *et al.*, 2021). In this context, Jost (2017) highlights the relevance of consumers' political attitudes in explaining different consumption patterns. For the case of plant-based milk

[8] "*The EAT-Lancet Commission consists of 37 world-leading scientists from 16 countries from various scientific disciplines. The goal of the Commission was to reach a scientific consensus by defining targets for healthy diets and sustainable food production. The findings of the Commission provide the first ever scientific targets for a healthy diet and sustainable food production within planetary boundaries that will allow us to feed up to 10 billion people by 2050.*", https://eatforum.org/eat-lancet-commission/.

[9] We do not consider other meat alternatives like cultured meats or insect-based products as meat substitutes as those are not yet established on the market.

Wolf, Malone and McFadden (2020) show, based on a study with 995 participants from the US, that more liberal households are more likely to consume plant-based milk. In contrast, the study by Li *et al.* (2023) showed that there is no relationship between political beliefs and the purchase intention of plant-based meat substitutes. Additionally, Marcus, Klink-Lehmann and Hartmann (2022) found, in an application of the theory of planned behavior, that the environmental and animal welfare concerns that German consumers indicate do not explain the attitude regarding meat substitutes and the behavioral intention to consume these products. Hence, given the potential benefits of meat substitutes, their low acceptance and the inconclusive results on the factors associated with their consumption, this study aims to determine the consumer characteristics associated with the consumption of meat substitutes both from a demographic perspective and with regard to the political attitudes of consumers in Germany.

The per capita consumption of meat in Germany was 52 kg in 2022 and follows a downward trend (60kg in 2017 and 62.4kg in 2007) (BMEL, 2023). On the other hand, the production volume of plant-based meat substitutes increased from 0.73 kg per capita in 2019 to 1.24 kg per capita in 2022 (DESTATIS, 2023b, 2022). Although the per capita consumption of meat is still forty times higher than that of meat substitutes, the trend of decreasing meat consumption and increasing meat substitute consumption makes Germany an interesting case study for the analysis of the factors related to the market shares of meat substitute products.

5.1.1 Acceptance of meat substitutes

There is a large body of research on the product attributes that influence, for example, the willingness to pay for meat substitutes (Apostolidis and McLeay, 2016, 2019), the barriers for consumers to switch to meat substitutes (Carlsson, Kataria and Lampi, 2022), or the consumer characteristics and attitudes related to meat substitutes demand (Bryant and Sanctorum, 2021; Heijnk, Espey and Schuenemann, 2023). Onwezen *et al.* (2021) review the recent literature on the acceptance of meat substitutes. They find that the differences in the acceptance of plant-based meat substitutes between consumer groups can be explained by motives like taste but also by attitudes and norms (Onwezen *et al.*, 2021). In turn, studies on demographic consumer characteristics yield mixed results as some report insignificant relationships while others report relationships that can explain the variation in the liking. Still, previous findings tend to show that young, educated people in urban areas prefer meat alternatives (Onwezen *et al.*, 2021). Moreover, Meier *et al.* (2022) highlight the importance of social desirability in sustainable food choices.

While the previous literature on plant-based meat substitute acceptance and consumption is mostly limited to stated-preference methods with the disadvantage that results are potentially affected by social desirability bias (Cerri, Thøgersen and Testa, 2019). Therefore, this study aims to address this disadvantage by relating consumer characteristics, like age or income, as well as political orientation to meat substitute consumption based on revealed preference data.

5.1.2 Political orientation and sustainable consumption

In their review of political ideology and consumers Jung and Mittal (2020) conclude that there is a growing importance of political ideology in daily life choices and consumer behavior. Studies with a focus on grouping consumers into political groups tend to use the terms liberal (left-wing) and conservative (right-wing) (Carney *et al.*, 2008; Adaval and Wyer, 2022). Conservatism and right-wing can be described as "the tendency to prefer safe, traditional, and conventional forms of institutions and behavior" (Wilson, 1973: 4). In contrast, liberal and left-wing consumers are described by their openness to change, fairness and diversity (Adaval and Wyer, 2022).

Based on this segmentation of liberal vs. conservative differences in consumer behavior exist. For example, Gromet et al. (2013) show that labels with environmentally friendly claims on light bulbs reduced the likelihood that more conservative consumers purchased the products even though they previously bought the otherwise similar unlabeled environmentally friendly version. Usslepp *et al.* (2022) show a negative relationship between conservatism and fair trade adoption, which is moderated by age and income. Furthermore, Irmak, Murdock and Kanuri (2020) show that when distinguishing between liberals and conservatives, the latter tend to act contrary to governmental food labeling regarding the healthiness of products as they perceive these labels as a threat to their freedom of choice. In addition, Fernandes and Mandel (2014) find that conservatism is related to more variety-seeking. They assume that this is due to social norms in the Western world regarding choice searches, which could point towards more openness towards new products.

In the context of meat consumption, conservative consumers tend to include higher shares of meat in their diets (Ruby, 2012) while Yule and Cummings (2023) highlight the disinterest of conservative consumers in meat substitutes. According to Nezlek and Forestell (2019) college students in the USA with greater support for the conservative party are more likely omnivores. Similarly, a longitudinal study of adults in New Zealand finds that political conservatism is linked to a lower probability of adopting plant-based diets and lower environmental efficacy, caused by the disbelief that personal actions influence climate change (Milfont *et al.*, 2021).

Additionally, in conservative environments, there is little support for the change to plant-based diets, hence, consumers are more likely to shift back to omnivore diets after attempting plant-based diets (Hodson and Earle, 2018). A possible explanation is that these consumers consider meat consumption as a part of their cultural identity, which could be threatened by vegetarian or vegan diets (Dhont and Hodson, 2014). Additionally, Wilks *et al.* (2019) find that conservatives have a greater aversion to cultured meat, which they explain with the fact that conservatism might be associated with the preservation of the traditional meat industry and with traditional eating behavior. However, the reported results are often based on stated self-evaluations regarding political attitudes, for example, on a scale from 1 (liberal) to 9 (conservative) (Wilks *et al.*, 2019), and on revealed voting data. Therefore, this study aims to explain meat substitute consumption by political ideology based on individual party outcomes.

In addition to the liberal-conservative scale some studies analyze the relationship between sustainability attitudes of consumers and their sustainable behavior. Haws, Winterich and Naylor (2014) show that scoring high on a green preferences scale indicates that consumers react positively to (green) product attributes. However, in general, there is an attitude-behavior gap between stating environmental concerns and the green behavior of consumers, which can be explained by the prices of the products (Gleim and J. Lawson, 2014). In particular, meat substitutes tend to be more expensive than traditional meat products (Petersen *et al.*, 2023). In this regard, Marcus, Klink-Lehmann and Hartmann (2022) find that consumers which are generally concerned for the environment have no direct intend to adopt and consume meat substitutes. To further investigate this discrepancy between attitude and behavior in relation to sustainable behavior, this study contributes to the literature by linking meat substitute consumption to the electoral outcomes of parties with strong or weak environmental efforts in their election programs.

5.1.3 Research objectives

Based on a revealed preference dataset we make the following three contributions to the literature:

1. using a sample for the German meat market for the period 2017-2021, we test whether sociodemographic and -economic factors are related to sustainable food choices in Germany;
2. we investigate whether the findings of previous literature on the relationship between liberalism/conservatism and the adoption of vegan/vegetarian diets are transferable to meat substitute consumption;

3. we further advance the literature by testing the relationship of an aggregated scale for green/ecological sustainability voting in a region and meat substitute consumption.

Our analysis is based on a sample of sales data from IRI (2023) for meat and meat substitute products, that we merge with data on demographic and political characteristics of 95 different regions in Germany, over the period 2017-2021. Though early studies showed that the market for plant-based alternatives will experience significant growth, sales and revenue of the sector are currently stagnating (Siegrist and Hartmann, 2023). Hence, our study may be of particular interest for marketing of food producers and retailers who aim to foster the demand for plant-based alternatives. Moreover, the results may be relevant to policymakers who are interested in implementing measures that increase the share of meat substitutes to tackle both public health and environmental issues arising from meat consumption.

The remainder of this article is structured as follows: In the next chapter, the six major German political parties are presented. In chapter three, the data and method are described. This is followed by the results and a discussion chapter with concluding remarks.

5.2 Background about the political parties in Germany and hypotheses

In Germany, there are six relevant parties on the federal level (Schmitt-Beck *et al.*, 2022). Those include the Alternative for Germany (AfD), the Christian Democratic Union-Christian Social Union (CDU/CSU), the Free Democratic Party (FDP), Alliance 90/Die Grünen (Greens), Die Linke (The Left) and the Social Democratic Party of Germany (SPD) (Schmitt-Beck *et al.*, 2022). The main information about these parties and their position regarding meat consumption and meat substitutes are summarized in Table 1. The AfD can be described as a populistic right-wing party that is most successful in the eastern regions of Germany (Weisskircher, 2020). The CDU/CSU is a block consisting of two separate parties that act as one in the federal parliament (Bawn, 1999). CDU/CSU is a conservative party that can be classified on the center-right of the political spectrum (Weisskircher, 2020). The FDP defines itself as a liberal party that can be located in the center-right with a strong belief in the economic market (Schmitt-Beck *et al.*, 2022). The focus of the Greens, in contrast, is on issues associated with sustainability and climate change and they can be classified on the left of the political spectrum (Schmitt-Beck *et al.*, 2022). Finally, the SPD is positioned on the center-left and The Left on the left wing of the political spectrum (Schmitt-Beck *et al.*, 2022). Lo, Proksch and Gschwend (2014a) present a general left-right score for political parties in Europe; the corresponding results for Germany are presented in Table 1. Note that the political scale presented in Lo, Proksch and Gschwend (2014a) is from a time when the AfD was just emerging and, therefore is not considered.

Therefore, we use the result of the AfD's sister party from Austria, which can be considered similar in terms of political opinions and ideology (Heinisch and Werner, 2019).

The above parties differ in their perception regarding the importance of taking measures to tackle anthropogenic climate change and in the way they want to take action to protect the climate. A study from the German Institute for Economic Research (DIW Econ GmbH) analyzed the importance of climate protection measures among the different parties (Handrich, 2021). They assessed the 2021 federal election programs based on the six sectors: Industry, energy, traffic, housing, agriculture and carbon sinks. Using an ordinal score from 0 to 4, they evaluated whether the program is sufficient to reduce Germany's emissions to a level of 65% below the 1990 emissions by 2030. The results can be ranked from bottom to top in terms of the ability of party programs to reduce emissions as follows: FDP, CDU/CSU, SPD, Left Party, and Green Party. The analysis excluded the AfD from the ranking because the party denies human influence on climate change (Handrich, 2021). Therefore, it could be ranked as the lowest in this ranking for climate action. In summary, there are considerable differences in the programs of the political parties regarding steps to tackle climate change.

