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Meat Alternatives: The State of the Industry, Barriers to Adoption, and Overcoming Barriers

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ABSTRACT

The world faces many environmental problems that can be linked to human activity, including links to the production of food. The meat industry is often seen as a major contributor to such problems. Meat alternatives are often proposed as a way to address these environmental problems. However, these products face barriers when it comes to their adoption by consumers, and firms that produce meat alternatives must overcome these barriers to be successful. I used data from a variety of academic works, newspaper articles, research reports, and company websites to find that these barriers are related to taste, nutrition, convenience, expense, law, perceived unnaturalness, and culture. Firms have addressed such barriers through methods including research and development, marketing campaigns, and legal action, amongst others.

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INTRODUCTION

The world is facing severe environmental problems such as climate change, high land and water usage, overfishing, and pollution. Many of these issues can be linked to the production and consumption of animal proteins. For example, in the United States in 2001, livestock consumed more than seven times as much grain as the human population; this amount of grains is enough to feed around 840 million people following a plant-based diet, nearly 3 times the US population at that time (Pimentel 2003). Land overuse is also very concerning: every year, about 90% of US cropland is losing soil at an alarming 13 times the sustainable rate due to unsustainable farming practices. Additionally, 60% of US pasture is being overgrazed and subjected to accelerated erosion (Pimentel 2003). Animal protein production uses significant amounts of water: producing 1 kilogram of animal protein requires approximately 100 times as much water as it takes to produce 1 kilogram of plant protein. For example, on rangeland for forage production of beef, more than 200,000 liters of water are required to produce one kilogram of beef (Pimentel 2003).

One way to address these issues is to replace animal proteins with more sustainable protein alternatives such as lab-grown meat and plant-based meat substitutes. Many products like these already exist. For example, brands like Tofurkey have made meat-like substitutes for many years, though the products are noticeably different from meat, while others have carefully crafted meat substitutes that have been modeled, down to the molecular level, on the composition of meat. While these products have gained significant traction among some consumer groups, other consumers tend to be very opposed to these products for a variety of reasons (Koch 2018), and this presents barriers

to the adoption of meat substitutes. What are the barriers to the adoption of meat substitutes and how are firms overcoming these barriers?

BACKGROUND ON MEAT

It is common knowledge that humans have been eating meat for thousands of years. This section will explore some of the reasons why people choose to eat meat and some information about its effect on human evolution: availability, its nutrition, and its evolutionary adaptation. In contemporary society, nutrition persists as a reason to eat meat, but cultural factors and taste become the main motivators.

AVAILABILITY

In pre-agricultural society, food sources were scarce and unpredictable. Without the predictability of agriculture, food had to come from either wild plants or wild animals. The early species hominin had a diet centered on plants, such as seeds, tubers, grasses, or fruits that was supplemented by animal foods (Baltic and Boskovic 2015).

NUTRITION

Meat is a highly nutritious food. It contains a high concentration of protein and fat as well as iron, several B vitamins, zinc, selenium, and phosphorus (Pereira and Vicente 2012). Protein is generally associated with meat. But different types of meat contain different amounts, ranging from only 12.3% protein in duck meat to 34.5% in chicken

breast. Additionally, some sources find that the protein in meat is superior to that of other foods – the protein digestibility-corrected amino acid score (PDCAAS) assigns a score of 0.92 to meat, while common vegetarian sources of protein such as chickpeas and lentils score near 0.5. However, it should be noted that this metric is disputed by some researchers. It is well-known that protein is an important nutrient for its role in muscle growth and maintenance as well as a host of other bodily functions. In addition to protein content, meat is a source of fatty acids. It is common knowledge that fat has the highest caloric value of the macronutrients, containing 9 calories per gram vs 4 calories per gram of carbohydrates or proteins. A smaller volume of meat may contain many calories due to fat content, depending on the type of meat, and therefore provide a lot of energy to the consumer. Finally, meat is nutritious because of its vitamin and mineral content. In terms of daily nutrition requirements, 100 grams of red meat provides about a quarter of the recommended intake for riboflavin, niacin, vitamin B6, and pantothenic acid, as well as nearly two thirds of recommended vitamin B12 intake, 37% of recommended selenium, 26% of recommended zinc, and 20% of recommended potassium. 100 grams of chicken breast provides 56% of recommended niacin and 27% of recommended vitamin B6, while 100 grams of turkey breast provides 31% of recommended niacin and 29% of recommended vitamin B6. High mineral and vitamin content make meat nutritious due to being rich in micronutrients beyond macronutrients like fat and protein.