Finally, the political parties have different recommendations and ideas for meat consumption in Germany. While the AfD and the CDU/CSU support traditional diets (CDU/CSU, 2021), the AfD is strictly against political interference, particularly in the form of a tax on meat products (AfD, 2021). Apart from food affordability in general, no reference concerning meat consumption is made in the program of The Left (Die Linke, 2021). The SPD, on the other hand, supports the dietary recommendations of the German Nutrition Society (SPD, 2021), which recommends a daily meat intake of 300 to 600 grams (DGE, 2023). This recommendation would imply a reduction of about 50% of current consumption. The Greens and the FDP are the only parties that refer to meat alternatives in their programs. While the FDP supports the introduction of in vitro meat in the EU (FDP, 2021), the Greens want to actively support plant-based meats and take measures to improve their market position by adjusting taxes compared to conventional meat products (BÜNDNIS 90/DIE GRÜNEN, 2021).

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Table 5-1 - Political Parties in Germany

Party	Founding Year	Members in 2021 in thousand[1]	Position[2]	Share of (Second) Votes 2021[3]	Position on meat consumption[4]	Position on meat alternatives[4]	Scaled left - right position γ [5]	CPA-score ω [6]
Bündnis 90/ Die Grünen (Greens)	1980	125.3	Left	14.8%	Fewer animal-based products	Support plant-based meat substitutes; improve tax efficiency of meat substitutes	-0.66 [2]	3.62 [6]
Die Linke (The Left)	2007	60.7	Left-wing	4.9%	None	None	-1.91 [1]	2.6 [5]
CDU /CSU[2]	1950	514.6	Center-right	24.1%	Informed consumer	None	0.60 [5]	1.81 [4]
SPD	1863	393.7	Center-left	25.7%	Support diet recommendations of the DGE with 300-600g per week	None	-0.46 [3]	1.79 [3]
FDP	1948	77.3	Center-right	11.5%	None	Support the approval of in vitro meat in the EU	0.21 [4]	1.24 [2]
AfD	2013	30.1	Right-wing	10.3%	No interference of legislation; No meat tax	None	Not evaluated FPÖ: 2.1 [6]	Not evaluated 0 [1]

Note:[1] Source: Statista (2023); [2]Source: Schmitt-Beck *et al.* (2022); [3] Source: The Federal Returning Officer (2023); [4]Sources: The electoral programs of the individual parties (CDU/CSU, 2021; SPD, 2021; AfD, 2021; FDP, 2021; BÜNDNIS 90/DIE GRÜNEN, 2021; Die Linke, 2021); [5] Score indicates from negative (left) to positive (right) the position of the political party. Source: (Lo, Proksch and Gschwend, 2014b, 2014a);[6] Source: Handrich (2021). CPA: Climate protection ambitions. The numbers in square brackets indicate the alternative ordered scores introduced in Chapter 3.1.

5.3 Data and method

5.3.1 Data

To create the dataset, we merged data from three different sources. First, we used retail scanner data on sausage, burger, and meat sales from the IRI (Information Resources Inc.) database over the 5-year period from 2017-2022 (IRI, 2023). The data are provided on a barcode level and include the sales volume in weight and Euros on the store level including the first two digits of the postal code in which the stores are located. This allowed us to aggregate the data on a yearly basis and the 96 different two-digit postal code areas. Based on the aggregation, we calculated the share of meat substitute (MS) sales (in €) in total sales (% MS €) in each of the 96 regions and five years. Note that our data only includes packed meat products from the self-service areas of supermarkets while products that are sold over a service counter within the supermarkets are not included. Therefore, we include only three different groups of products, sausages, meat balls, and breaded meats, like escallops and nuggets, as including products like tofu without the counterpart steak that is available at the meat counter would decrease the comparability of meat and meat substitute sales. Furthermore, these product categories represent comparable categories of products that are similarly processed and used (Petersen and Hirsch, 2023). The total sales volume on which our sample is based amounts to 471.8 million Euros, of which 42.0 million Euros are attributable to the sale of meat substitute products.

Secondly, previous literature on sustainability and meat substitute consumption has shown some links between age, education and income, and the consumption of meat substitutes (e.g. Panzone *et al.*, 2016; Onwezen *et al.*, 2021). People with higher incomes tend to be more open to meat substitutes, which could explain the differences in the proportion of meat substitutes across regions. In urban areas, the proportion of vegetarians and vegans is higher, and the same is true for university students, and people with higher education, which may explain lower meat consumption or higher meat substitute consumption in these groups, respectively. On the other hand, we expect age to be negatively associated with the proportion of meat substitutes in total sales in a region as older people are less willing to accept alternative meats (Onwezen *et al.*, 2021). In our analysis we therefore consider average per capita income (Avg. Income) and age (Avg. Age), population density (Pop. Density), proportion of university students (Share Students), and proportion of women (Share Female %) in a region as sociodemographic and economic factors that are potentially related to meat substitute consumption. The data on these characteristics for each region are collected from the Federal Statistical Office in Germany (DESTATIS, 2023a). However, for two cities the data are aggregated to the city level comprising a total of 6 postal code areas reducing the total number of postal code areas in our sample to 92.

Third, we collect data on election results. Two federal elections (2017 and 2021) and one election to the European Parliament (2019) took place in the period. Voting in the federal (Bundestag) election in Germany consists of two votes. While the first vote refers to a local candidate, the second vote refers to the total percentage of seats a party receives in the election. Since preferences for particular candidates may differ from actual political beliefs, we only consider the share that each party achieved in the second vote in each of the 92 postal code regions. For the European Parliament elections, we consider the total share from the postal code region. We collect data on the second vote for the six major parties that entered the parliament: CDU-CSU (Share CDU %), SPD (Share SPD %), Greens (Share Green %), FDP (Share FDP %), AfD (Share AfD %), and The Left (Share The Left %). Note that Germany has other regional elections, such as state or mayoral elections. However, we do not use data on these elections because they do not occur simultaneously throughout Germany. We further include the turnout (Turnout %) as a measure of satisfaction with democracy (Grönlund and Setälä, 2007).

In our analysis, we additionally test whether the overall voting propensity in a region is related to meat substitute consumption. For this purpose, we calculate four different scores for each region: Left-Right, Left-Right Ordered, Climate Protection Ambitions (CPA), CPA Ordered. To calculate the left-right score, we use the estimated values (γ) for the position of political parties on the left-right scale in Europe derived by Lo, Proksch and Gschwend (2014a) and presented in Table 1 and weight them with the electoral results (percentage share) in the second vote (SV) of each party in a given region and year:

$$Left - Right_{i,t} = \sum_{p=1}^{P} \gamma_p * SV_{p,i,t} \ for \ i = 1,..,92 \tag{1}$$

The lower the resulting Left-Right score, the higher the election result for left/liberal parties in a given region and year. Conversely, the higher the left-right score, the better the election result for right/conservative parties. In addition to the left-right score, we derive a value for the vote for climate protection ambition (CPA) in a region i at time t. Analogous to the left-right score, we take the values for the ambition of each party's climate change program to achieve the 2030 climate change targets (ω) following Handrich (2021) (see Table 1) and calculate a CPA score for each region and period:

$$CPA_{i,t} = \sum_{p=1}^{P} \omega_p * SV_{p,i,t} \; for \; i = 1,..,92 \tag{2}$$

The higher the resulting CPA score, the higher the electoral support for political parties with strong climate change ambitions. The respective scores for γ and ω are included in Table 1.

For the AfD the study of Lo, Proksch and Gschwend (2014a) and the study of Handrich (2021) do not report values for γ and ω. Hence, we replace the respective value for the calculation of the Left-Right score with the score from the FPÖ, which is a comparable party from Austria (Heinisch and Werner, 2019), and with a 0 in the CPA score. To control for these specifications, we create two alternative ordered scores in addition to the Left-Right score and the CPA score based on a ranking from 1 to 6 of the individual parties, whereby for the alternative Left-Right (Left-Right ordered) score lower values indicate more liberal/left values while for the alternative CPA (CPA ordered) score higher values indicate stronger electoral support for strong climate protection ambitions. The respective values for the alternative ordered scores are included in Table 1.

We merge the data from the three sources based on the postal codes and the three election years in the period between 2017-2022. Hence, the final sample includes information from the 92 postal code areas for the three years 2017, 2019 and 2021, resulting in 276 observations.

5.3.2 Method

To estimate the relationship between the market share of meat substitutes and the voting behavior, controlling for the socioeconomic factors in the regions, we estimate linear regression models. Therefore, our model includes the % *MS €* as the dependent variable, i.e., the sales of meat substitutes divided by the total sales of meat and meat substitutes in a region (i) and period (t). In the first model, we include the election results of the *P* different political parties measured by their electoral results in the share of votes (SV) in each region and year and two time dummy variables for the years 2019 and 2021 (Y*19*, Y*21*):

$$\%MS\ €_{i,t} = \alpha_i + \sum_{p=1}^{P} \beta_p * SV_{p,i,t} + \sum_{p=1}^{P} \beta_{p_{EU}} * SV_{p,i,t} * Y19_{it} + \beta_{Y19} * Y19_{it} + \beta_{Y21} * Y21_{it} + u_{i,t} \tag{3}$$

where $u_{i,t}$ is a random error term. The parameters β_p indicate the relationship between the share of the votes for the respective political party p and the overall % MS €. We also include interaction terms between the shares of votes and the dummy variable for the year 2019. The respective parameters $\beta_{p_{EU}}$ indicate whether the relationship between the voting share and the share of meat substitutes differs for the European election. We first estimate the model in (3) separately for each party and afterwards estimate a complete model that jointly includes the results of all parties as independent variables.

We then extend the model by adding a set of *C* different socioeconomic and -demographic characteristics of the regions (SOC). The resulting model is defined as follows:

$$\%MS\ €_{i,t} = \alpha_i + \sum_{p=1}^{P} \beta_p * SV_{p,i,t} + \sum_{p=1}^{P} \beta_{p_{EU}} * SV_{p,i,t} * Y19_{it} + \sum_{c=1}^{C} \beta_c * SOC_{c,i,t} + \beta_{Y19} * Y19_{it} + \beta_{Y21} * Y21_{it} + u_{i,t} \tag{4}$$

where $u_{i,t}$ is a random error term. The parameters β_c indicate the relationship of the socioeconomic variables with the share and the β_p indicate the relationship between the share of the votes for the respective political party p and the overall % MS €. We again first estimate the model in (4) separately for each party and subsequently estimate a complete model that jointly includes all parties.

In the second part of the analysis, we use the overall tendencies regarding left and right voting (Left-Right score and the alternative Left-Right score) instead of the results for the share of votes (SV). We again include the C different socioeconomic and -demographic characteristics of the regions (SOC) and the time dummy variables. The resulting model is defined as follows:

$$\%MS\ €_{i,t} = \alpha_i + \beta_{LR} * Left - Right_{i,t} + \beta_{LR_{EU}} * Left - Right_{i,t} * Y19_{i,t} + \sum_{c=1,\ldots,C}^{C} \beta_c * SOC_{c,i,t} + +\beta_{Y19} * Y19_{it} + \beta_{Y21} * Y21_{it} + u_{i,t} \tag{5}$$

Similarly, for the overall electoral support for Climate Protection Ambitions (CPA score and the alternative CPA score) the model is defined as follows:

$$\%MS\ €_{i,t} = \alpha_i + \beta_{CPA} * CPA_{i,t} + \beta_{CPA_{EU}} * CPA_{i,t} * Y19_{i,t} + \sum_{c=1,\ldots,C}^{C} \beta_c * SOC_{c,i,t} + +\beta_{Y19} * Y19_{it} + \beta_{Y21} * Y21_{it} + u_{i,t} \tag{6}$$

Since our data comprises three years and 92 different regions, we assume to have a panel data set. Equations (3-6) can therefore either be estimated using a random effects model or a fixed effects model. The random effects model is preferred over the fixed effects model if the individual intercept is unrelated to the explanatory variables in the model (Wooldridge, 2013). Testing this assumption using the Hausman test reveals that the fixed effects model is the preferred choice to estimate equations (3)-(6). The results are presented in Appendix Table 1.

5.3.3 Robustness check

Johnston, Jones and Manley (2018) emphasize that research on voting behavior potentially suffers from confounding and collinearity. A frequently used approach to solve this problem is to collect more data or to drop variables from the analysis (Wooldridge, 2013). However, O'Brien (2017) highlights that dropping one variable of interest based on a high variance inflation factor undermines the purposes of multiple regression analyses to control for other variables. Additionally, the model could then suffer from omitted variable bias (Wooldridge, 2013). Hence, Johnston, Jones and Manley (2018) suggest performing a principal component analysis or a factor analysis on the independent variables and in a second step estimate a regression model with the resulting factors as independent variables. Afterwards, standardized coefficients can be obtained based on the sum product of each variable's factor loading with the estimated regression coefficients (Massy, 1965; Johnston, Jones and Manley, 2018). These coefficients can then be interpreted in terms of their relative importance to the model.

The data in our sample also suffer from a high correlation between some of the variables, particularly between the voting behavior and the sociodemographic variables. Additionally, with the % MS €, i.e. the dependent variable. Table 2 in the appendix contains the pairwise correlations between the variables. For example, there is a high positive correlation between the average age in a region and voting for the AfD in that region ($\rho_{AfD,Age} = 0.75$) and a high negative correlation between both variables and the share of meat substitutes ($\rho_{AfD,\%MS€} = -0.51$; $\rho_{Age,\%MS€} = -0.425$). Hence, to account for this structure in the data, we perform a factor analysis for the variable sets considered in the models (4)-(6) as they include the sociodemographic. The respective factor loadings are then determined for the F different factors based on the Eigenvalue criterion of 1 and varimax rotation (Backhaus *et al.*, 2021). Factor scores are afterwards calculated for each factor and observation. These factor scores are then used as variables to estimate the model below:

$$\%MS\,€_{i,t} = \alpha_i + \sum_{f=1,\dots,f}^{F} \beta_f * Faktor_{f,i,t} + 19_{it} * \beta_{19} + 21_{it} * \beta_{21} + u_{i,t} \quad for\ i = 1,..,92 \tag{7}$$

The estimated $\widehat{\beta_f}$s are then used to calculate the standardized coefficients as a sum product with the varimax rotated factor loadings.

5.4 Results

5.4.1 Descriptive results

Table 5-2- Sample Statistics

Variable	Mean	Std. Dev.	Min	Max
% MS €	8.6%	0.051	1.2%	25.6%
Share Green %	13.9%	0.07	1.6%	31.4%
Share The Left %	6.4%	0.04	1.6%	18.8%
Share SPD %	20.4%	0.07	6.1%	36.3%
Share CDU %	29.2%	0.07	14.2%	55.2%
Share FDP %	9.1%	0.03	2.0%	17.2%
Share AFD %	11.9%	0.06	4.5%	32.7%
Left-Right	0.136	0.132	-0.207	0.571
Left-Right Ordered	3.496	0.254	2.645	4.070
CPA	1.678	0.186	1.105	2.053
CPA Ordered	3.151	0.276	2.291	3.759
Turnout (in %)	71.4%	0.08	52.4%	83.4%
Share students (in %)	3.3%	0.026	0.0%	11.8%
Avg. Income (in 10.000 €)	2.328	0.228	1.855	3.192
Avg. Age (years)	44.868	1.641	40.7	49.382
Pop. Density (in people/km^2)	509.325	787.358	47.429	4789.835
Share Female (in %)	50.6%	0.004	49.5%	51.8%

N=276. Note: The voting results do not represent the general election results as the values are not weighted according to the population in the respective regions.

In Table 2 we present the descriptive statistics. It can be observed that meat substitutes have an average market share of 8.6%, with a minimum of 1.2% and a maximum of 25.6% in a postal code area. Note that this share is larger than the share reported by the Federal Statistical Office for the population in Germany, which indicates a market share of 1.3% for 2021 (DESTATIS, 2022). This might be due to the selected product categories. Additionally, the market share increases significantly from 5.3% in 2017 to 7.4% in 2019 (p=0.00) and further to 13.2% in 2021 (p=0.00).

The average percentage received by the Greens across all postal code areas over the three years is 13.9%, while the lowest value over the observed period is 1.6% and the highest is 31.4%. Note that the values for the individual parties do not add up to 1, as there are also smaller parties in Germany, however, they are not represented in the parliament (Bundestag) and therefore excluded from the analysis. The mean left-right value of 0.136 with a minimum of -0.207 and a max value of 0.571indicates a center-right position across the German regions. Furthermore, the mean CPA of 1.678 with a minimum of 1.105 and a maximum of 2.053indicates a moderate vote for strong climate ambitions. The average turnout across regions is 71.4% while 3.3% of people in the regions are students at universities or colleges. Finally, there are on average slightly more women than men in the regions. A graphical representation of the distribution of the socioeconomic variables across regions for the year 2021 is included in the Appendix Figure 1.

Figure 1a presents the share of meat substitutes in the total meat market in Germany by postal code regions for the year 2021. The figure reveals considerable differences in the meat substitute purchase behavior across regions. In particular, the market shares of meat substitutes are higher in the southwest of Germany than in the northeast of Germany. The highest market share can be observed in the region around Heidelberg in the federal state Baden Württemberg with 25.59%, while the lowest share of 2.64% is observed in a region in the east of Mecklenburg-Vorpommern and north of Brandenburg.

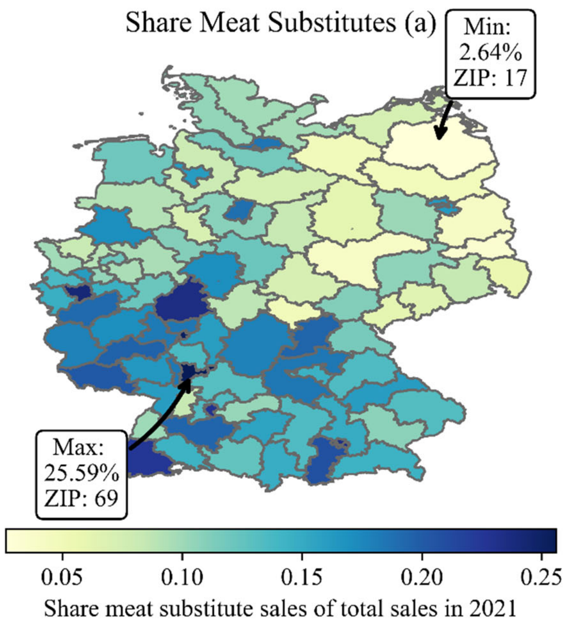

Figure 5-1 Meat substitute consumption and election results of the AFD and the green party in the federal election in Germany in 2021 by regions

Note: ZIP: postal code region.

In the eastern regions of Germany, the Green Party, which stands for strong climate ambitions and left policies, receives worse results than in the western regions of Germany (cf. Figure 1b). Additionally, the Green Party receives higher shares in large cities like Berlin and the highest share in the Munich region with 26.1%. However, the minimum for the Greens in the 2021 federal election is in the region that includes the Saarland in the southwest of Germany with 1.61%, which is due to errors of the Green party in the registration. The Greens could not agree on a state list in the Saarland and were therefore ineligible for the second vote (Bloomberg, 2021). In contrast, the AfD, as an example of a party without climate protection ambitions and right-wing policies, receives more votes in percentage terms in the eastern regions of Germany and lower shares in the western regions (cf. Figure 1c). The AfD achieved its lowest percentage in the Munich region of Bavaria with 4.54%, and its highest share in eastern Saxony with 32.07%.

In summary, there are not only regional differences in voting behavior for the individual parties, but the market share of meat substitutes also varies considerably from region to region in Germany. The factors related to these differences are explored in the next chapter.

5.4.2 Results on voting, socioeconomic factors, and consumption of meat substitutes.

Table 3 includes the estimated results for equation (3). In columns (1) through (6) we present the estimates for each party separately while in column (7) we present the joint estimates. A percentage point increase in the share of votes for the Green party in a region is associated with a 0.405 percentage points higher share of meat substitutes in the respective market ($p<0.01$). However, this effect is slightly lower but still significant (0.405-0.243= 0.162; $F=25,58$, $p<0.001$) for the EU election in 2019. Furthermore, we observe a positive association of voting for The Left and a negative for the SPD with the share of meat substitutes. For both models, the relationship is statistically significant. For the market-liberal party FDP, however, there is no statistically significant relationship between the electoral shares in the federal elections ($p>0.1$) or in EU elections ($F=2.59$, $p=0.081$). The results for the two conservative parties are mixed. While the relationship between voting for the CDU is positively associated with the market share of meat substitutes, the relationship is as expected negative for the AfD, though slightly lower/higher for the EU election in 2019, respectively. Finally, the estimated coefficients for the time dummy variables for the years 2019 and 2021 show that the market share of meat substitutes has increased in the observed period.