EVOLUTIONARY ADAPTATION

The human choice to eat meat may have played a role in differentiating us from other primates. While extant apes and humans are both descendants of an herbivorous

ancestor and share similar digestive kinetics and gut anatomy, they employed different strategies of nutrition over time that manifested themselves in evolutionary outcomes. Humans, through consuming meat, were able to supply essential amino acids and micronutrients, and did so by eating smaller volumes of meat that left space for plant foods to supply energy. This may have provided numerous benefits in human evolution. The digestive systems and anatomy shared by humans and extant apes, when herbivorous, associated an increase in body size with a decrease in dietary quality. But through meat consumption, humans may have been able to have larger bodies without sacrificing their sociality, mobility, or agility, and it may also have helped provide the energy needed for cerebral expansion (Milton 1999).

CULTURE

Aside from evolutionary differentiation, meat has played a big role in human culture. Part of this role has been as a defining part of masculinity. Within human culture, foods are gendered, but are done so culturally rather than biologically, leading to different genderings in different cultures. Since this paper focuses on Western products, the relevant gendering will be that of industrialized western societies. Since people establish their identities partially through food consumption, gendered foods are an important part of such identity establishment, particularly in gender identity, and therefore are linked to human culture (Sobal 2006).

TASTE

Another reason people eat meat is because of its characteristic umami-heavy taste. Interestingly, most of meat's flavor comes from the cooking process; uncooked meat has essentially no aroma and only tastes slightly blood-like (Mottram 1998). According to Mottram, when meat is cooked, different heat-driven reactions occur to create the characteristic "meat taste". This seems to be good news for meat substitutes, since the cooking process could help them achieve meat-like flavor. I'll discuss this later in the second and third section of the paper.

SECTION I - WHAT IS GOING ON WITH MEAT SUBSTITUTES?

In the first section of this paper, I will discuss the current state of the meat substitutes industry including market trends, major firms, consumer behaviors, current food industry stakeholder partnerships, production technologies, ingredients, nutrition, and two of the most successful producers, Beyond Meat and Impossible Foods, as well as current innovations.

MARKET TRENDS

According to British investment bank Barclays, the market for alternative meat is growing quickly. From 2019 to 2029, they expect a massive growth in the industry to $140 billion, or 10% of the projected global $1.4 trillion meat market (Barclays 2019). Alternatively, Grand View Research is much less optimistic: they expect the 2019 $3.3 billion market to grow to only around $13.63 billion by 2027 (Grand View Research 2020). Each source lists growth factors for the market that drive consumer interest in plant-based diets, such as interest in animal welfare, environmental concerns regarding the production of meat, and the health effects of (not) eating meat.

But these alternatives are not just for vegetarians or vegans: in fact, in the UK, 92% of plant-based meals are consumed by so-called “flexitarians,” or people that reduce their meat consumption without eliminating it (Barclays 2019). Other research also finds that non-vegetarian people are reducing their meat consumption. In the United States, a national survey found that two thirds of people were reducing their meat consumption, a huge opportunity for producers of alternatives to meat (Neff et al. 2018).

Investment in alternative meat is increasing: for example, the number of firms investing in cultured meat increased from four in 2015 to around 70 in 2021, and in 2020, Memphis Meats, a cultured meat startup, raised $186 million, which is more than the entire cultured meat industry had raised prior to this investment (Grunwald 2021).

MAJOR FIRMS BY PRODUCT TYPE

In this section, I discuss the meat alternatives that are the focus of this paper and the major firms that produce plant-based meat and those that produce or research cultured meat.

Plant-Based Meat

Consulting Firm iMarc Group lists the following top ten firms that operate in the plant-based meat market: Amy's Kitchen, Inc; Beyond Meat; Boca Foods Company (owned by Kraft); Gardein Protein International (owned by Conagra); Impossible Foods, Inc; Maple Leaf Foods; MorningStar Farms (owned by Kellogg); Quorn Foods; The Vegetarian Butcher (owned by Unilever); and VBites Food Limited (iMarc Group 2021). It is notable that four of the top ten brands are owned by Kraft, Conagra, Kellogg, and Unilever, some of the largest food companies in the world. Their participation indicates the importance and expected growth of this segment.