Table 5-3 Results of fixed effects regression models explaining meat substitute consumption in Germany by voting behavior

	(1) (Green) % MS €	(2) (The Left) % MS €	(3) (SPD) % MS €	(4) (FDP) % MS €	(5) (CDU) % MS €	(6) (AFD) % MS €	(7) (All % MS €
Share Green %	.405***						.318*
	(.099)						(.164)
Share Green %*Y19	-.243***						-.316***
	(.044)						(.109)
Share The Left %		.820***					.383
		(.145)					(.279)
Share The Left %*Y19		.010					-.277**
		(.022)					(.129)
Share SPD %			-.517***				-.185
			(.071)				(.185)
Share SPD %*Y19			-.024				-.124
			(.023)				(.108)
Share FDP %				-.117			.225
				(.126)			(.254)
Share FDP %*Y19				-.172**			.064
				(.077)			(.117)
Share CDU %					.355***		.014
					(.093)		(.168)
Share CDU %*Y19					-.157***		-.249**
					(.036)		(.105)
Share AFD %						-.706***	-.712***
						(.149)	(.214)
Share AFD %*Y19						.103***	-.112
						(.019)	(.102)
2019 (EU dummy)	.024***	.05***	.001	.024***	.081***	-.003	.171*
	(.003)	(.006)	(.004)	(.005)	(.014)	(.004)	(.095)
2021 (dummy)	.058***	.114***	.108***	.08***	.112***	.064***	.073***
	(.006)	(.007)	(.006)	(.004)	(.01)	(.004)	(.017)

	(1) (Green) % MS €	(2) (The Left) % MS €	(3) (SPD) % MS €	(4) (FDP) % MS €	(5) (CDU) % MS €	(6) (AFD) % MS €	(7) (All % MS €
Constant	.018**	-.021	.157***	.065***	-.066**	.146***	.094
	(.009)	(.013)	(.014)	(.013)	(.031)	(.019)	(.151)
Observations	276	276	276	276	276	276	276
Within R2	0.856	0.860	0.871	0.833	0.847	0.854	0.895
Overall R2	0.621	0.084	0.264	0.406	0.444	0.579	0.629
Between R2	0.4	0.236	0.001	0.134	0.050	0.369	0.435
ll	788.164	792.12	802.444	767.291	779.325	786.288	831.161
F-stat	206.153	184.837	178.33	115.049	161.797	146.896	89.288
p	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F-Test party coefs.	25.580	31.700	27.630	2.590	18.590	21.810	11.840
P	0.000	0.000	0.009	0.081	0.000	0.000	0.000

Note: The standard errors are cluster robust by postal code region. The reference year is 2017. Alternative for Germany (AfD), the Christian Democratic Union-Christian Social Union (CDU), the Free Democratic Party (FDP), Alliance 90/Die Grünen (Green), Die Linke (The Left) and the Social Democratic Party of Germany (SPD). a The Joint F-stat party c. is the value of the F-test for the null hypothesis that the estimated coefficients of the party are jointly equal to 0. * p<.10; ** p<.05; *** p<.01. *

Column (7) in Table 3 contains the combined results including the results of all parties in a single estimation. Again, voting for the Green Party is associated with a higher market share of meat substitutes. However, this effect is reduced to almost zero for the 2019 European election. In addition, we observe a negative association between the election share of The Left and the CDU in the EU election, but the coefficients for the federal election do not differ from zero. Finally, voting for the AfD is again associated with lower meat substitute consumption and the effect does not differ for the 2019 EU election. For the remaining parties, we find no link between the election results and meat substitute consumption. Thus, while we find that voting for the Greens, the most sustainable among the analyzed parties and the only party explicitly in favor of supporting the market success of meat substitutes is positively related to meat substitute consumption, the opposite is found for the AfD.

Table 4 shows the estimation results of equation (4) which examines the relationship between the market share of meat substitutes and the voting behaviour controlling for socioeconomic factors. In columns (1) through (6) of Table 4 we present the estimates for each party separately and in (7) we present the joint estimates. Column (8) includes the standardized coefficients as described in 3.3.

The model in column (1) includes the election results of the Green party as the main independent variable and the sociodemographic control variables. The result of the estimated coefficient for the Share Green % variable indicates a positive relationship between the share that the green party receives in a region and the market share of meat substitutes in the region. More precisely, a one percentage point higher share of the second votes for the Green party is associated with a 0.333 percentage points higher share of meat substitutes in the market. This supports the hypothesis that green voting behavior is related to higher meat substitute sales. However, this relationship is lower for the election of the European parliament in 2019 (.333-.245=.088; $F=20.710$, $p<0.01$). The results for the party The Left, (column 2), which has, according to Handrich (2021) the second most ambitious green election program, differs as the overall relationship is statistically insignificant. Still, the interaction term of the European Parliament election in 2019 and the federal result of The Left is positively associated with the share of meat substitutes in the market. The estimated coefficient for the share of the SPD and the market share of meat substitutes is statistically significant and negative. Therefore, the results partially contradict the hypothesis that more liberal/left voters eat more sustainable foods. However, voting for strong sustainability ambitions, via the Green Party is related to higher meat substitute consumption in a region.

Table 5-4 Results of fixed effects regression models explaining meat substitute consumption in Germany by socioeconomic and voting factors

	Fixed effects estimation							Standardized coefficients factor analysis
	(1) (Green) % MS €	(2) (Left) % MS €	(3) (SPD) % MS €	(4) (FDP) % MS €	(5) (CDU) % MS €	(6) (AFD) % MS €	(7) (All Parties) % MS €	(8) (All Parties)
Share Green %	.333*** (.101)						.425** (.211)	0.029
Share Green %*Y19	-.245*** (.046)						-.240 (.200)	
Share The Left %		-.057 (.178)					-.390 (.272)	-0.002
Share The Left		.192*** (.047)					-.078 (.205)	
Share SPD %			-.228*** (.077)				-.126 (.145)	-0.019
Share SPD %*Y19			-.002 (.027)				-.035 (.163)	
Share FDP %				.171 (.147)			.386 (.269)	0.013
Share FDP %*Y19				-.228** (.094)			.073 (.158)	
Share CDU %					.232*** (.073)		.174 (.155)	0.004
Share CDU %*Y19					-.124*** (.036)		-.116 (.176)	
Share AFD %						-.084 (.114)	-.077 (.215)	-0.023
Share AFD %*Y19						.139*** (.024)	.047 (.186)	
Share students	.056 (.322)	.056 (.43)	.108 (.419)	.127 (.422)	.074 (.455)	.086 (.43)	.251 (.353)	0.046
Avg. Income	-.674*** (.169)	-.502*** (.185)	-.383** (.191)	-.469** (.2)	-.397** (.186)	-.413** (.172)	-.856*** (.175)	0.031

	Fixed effects estimation							Standardized coefficients factor analysis
	(1) (Green) % MS €	(2) (Left) % MS €	(3) (SPD) % MS €	(4) (FDP) % MS €	(5) (CDU) % MS €	(6) (AFD) % MS €	(7) (All Parties) % MS €	(8) (All Parties)
Avg. Income[2]	.118***	.09**	.058	.083**	.062*	.072**	.16***	
	(.033)	(.037)	(.037)	(.041)	(.036)	(.033)	(.035)	
Avg. Age	.892***	1.313***	.922***	1.294***	1.179***	1.288***	.918***	-0.051
	(.254)	(.314)	(.289)	(.278)	(.261)	(.282)	(.307)	
Avg. Age[2]	-.009***	-.014***	-.01***	-.014***	-.012***	-.014***	-.009***	
	(.003)	(.003)	(.003)	(.003)	(.003)	(.003)	(.003)	
Turnout in %	.127**	-.004	.095	.122*	.03	.037	.115	0.007
	(.05)	(.058)	(.06)	(.062)	(.06)	(.057)	(.101)	
Pop. density	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000**	0.057
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	
Share Female in %	-5.073	-4.7	-1.059	-2.985	-3.247	-3.775	-7.155	0.003
	(4.149)	(4.733)	(5.145)	(4.916)	(4.923)	(4.694)	(4.538)	
2019 (EU-dummy)	.055***	.008	.028**	.062***	.071***	.008	.076	
	(.008)	(.016)	(.013)	(.012)	(.013)	(.013)	(.16)	
2021 (dummy)	.061***	.074***	.091***	.077***	.096***	.074***	.048**	
	(.013)	(.015)	(.013)	(.012)	(.013)	(.012)	(.02)	
Constant	-18.101***	-27.611***	-20.906***	-28.048***	-25.909***	-27.654***	-17.964**	
	(6.522)	(7.711)	(7.23)	(7.257)	(6.798)	(7.243)	(7.352)	
Observations	276	276	276	276	276	276	276	
Within R2	0.922	0.909	0.907	0.906	0.909	0.912	0.930	
Between R2	0.058	0.078	0.077	0.108	0.061	0.098	0.011	
Overall R2	0.062	0.079	0.068	0.091	0.062	0.083	0.045	
ll	872.439	850.823	848.448	846.641	851.193	855.381	888.289	
F-stat all coefs.	146.044	111.535	119.547	107.324	117.748	111.062	96.414	
P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Joint F-stat party c.[a]	20.710	11.960	5.010	5.600	11.710	17.55	9.300	
P	0.000	0.000	0.009	0.005	0.001	0.000	0.000	

Note: The standard errors are cluster robust by postal code region. The reference year is 2017. Alternative for Germany (AfD), the Christian Democratic Union-Christian Social Union (CDU), the Free Democratic Party (FDP), Alliance 90/Die Grünen (Green), Die Linke (The Left) and the Social Democratic Party of

Germany (SPD). [a] The Joint F-stat party c. is the value of the F-test for the null hypothesis that the estimated coefficients of the party are jointly equal to 0. The results of the factor analysis and the subsequent fixed effects estimation are included in Appendix Table 4 and 5. * $p<.10$; ** $p<.05$; *** $p<.01$. *

Turning now to the more conservative parties with less strong environmental programs based on Handrich's (2021) assessment. The association between the federal FDP election result and market share is not significant, while the association for the 2019 European elections is negative. The estimated relationship for the largest conservative party (CDU), based on the federal election results, and the total share of meat substitutes is positive. However, the interaction term of the European Parliament elections and the CDU share reduces the overall positive relationship (0.232-0.124=0.108; F=11.710, p<0.01). Finally, the estimated coefficient for the AFD is negative, as expected, but not significantly different from zero, which contradicts the hypothesis that more conservative voters tend to eat less sustainable products. Furthermore, the relationship is even positive for the interaction between the share of the AfD and the dummy variable for the European Parliament elections. Thus, this result somewhat contradicts the hypothesis that more conservative/less liberal voters consume less sustainable food. When combining the results of all parties in one model (column (7)), only the relationship between the share of the Green party and the market share of meat substitutes remains statistically significant and positive.

The influence of socioeconomic factors is largely consistent across models. While we find no relationship between gender or the proportion of students in the total population with the market share of meat substitutes, we find that income and age have a U-shaped and an inverted U-shaped relationship with the market share, respectively. Based on the model in column (1) income is negatively related to meat substitute consumption until 2.86[10] i.e. 28.600€ while it is associated with higher meat substitute consumption, after the this threshold. Higher average age in contrast is associated with higher shares of meat substitute consumption, however, this association turns negative at an age of 49.5. In addition, population density is positively related to the market share of meat substitutes, suggesting higher meat substitute consumption in urban areas. The relationship between turnout and market share of meat substitutes tends to be positive but is only statistically significant in two of the seven models. The R^2 of the models ranges from 90.6% for the FDP model (column (4)) to 93% for the model including all parties' results (column (7)) indicating that the included political and sociodemographic factors explain a large share of the variance in the market share of meat substitutes.

In column (8) the standardized coefficients for the model in column (7) are presented. The standardized coefficients are calculated as the sum product of the estimated coefficients from

[10] According to Wooldridge (2013) the turning point can be calculated as $x^* = -\frac{\widehat{\beta_1}}{2*\widehat{\beta_2}}$, whereby $\widehat{\beta_1}$ belongs to the linear term, while $\widehat{\beta_2}$ belongs to the quadratic term. The

the model using factors as independent variables (Appendix Table 5) and the factor loadings (Appendix Table 4). These standardized coefficients can be interpreted as relative strength of the respective independent variable in explaining variation in the dependent variable (Johnston, Jones and Manley, 2018). The results reveal that population density shows the most considerable strength in explaining the variance in our model, as its standardized coefficient is the largest in absolute values. Thus, the share of meat substitutes in the market is higher in areas with higher population densities confirming the above results. This is followed by the negative relationship between age and the market share of meat substitutes and positive relationships with both the proportion of students and income. The highest standardized coefficient in related to voting for political parties is the coefficient for the Green Party, which turns out to be positive. This confirms our finding that the market share of meat substitutes increases the most when the Greens achieve strong election results. In contrast, the share decreases the most when electors vote for the AfD, followed by the SPD.

In summary, the results suggest that socioeconomic characteristics and the election results for the Greens and the AfD have the strongest predictive power in explaining the share of meat substitutes in different regions.

5.4.3 The left-right score and CPA score and meat substitute consumption

In the following, we focus on the scores for left-right and climate change (CPA) voting in Germany and meat substitute consumption. Figure 2a. shows the distribution of left-right voting behavior in Germany in 2021. Note that a higher score indicates a tendency toward conservative/right parties in a region, while a lower score indicates a tendency toward more left/liberal voting behavior. The lowest score is observed in the Hamburg region, while the highest score is found in the eastern part of Saxony. Regarding the CPA a higher score indicates a higher share of votes for political parties with stronger climate protection ambitions. Figure

2b shows that there is stronger voter support for the CPA in the western parts of Germany as compared to the eastern part.

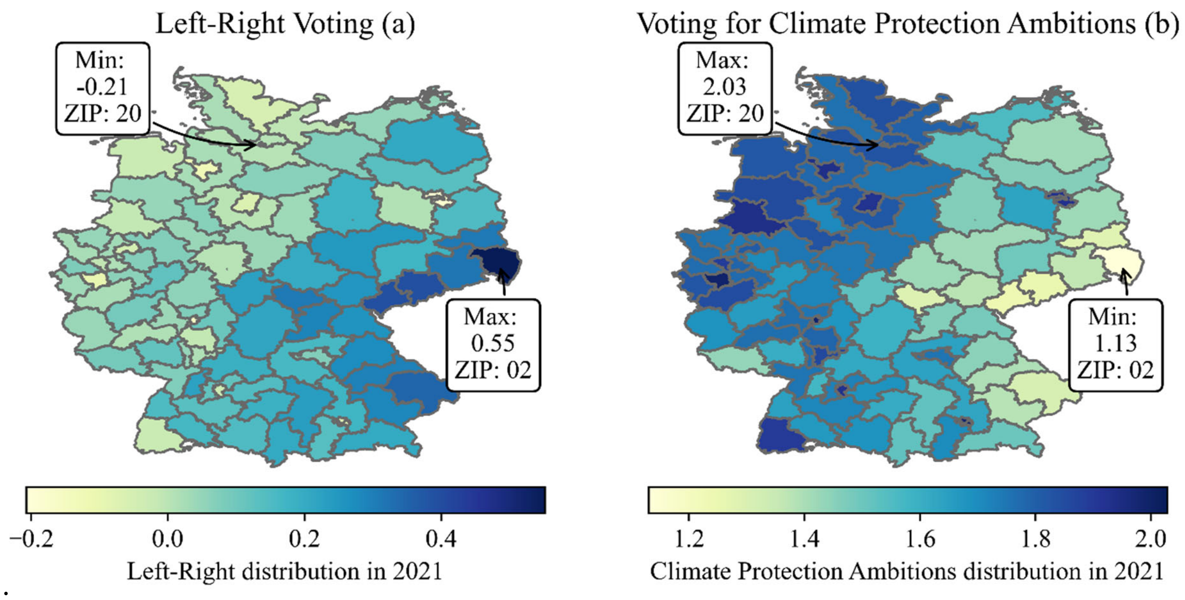

Figure 5-2 - Regional Distribution of the Left-Right Score and CPA in 2021
Note: The Left-Right score is calculated based on the results of Lo et al. (2014b), while the CPA-Score is based on the results of Handrich (2021). The calculation is explained in equation 1 and equation 2, respectively. ZIP: postal code region..

Table 4 presents the regression results for the relationship of meat substitute consumption with the left-right score and voting for climate change ambitions in the regions (CPA score). The model in column (1) shows that there is a significant relationship between the interaction of the left-right score with the 2019 (EU parliament) dummy and the market share of meat substitutes. Although the respective coefficient is positive, the negative main effect for the Left-Right score means that the overall relationship for the EU is negative (-0.054+0.042=-0.012; F=7.590, p<0.01). Column 2 shows that this result does not remain robust if the ordered score for left-right voting is used. The estimated coefficient for the association between voting for climate change ambitions (CPA) and the share of meat substitutes in column (3) is as expected positive and statistically significant. However, the relationship is somewhat reduced by the 2019 European Parliament election. The results are robust to the alternative specification in column (4) where the ordered CPA is used. Therefore, in line with the results in section 4.2, we find evidence for the hypothesis that the more conservative a region is, the lower the market share of meat substitutes. Moreover, we find evidence for a relationship between voting for climate change ambitions and the market share of meat substitutes. However, overall, the CPA score appears to be a better predictor of meat substitute consumption than the Left-Right score in

Germany. The results for the socioeconomic variables are similar to those in Table 3, except for the quadratic relationship between income and meat substitute consumption.

Table 5-5 - Results of fixed effects regression models of meat substitute consumption and Left-Right voting and CPA in Germany

	Fixed effects estimation				Standardized coefficients after factor analysis	
	(1) % MS €	(2) % MS €	(3) % MS €	(4) % MS €	(5)	(6)
Left-Right	-.054 (.069)				-0.026	
Left-Right*Y19	.042*** (.012)					
Left-Right ordered		-.002 (.023)				
Left-Right ordered*Y19		.026** (.011)				
CPA			.109*** (.037)			0.007
CPA*Y19			-.055*** (.011)			
CPA ordered				.049** (.021)		
CPA*Y19				-.029*** (.007)		
Share students	.092 (.424)	.072 (.437)	.067 (.362)	.051 (.394)	0.021	0.016
Avg. Income	-.333* (.19)	-.39** (.194)	-.518*** (.173)	-.459** (.18)	-0.009	-0.004
Avg. Income^2	.047 (.037)	.057 (.038)	.08** (.033)	.066* (.035)		
Avg. Age	1.174*** (.325)	1.217*** (.292)	.911*** (.264)	1.066*** (.267)	-0.0003	-0.001
Avg. Age^2	-.013*** (.004)	-.013*** (.003)	-.009*** (.003)	-.011*** (.003)		
Turnout in %	.123** (.052)	.119** (.057)	.184*** (.058)	.181*** (.056)	-0.008	0.0001
Pop. density	.001*** (0)	.001*** (0)	0.000*** (0)	0.000*** (0)	0.030	0.015
Share Female in %	-3.211 (4.812)	-2.855 (4.809)	-4.929 (4.228)	-4.553 (4.345)	0.029	0.020
2019 (EU dummy)	.036*** (.012)	-.04 (.048)	.139*** (.02)	.144*** (.025)		
2021 (dummy)	.077*** (.013)	.083*** (.015)	.077*** (.012)	.08*** (.013)		
Constant	-25.453*** (8.413)	-26.517*** (7.602)	-19.067*** (6.581)	-22.616*** (6.791)		
Observations	276	276	276	276		
Within R2	.907	.906	.918	.912		
Between R2	.101	.101	.06	.07		
Overall R2	.08	.079	.06	.065		
ll	848.034	847.118	865.126	855.452		
F-stat	110.487	111.725	130.38	119.747		

	Fixed effects estimation				Standardized coefficients after factor analysis	
	(1) % MS €	(2) % MS €	(3) % MS €	(4) % MS €	(5)	(6)
P	0.000	0.000	0.000	0.000		
Joint F-stat Score[a]	7.590	4.590	16.430	10.990		
p-value	0.001	0.013	0.000	0.000		

Note: The standard errors are cluster robust errors by postal code region. The reference year is 2017. # is the interaction of the variable with the EU Parliament dummy variable. Climate Protection Ambitions (CPA). * p<.10; ** p<.05; *** p<.01. The standardized coefficients are calculated based on the sum over the product of each variable's factor with the regression coefficients estimated in Table 6 and 7 in the Appendix. [a] The Joint F-stat Score. is the value of the F-test for the null hypothesis that the estimated coefficients of the scores are jointly equal to 0.

We also perform the same robustness checks as above and report results for the standardized coefficients in columns (5) and (6). The results indicate that the population density has again a strong influence on explaining the variance in the % MS €. Additionally, we find that more conservative regions correspond to regions with less meat substitute consumption. Finally, we find that the CPA score is moderately related to the variance of the market share of meat substitutes, while we find stronger contributions by gender, the share of university students and the population density.

5.5 Discussion, policy implications & conclusion

The need to cut meat consumption both due to public-health and environmental concerns remains a challenge (Willett *et al.*, 2019). Meat substitutes are a potential alternative that could contribute to reducing the intake and external effects of meat consumption (Siegrist and Hartmann, 2023). However, the market growth of meat substitutes has turned out to be lower in recent year than estimated, for example, by the investment bank Barclays in 2019 (Barclays, 2019). Although we find that the overall market share increased from 2017-2021, there are significant regional differences within Germany regarding the market share of meat substitutes.

Our results show that the differences in meat substitute consumption between regions in Germany can mainly be attributed to differences in socioeconomic and demographic factors as well as political attitudes toward the Green party and climate protection ambitions. Our results are in line with those of Carlsson, Kataria and Lampi (2022), who found that differences in the willingness to switch to meat substitutes can be explained by differences in the age and the population density of a region. Additionally, in line with the findings of Heijnk, Espey and Schuenemann (2023), we find no support for differences in the share of meat substitutes that can be attributed to gender. However, our findings regarding gender and meat substitute consumption for Germany contradict the results reported in the literature review of Onwezen *et al.* (2021). The findings on the relationship between income and the adoption of meat substitutes are mixed in previous literature. For example, Li *et al.* (2023) report that there is no relationship between income and the purchase intent for pea burgers and a negative relationship for meat substitute burgers with animal proteins. Additionally, Heijnk, Espey and Schuenemann (2023) report a negative relationship of income and the attitude towards plant-based meat substitutes, while Carlsson, Kataria and Lampi (2022) report no relationship on the willingness to switch. Our results, however, indicate a U-shaped relationship between average income in a region and the share of meat substitutes in the market. Hence the relationship between income and meat substitute consumption seems to vary by the context analyzed and by the income-level meaning that further research is needed in that respect. In contrast, the positive relationship of population density seems to be consistent with previous literature (Carlsson, Kataria and Lampi, 2022; Onwezen *et al.*, 2021).

Besides sociodemographic factors, the aim of this article is to examine whether political voting is compatible with consumption. Jost (2017) argues that there are large differences regarding meat consumption between consumers who identify as liberal and those who identify as conservative. Along these lines, previous literature has analyzed the relationship between liberal and conservative attitudes and meat consumption. While Nezlek and Forestell (2019) report that consumers who tend to be more conservative consume more meat, Milfont *et al.* (2021) report that consumers who tend to be more liberal are more likely to be vegan or vegetarian. On the other hand, Li *et al.* (2023) who analyzed the preferences for beef, blended (mixed beef and mushroom), pea protein or animal-like protein burgers, found no relationship of a liberal attitude compared to other political attitudes and meat substitute preferences. Our results reveal that the differences in meat substitute consumption can be explained by the Left-Right voting attitude within a region. More specifically, we find strong evidence that meat substitute consumption is higher in regions where the Greens, who can be considered the party with the strongest election program for climate actions (Handrich, 2021) and who are the only party to actively promote meat substitutes in their election program, achieve better election results with the market share of meat substitutes. Moreover, our results indicate, although not quite as clearly, that voting behavior for the right-wing party (AfD) in Germany is negatively related to meat substitute consumption. However, based on the joint score for left-right voting behavior, for the European election we find evidence for higher meat substitute consumption in regions with a more conservative/right voting behavior.

In addition, to the left-right heuristic we analyzed the relationship of voting behavior for climate protection measures and meat substitute consumption. While Marcus, Klink-Lehmann and Hartmann (2022) find no support for the relationship between German consumers' environmental concerns and the intent to consume meat substitutes, Heijnk, Espey and Schuenemann (2023) report a positive relationship between a favorable attitude towards meat substitutes and climate concerns in Germany. We also find strong support for a positive relationship between the voting for climate protection attitudes (CPA scale) in a region and consumption of meat substitutes. This also indicates that the CPA score might be the more appropriate heuristic compared to the right-left score to explain meat substitute consumption.

5.5.1 Managerial implication

Several managerial implications for agribusiness actors can be derived from our results. First, we find differences in the share of meat substitutes that can be explained by the income of the people in the regions with lower consumption levels of meat substitutes in regions with lower income. There is evidence, that consumers perceive that there exists a vegan tax for meat substitutes which in turn might acts as a barrier for consumers (Kerslake, Kemper and Conroy, 2022). Considering also the significantly higher prices of meat substitutes in Germany in comparison to meat products (Petersen, Hartmann and Hirsch, 2021) there might be the need to adjust the prices of meat substitutes if products should reach more consumers particularly in regions with lower average incomes.

In the case of Germany, the age group of over 60 accounts for almost 30% of the population (DESTATIS, 2023c). However, in the literature and according to our results, age is negatively related to meat substitute consumption (e.g. Carlsson, Kataria and Lampi, 2022; Heijnk, Espey and Schuenemann, 2023; Onwezen *et al.*, 2021). Therefore, manufacturers should take steps to convince older consumers of the quality of meat substitutes as a healthy alternative to meat products using adapted marketing strategies that are more effective for consumers of this age.

Finally, in the context of plant-based meats Yule and Cummings (2023) show that there is an increasing interest in the advertisement that is congruent with consumers' own political ideas. Our results show that there is a relationship between political parties and meat substitute consumption in particular for the Green party. Therefore, marketing strategies that separate the market by consumer groups according to voting behavior might help meat substitute producers to increase their market share. Hoogstraaten *et al.* (2023) report that producers of meat substitutes use the environmental benefits of their products only as secondary claims and focus more on emphasizing the taste of the products. Therefore, efforts could focus specifically on issues related to environmental benefits to better appeal to voters of the Green party, even if consumers' political attitudes do not show a general interest in environmental sustainability or animal welfare.

5.5.2 Policy implications

Similar to the managerial implication that meat substitutes should be offered at lower prices in order to reach a broader customer group, there is a need to change the framework conditions so that the prices for meat substitutes are lowered (Funke *et al.*, 2022). In the case of Germany, where meat products are taxed with a value-added tax (VAT) of 7% while meat substitutes are taxed at 19%, this could be achieved by lowering the tax rate for meat substitutes. Alternatively, taxes on meat products could be increased, which could lead to relatively cheaper meat substitutes (Siegrist and Hartmann, 2023). Roosen, Staudigel and Rahbauer (2022) show that an increase in meat taxes in Germany would lead to considerable changes in meat consumption as the demand for pork and beef products is rather elastic. Zhao *et al.* (2022) find that own-price elasticities of meat in the US are lower than those of plant-based meat substitutes (Zhao *et al.*, 2022). Hence, increases in the tax for meat products, in combination with decreases in the tax for meat substitutes could lead to considerable consumption changes towards less meat consumption and increased meat substitute consumption. However, Zhao *et al.* (2022) report no relevant cross-price elasticity between (red) meat and meat substitutes, so that particularly a decrease in the tax on meat substitutes could lead to higher market shares of meat substitutes.

5.5.3 Limitations

Despite the strengths of this study, such as the revealed preference data from supermarkets rather than stated preference data, it is not without limitations. Since we do not have household characteristics that match the sales data at the consumer-level, we can only assume that the differences in the sociodemographic variables and voting behavior across the regions explains the variance in the market share of meat substitutes. Therefore, it would be interesting to see whether the results can be replicated with other data sets in the future. Second, political opinions and voting behavior vary considerably over time depending on recent events. However, we only observe political opinions at three different points in time. Therefore, attitudes towards the parties at other points in time in the same year might differ from those at the election. Nevertheless, we believe that the political opinions reflect well the political views of the German population in the different years. Third, our study is based on a sample from supermarkets, discounters and hypermarkets. Therefore, the data does not include a considerable proportion of products sold/consumed in Germany, such as at butchers or in restaurants. As a result, the market for meat and meat substitutes is not fully included in the market share calculation. However, the aim of the study is to estimate and test the relationship between consumer characteristics as well as voting behavior with meat substitute consumption. Since the same sample characteristics apply to the regions, we consider the data sufficient to explain the relationship. Finally, the results could be affected by endogeneity caused by the omission of variables related to consumers' lifestyle segments, which could be related to both meat substitute consumption and voting behavior (Grunert, 2006; Hoek *et al.*, 2011).

5.5.4 Conclusion

In this paper, we used revealed preference data on the sales of meat and meat substitutes in Germany to test the left-right and the environmental concerns framework to explain meat substitute consumption. We find significant differences in the level of meat substitute consumption across regions, and a growing market share over the years 2019 and 2021. We conclude that the left-right framework is less suitable for explaining meat substitute consumption than the environmental concerns framework. In summary, however, besides sociodemographic differences, in age, population density and income, which are important for explaining differences in meat substitute consumption, we also find evidence that political attitudes are related to sustainable food choices.

5.6 Appendix

Table 5-6A - Hausman test for random effects

Equation 3	(1) (Green) % MS €	(2) (Left) % MS €	(3) (SPD) % MS €	(4) (FDP) % MS €	(5) (CDU) % MS €	(6) (AFD) % MS €	(7) (All Parties) % MS €
Hausmann test for random effects χ^2	5.110	107.71	31.85	26.79	4.63	6.82	57.8
p	0.078	0.000	0.000	0.000	0.099	0.033	0.000
Equation 4	(1) (Green) % MS €	(2) (Left) % MS €	(3) (SPD) % MS €	(4) (FDP) % MS €	(5) (CDU) % MS €	(6) (AFD) % MS €	(7) (All Parties) % MS €
Hausmann test for random effects χ^2	65.70	65.850	45.780	68.710	63.320	77.000	67.130
p	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 5-7A– Matrix of correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) % MS all €	1.000														
(2) Share students	0.307	1.000													
(3) Avg. Income	0.484	0.044	1.000												
(4) Avg. Age	-0.425	-0.342	-0.548	1.000											
(5) Turnout in %	0.313	0.045	0.113	-0.167	1.000										
(6) Pop. density	0.271	0.473	0.262	-0.506	0.030	1.000									
(7) Share Female in %	0.084	0.192	-0.035	0.165	-0.007	0.315	1.000								
(8) Share Green in %	0.416	0.270	0.542	-0.541	-0.424	0.395	0.145	1.000							
(9) Share The Left in %	-0.508	0.033	-0.657	0.491	-0.002	0.034	0.148	-0.521	1.000						
(10) Share SPD in %	0.292	0.143	-0.207	-0.028	0.410	0.047	0.236	-0.083	-0.141	1.000					
(11) Share CDU in %	-0.205	-0.237	0.217	-0.258	0.023	-0.258	-0.324	-0.178	-0.307	-0.420	1.000				
(12) Share FDP in %	0.357	0.098	0.243	-0.317	0.804	0.178	0.102	-0.183	-0.134	0.487	-0.134	1.000			
(13) Share AFD in %	-0.511	-0.206	-0.525	0.749	-0.072	-0.291	-0.064	-0.608	0.696	-0.339	-0.254	-0.232	1.000		
(14) Left-Right	-0.415	-0.403	-0.131	0.469	0.033	-0.501	-0.351	-0.622	0.131	-0.541	0.434	-0.172	0.675	1.000	
(15) CPA	0.383	0.324	0.412	-0.707	-0.093	0.431	0.225	0.799	-0.453	0.274	-0.006	0.132	-0.857	-0.831	1.000

Note: $\rho_{x,y}$ Pearson correlation between variable x and y.

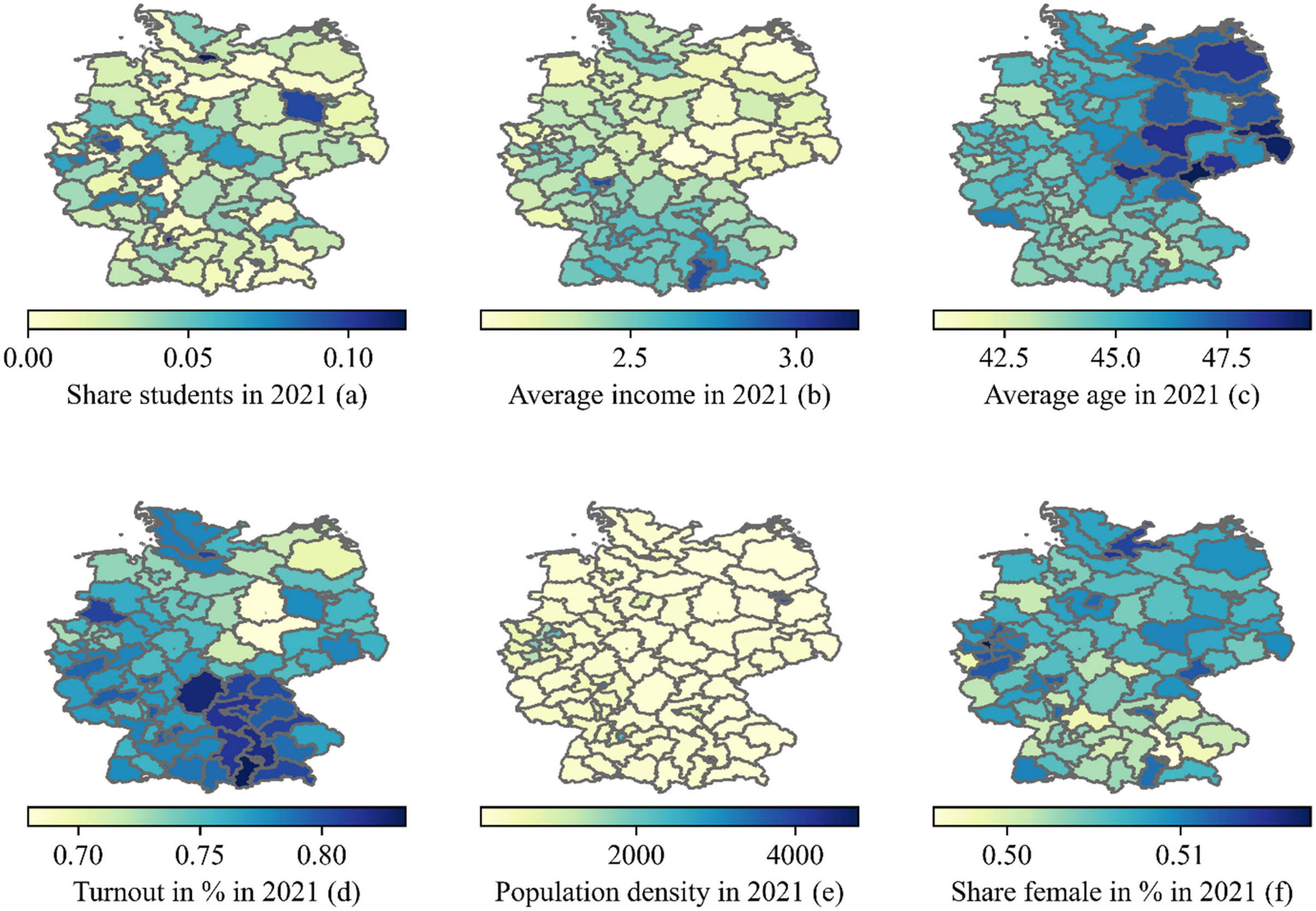

Figure 5-3A – Distribution of socioeconomic variables across regions for 2021

Appendix Factor Analysis

Prior to the factor analysis, we perform the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test for sphericity to determine whether the data are suitable for factor analysis (Backhaus *et al.*, 2021). The Bartlett test, which compares the correlation matrix with the identity correlation matrix, is significantly different from 0, hence, implying that the correlation matrix is unequal to the identity matrix (Backhaus *et al.*, 2021). However, the overall KMO test result of 0.49 is slightly below the lower bound of 0.5, indicating that the data are poorly suited for factor analysis (Kaiser and Rice, 1974). The full results are presented in Appendix Table 2. However, the results are likely due to the low correlation between each party's election results. Thus, due to the closeness to the overall cut-off of 0.5, we proceed with the factor analysis. The results of varimax-adjusted factor loadings are presented in Table Appendix Table 3 and Appendix Table. 5.

Table 5-8A - Kaiser-Meyer-Olkin Measure of Sampling Adequacy

	KMO[1]
Share students	0.814
Avg. Income	0.637
Avg. Age	0.637
Turnout in %	0.689
Pop. density	0.603
Share Female in %	0.308
Share Green in %	0.441
Share The Left in %	0.564
Share SPD in %	0.264
Share CDU in %	0.222
Share FDP in %	0.594
Share AFD in %	0.523
Overall	0.492

Note: [1]The test was performed using Stata's 'estate kmo' command.

Table 5-9A - Results of varimax-adjusted factor loadings

	All			
	F.1	F.2	F.3	F.4
Share Green in %	-0.72	-0.47	0.37	0.17
Share T. Left in %	0.91	-0.03	0.22	0.04
Share SPD in %	-0.16	0.50	-0.12	0.75
Share FDP in %	-0.25	0.05	-0.28	-0.76
Share CDU in %	-0.16	0.89	0.13	0.16
Share AFD in %	0.89	-0.14	-0.14	-0.09
Share students	-0.05	0.06	0.75	0.15
Avg. Income	-0.73	0.08	0.19	-0.27
Avg. Age	0.70	-0.24	-0.49	0.28
Turnout in %	0.04	0.95	0.02	-0.01
Pop. density	-0.16	0.05	0.87	0.10
Share Female in %	0.05	-0.07	0.29	0.62

Note: F.: Factor.

Table 5-10A - Results of fixed-effects estimation of the factors and the share of meat substitutes

	(1) (All) % MS €
Factor 1	-0.016
	(0.019)
Factor 2	0.006
	(0.009)
Factor 3	0.065***
	(0.021)
Factor 4	-0.023***
	(0.006)
2019 (EU dummy)	0.032***
	(.011)
2021 (dummy)	.112***
	(.009)
_cons	0.038***
	(0.005)
Observations	276
Within R^2	0.868
Overall R^2	0.444
Between R^2	0.354
ll	799.905
F-stat	140.76
P	0.000
Hausmann test for random effects χ^2	34.020
p	0.000

Table 5-11A - Results of varimax-adjusted factor loadings for Left-Right and CPA-score

	Left-Right		CPA		
	F.1	F.2	F.1	F.2	F.3
Left-Right	-0.76	0.25			
CPA			0.77	0.32	-0.22
Share students	0.66	0.22	0.30	0.66	0.11
Avg. Income	-0.01	0.77	0.75	-0.16	0.10
Avg. Age	-0.28	-0.88	-0.93	-0.06	-0.14
Turnout in %	-0.12	0.36	0.04	0.01	0.98
Pop. density	0.73	0.40	0.51	0.65	0.05
Share Female in %	0.70	-0.35	-0.17	0.80	-0.07

Note: F.: Factor.

Table 5-12A - Results of fixed-effects estimation of the factors and the share of meat substitutes

	(1) % MS €	(2) % MS €
factor1_lr	0.070***	
	(0.025)	
factor2_lr	-0.001	
	(0.022)	
factor1_cpa		0.013
		(0.014)
factor2_cpa		0.039
		(0.036)
factor3_cpa		-0.001
		(0.006)
2019 (EU dummy)	0.000	0.020**
	(0.007)	(0.008)
2021 (dummy)	0.070***	0.080***
	(0.007)	(0.006)
_cons	0.063***	0.053***
	(0.003)	(0.004)
Observations	276	276
Within R2	0.848	0.836
Overall R2	0.259	0.425
Between R2	0.122	0.189
ll	780.335	770.016
F-stat	133.681	103.417
p	0	0
Hausmann test for random effects χ^2	17.060	10.170
P	0.002	0.017

Standard errors are in parentheses *** p<.01, ** p<.05, * p<.1

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6 Summary, Conclusion, Limitations and Future Research

6.1 Summary and conclusion

In the context of sustainability concerns towards meat products (Godfray *et al.*, 2018) this work aims to analyze characteristics of meat substitute consumers and the barriers to the consumption of meat substitutes that can be classified as more environmentally sustainable than conventional meat products (Clark *et al.*, 2022). The first goal is to estimate the hedonic prices of meat and meat substitutes considering that consumers perceive the high price as a barrier to meat substitute consumption (Kerslake, Kemper and Conroy, 2022). The second objective is, considering the information asymmetry on the nutritional quality of the products, to determine the reliability of credence attribute labelling in the meat and meat substitute market in the context of the nutritional quality and artificialness of the products. Given the public health concerns and related public health costs towards (processed) meat (Godfray *et al.*, 2018; Springmann *et al.*, 2018) and meat substitutes (Wickramasinghe *et al.*, 2021) the third goal is to determine the nutritional quality of the products available in the food market. The fourth and final goal, considering previous findings from choice experiments on the differences between consumer segments in meat substitute adoption (Onwezen *et al.*, 2021), is to investigate consumer characteristics associated with higher levels of meat substitute consumption in Germany. To achieve these goals and objectives this thesis consists of four first authored articles (Chapters 2-5) researching the European meat and meat substitute markets, with a particular focus on the German market.

In the first article (chapter 2), we analyze the prices of products in the German meat and meat substitute market for sausages using a hedonic pricing model with a stochastic frontier that controls for information asymmetry in the market. Thereby, a sample of IRI's scanner data for weekly sales in the product category sausages is used, which is merged with information on product characteristics from the Mintel database and producer webpages. The final sample consists of 183,717 aggregated monthly product price observations, of which 136,545 are prices for meat products and 47,172 are prices for meat substitutes for 24 months starting in 2020. Despite previous literature reporting that meat substitutes yield a lower utility to the average consumer, the prices of meat substitutes (1.526 €/100g) are significantly higher ($p = 0.001$) than those of traditional meat sausages (1.012 €/100g). This supports the argument of perceived higher prices. Hence, policymakers might, in order to increase meat substitute consumption and account for the lower utility levels they provide, have to foster strategies to reduce the price of meat substitutes, like the change of the value-added tax in Germany on meat substitutes to reduce the prices.

For the main ingredients pork is valued most in the meat sausage market, while pea-based meat substitutes obtain the highest price premium in the meat substitute market (0.269 €/100g). Interestingly, while healthier meat substitute sausages are valued higher, reflected by a lower price for a higher A-Score, the opposite is true for meat sausages. Moreover, the labeling of healthier products (Science & Absence) is related to lower prices for meat substitutes and higher prices for meat sausages. Furthermore, we find that credence attribute labels are mostly related to higher prices in both markets with exceptions, like ethical animal claims on meat substitutes (-0.124€) and quality claims (-0.058€) on meat sausages. Hence, manufacturers should carefully choose which label to use on the product package in order to achieve a higher price.

Furthermore, the results of the stochastic frontier model that accounts for information asymmetry indicate a systematic deviation from the optimal price for the producer in both the meat and the meat substitute sausage markets. Hence, the price is lower than the hedonic price, i.e., the true valuation, of the products. This deviation, however, can be reduced by credence attribute labeling. Hence, the labeling of credence attributes is an important strategy for manufacturers in the sausage market. The strategy seems to have already been adopted by the producers of meat substitutes, as there are more labels observed on meat substitutes than on meat sausages. Hence, the individual credence attribute labels are important not only to achieving a higher price but also to closing the information asymmetry with consumers and thereby making it possible to achieve a price closer to the hedonic price.

In the second article of this thesis (Chapter 3), we analyze the reliability of FOP labeling in the context of nutritional quality as well as the usage of food additives for meat and meat substitutes. Thereby, we use a sample of red and poultry meat as well as vegan and non-vegan meat substitutes from Mintel's Global New Product Database for the German market for the period 2010–2018. The final sample consists of 5,482 products, of which 3,601 are red meat products, 1,141 are poultry meats, and 740 are meat substitutes, of which 232 are non-vegan meat substitutes and 508 are vegan meat substitutes. For nutritional quality, a proxy, the A-score, includes information on the salt, sugar, saturated fat, and energy content of the products—the nutrients to limit—while the number of different food additives is used as a proxy for artificialness. The FOP labeling of the sample products is categorized into four different categories that aim at the healthiness of the products or can be interpreted by consumers as such (cf. Chapter 1.3.3 or Chapter 3.2.1).

The first result indicates based on the new entries to the database that meat substitutes are gaining importance in the market, as in comparison to the other categories, red and poultry meat, the share of total observations is increasing between 2010 and 2018. Further, the results on nutritional quality show that poultry meat (11), non-vegan meat substitutes (10.7), and vegan meat substitutes (9.4) score on average a lower A-score than red meat (16.5), whereby a lower A-score indicates less content of the above-mentioned nutrients to limit. Hence, in the debate on reducing the impact of lifestyle-related diseases that are related to the overconsumption of these nutrients, meat substitutes, particularly vegan meat substitutes, can play an important part in improving public health. Furthermore, we find, in comparison, fewer additives in poultry and vegan meat substitutes than in red meat and non-vegan meat substitutes. Thus, despite the public perception that meat substitutes contain more additives and are less natural, traditional red meat products perform worse in that respect. Hence, vegan meat substitute products are less artificial than red meat products based on the number of different additives used.

As regards the estimated results on the relationship between the A-score and the labels we find no relationship between the labels and the nutritional quality of the products, except for the Science and Absence category that includes labels like reduced in fat. However, when separating the sample and estimating the models for the individual meat categories, we find the label category Natural and Absence, which includes, for example, the GMO-free label, to be related to more nutrients to limit in red meat and fewer nutrients to limit in poultry meat and (vegan) meat substitutes. Further, the label category Natural and Presence, which includes, for example, the organic label, is related to fewer nutrients to limit in (non-vegan) meat substitutes, and Science and Presence labels are related to more nutrients to limit in red meat and fewer nutrients to limit in (non-vegan) meat substitutes. Thus, in general, the labels do not appear to be consistently associated with the nutritional quality of products, and consumers should therefore be cautious when judging the nutritional quality of products based on product labels that do not directly target the nutrient content.

In the third article of this dissertation (chapter 4) we analyze and compare the nutritional quality of red meat, poultry meat, and vegan and non-vegan meat substitutes. Thereby, a sample of products from five major European countries is used: France, Germany, Italy, Spain, and the United Kingdom. The data originates from the Mintel database for the time horizon 2010–2020 and includes a total of 19,941 observations, which represent products that enter the food market in the respective countries. In France and the United Kingdom, poultry products are more prevalent in the samples than in Germany, Italy, and Spain (23%, 27%, 27%), with shares of 31% and 39% respectively. In addition, the proportion of vegan meat substitutes is lowest in the United Kingdom (8%), while it is at least 10% in all other countries. Furthermore, we find that vegan and non-vegan meat substitutes are lower in energy, fat, saturated fats, salt, and protein than red meat products per 100 g while containing more carbohydrates, fiber, and sugar than red meat. For example, on average, red meat contains 40 kcal, 5 g saturated fat, 5 g protein, and 1 g salt per 100 g more than vegan meat substitutes, but 4 g fiber and 10 g carbohydrates less than vegan meat substitutes.

To improve comparability, the products were further clustered into more homogenous clusters: burgers, coated meat, cold cuts, meatballs, roasting/cooking, and sausages. While the results for fat content and saturated fat content are similar to the original, non-clustered results, a contrasting picture emerges for salt content. For example, for cold cuts, i.e., ham and salami, we observe that red meat contains almost twice as much salt as meat substitutes. Hence, when comparing the nutritional quality of products and recommending substitutions, it is important to consider the individual product clusters.

In summary, we find that meat substitutes, depending on the category, can improve the nutritional composition of diets, as the nutrients of concern (i.e., saturated fats and salt) that are observed in particularly high amounts in red meat products, like cold cuts, are to a lesser extent observed in meat substitutes. Hence, our results question to some extent the heuristic of ultra-processed products being automatically unhealthier as the intake of undesired nutrients could be reduced by substituting meat with meat substitute alternatives. Therefore, in light of the public health concerns, which are also partly related to the high levels of meat consumption (Springmann *et al.*, 2018) meat substitutes can provide an option to reduce the public health costs. Finally, meat substitutes, when replacing meat, can reduce the external effects and consequently the cost of meat production on the environment, given their better environmental footprint (Clark *et al.*, 2022).

In the fourth and final chapter of this thesis, we analyze the differences in the demand for meat substitutes across Germany (Chapter 5). The focus lies on differences in socioeconomic factors among consumers and differences in voting behavior, with a particular focus on left/liberal vs. right/conservative voting. Thereby, we used a sample from the IRI database that includes a sales volume of 471.8 million euros, of which 42.0 million euros are attributable to meat substitute products. These data were matched with federal statistics on sociodemographic and economic factors as well as electoral results. First, we find an increasing market share of meat substitutes for the years 2017–2021 in Germany (5.3%-13.2%), however, with considerable differences across regions.

The results of the study reveal that the differences in the market share of meat substitutes can be explained by voting for the Green party, which can be considered left to center-left with a focus on environmental sustainability (Schmitt-Beck *et al.*, 2022) and by voting for the AfD, which can be considered as a right-wing party (Weisskircher, 2020). Furthermore, when measuring Left-Right voting behavior on a single scale we find a negative relationship between voting conservative vs. liberal with the share of meat substitutes. Furthermore, we find evidence for a relationship between voting for stronger climate protection ambitions and the share of meat substitutes. In summary, the results indicate that voting behavior is related to differences in meat substitute consumption. These results indicate that the marketing strategies of producers of meat substitutes in their current form are not sufficient to reach the broader population and particularly conservative consumers and that only small consumer subgroups are appealed by the utility levels provided by meat substitutes.

In addition to the findings on differences in meat substitute consumption that can be explained by differences in political voting behavior, the results indicate that the divergent levels of meat substitute consumption can be explained by differences in socioeconomic factors like income and sociodemographic factors like age. Thereby, income is negatively related to meat substitute consumption until an average yearly income of 28,600€ and with higher meat substitute consumption after this threshold. This might indicate, in line with the results of the first study (Chapter 2) that the prices of meat substitutes are too high and people with less income cannot afford them. Furthermore, age is positively related to meat substitute consumption, with a turning point at an age of 49. Hence, manufacturers are again not successful in marketing their products according to the preferences of large consumer groups and convincing them of meat substitute adoption.

To summarize, over the years, meat substitute innovations have gained importance in the European meat market; however, they are still a niche market. The results show that they tend to be sold at higher prices than traditional meat products, which might impose a barrier to their consumption as consumers are price-sensitive. On the other hand, meat substitutes, despite being classified as ultra-processed products, provide nutritional benefits over their traditional meat counterparts. Hence, meat substitutes could, in comparison to traditional meat products, improve public health outcomes and therefore reduce associated public health costs related to red meat consumption. However, for consumers, product labeling is not always a consistent predictor of healthier products. Finally, we find considerable differences in meat substitute consumption across regions, which can be explained not only by political preferences for liberal and conservative parties but also by income and age. Hence, the current marketing strategies of manufacturers of meat substitutes are not enough to reach a broader part of society.

6.2 Limitations and future research

Despite several strengths of the research articles in this dissertation, like the comprehensive sample sizes, they are not without limitations that require future research. First, the hedonic pricing model of Rosen (1974) assumes perfect competition, infinite product combinations, and information symmetry (Bajari and Benkard, 2005). While in the first article, we consider the effect of imperfect information on the price with the stochastic frontier, we do not account for the other assumptions that might bias the results. However, there is evidence that producers (Jafari *et al.*, 2023) and retailers charge mark-ups (Koppenberg and Hirsch, 2022) on the prices in the European food market and a continuum of products is likely impossible. Moreover, in food markets products are sold in a way that makes the comparison between products and stores for consumers difficult resulting in additional higher prices that affect the hedonic pricing model (Richards *et al.*, 2020). Hence, there is a need to estimate hedonic-pricing models that account for these limitations like the hedonic model suggested by Bajari and Benkard (2005), which is however more demanding in data requirements than the traditional hedonic pricing model.

Second, research articles two and three (Chapters 3 and 4) calculate and compare the average nutritional values of meat and meat substitutes. While they use comprehensive samples from different countries, they neglect the role of micronutrients in the diets. Hence, as meat is a major source of zinc and iron, future research should investigate the consequences of shifting to meat substitutes on the micronutrient supply. In addition to drawing final conclusions on public health effects, this area would need modeling studies, like the study of Springmann *et al.* (2018), who model the effects of reduced meat consumption on health and research the shift in diets towards more meat substitutes. There is also a need for further observational studies that monitor the effect on human health, like the study of Crimarco *et al.* (2020) that considers, however, 36 people only.

Third, against the background of environmental sustainability, the present studies only analyze the relevance of meat substitutes based on the definition in 1.1 and 1.2.2. However, in the future, the relevance of other meat substitutes, like 3D-printed meat or cultured meat, might increase (Siegrist and Hartmann, 2023). Hence, the presented results on the prices, based on the assumed underlying utilities, the nutritional aspects of meat substitutes, and the preferences for meat substitutes could change in the future, making research in on meat substitute innovations based on these new technologies necessary.

Finally, the European meat market is the largest food processing sector in the European Union (cf. Figure 1-1), therefore, changes towards higher levels of meat substitute consumption could change the underlying labor markets considerably. Hence, besides considering the environmental and public health perspectives future research should also focus on social sustainability, by considering potential changes on the labor market.

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