Cultured Meat

In contrast to plant-based meat, cultured meat has not yet hit the market as of this writing, with one notable exception: in December 2020, Singapore granted approval to US-based firm Eat Just, who sold lab-grown chicken nuggets at a single restaurant in a

meal that consisted of four such nuggets for USD $23 (Grunwald 2021). Still, there exist around 70 firms currently engaged in research and development of cultured meat technologies. The top firms engaged in cultured meat research are Mosa Meat, Memphis Meats, Aleph Farms, BlueNalu, and Finless Foods (Dent 2020). It remains to be seen whether cultured meat can be successfully and profitably commercialized, but the participation of so many firms in research and development seems to indicate that they believe commercialization to be possible.

CONSUMER PURCHASES AND SUPERMARKET STOCKING

Supermarket stocking is a good indicator for consumer purchases, because the stores have an incentive to provide what people want. A trend of increasing stocking of meat alternative products further proves the growth of this segment, demonstrating consumer interest in new plant-based products. In a 2020 survey of 1,009 US adults, 28% had tried a new plant-based meat alternative within the last year (Webster 2021). According to the Good Foods Institute, sales of plant-based meats in the US grew by 16% and 18% in 2018 and 2019, for total unit sales of more than 208 million in 2019. Fourteen percent of all US households (about 18 million) purchased plant-based meat in 2019, 8.5% more than in 2018. Of these purchasers, 60.1% made 2 or more purchases. Out of these sales, frozen products account for 65.7%, refrigerated for 33.2%, and shelf-stable for 1%. Notably, the report found that plant-based meat is increasingly being stocked in meat coolers rather than in produce sections. The most sold products were burgers, followed by sausages/hot dogs and chicken/breakfast patties (Good Food Institute 2020).

Audits of supermarket shelves support rising consumer interest in meat alternatives: the total increase of plant-based meat substitutes in an audit of 4 Australian supermarkets from 2015 to 2019 was 429%, growing from 26 products to 137 (Curtain and Grafenauer 2019). Additionally, over 80% of the products found in this audit had been labeled as vegetarian, vegan, plant-based, or meat-free to attract consumers. In Canada, an audit of 7 supermarkets found an "increasing" number of plant-based products in the stores, though it noted issues with marketing and shelf placement that will be discussed in the barriers section of this paper (Gravely and Fraser 2018).

CONSUMER REDUCTION OF MEAT CONSUMPTION

The literature seems to find that consumers are reducing their meat consumption for a variety of reasons. A 2015 nationally representative survey of 1,112 US adults found that two thirds of participants were actively reducing the amount of meat they ate, especially red meat and processed meat. Most often, these reductions were done for health benefits or because of the cost of meat. Additionally, this survey found that in 2015, very few people were featuring meat imitation products in meatless meals: only 3% of meat-reducers indicated they did so often (Neff et al. 2018). Given the increase of meat alternative sales since 2015, it appears that the firms producing such products have been able to change this figure. For details, see Figure 1 (table reproduced from Neff et al. 2018) below:

Figure 1: Table from Neff et al. 2018

Table 1 Demographic characteristics generally and by 'meat reducers' in a nationally representative adult sample: USA, 2015

	Survey (*n* 1112)			National comparison %	% Meat reducers in category	% Non-meat reducers in category
	n	Unweighted %	Weighted %			
	1112	100·0	100·0	100·0	66	33
Age**						
18–24 years	97	8·7	11·3	11·3	10	13
25–34 years	173	15·6	17·9	16·7	16	23
35–44 years	167	15·0	17·5	16·7	16	21
45–54 years	205	18·4	17·0	19·0	19	12
55–64 years	239	21·5	18·9	17·3	20	17
≥65 years	231	20·8	17·4	18·9	19	14
Household income						
< $US 10 000	44	4·0	5·0	6·8	3	6
$US 10 000–24 999	135	12·1	12·9	16·8	10	14
$US 25 000–49 999	226	20·3	22·5	26·2	22	23
$US 50 000–74 999	210	18·9	18·4	19·2	22	17
≥ $US 75 000	497	44·7	41·2	30·9	43	40
Gender*						
Female	567	51·0	51·8	52·4	45	55
Race/ethnicity						
White	792	71·2	65·5	82·4	66	66
Black	106	9·5	11·5	9·9	12	11
Other	87	7·8	7·8	7·7	8	7
Hispanic						
Hispanic	127	11·4	15·2	11·3	15	16
Non-Hispanic	985	88·6	84·8	88·7	85	84
Education						
Less than high school	97	8·7	12·4	13·0	14	12
High school	319	28·7	29·6	30·3	31	29
Some college	319	28·7	28·7	28·7	28	29
Bachelor's degree or higher	377	33·9	29·2	28·0	27	30
US region						
Northeast	212	19·1	18·2	18·1	18·0	18·8
Midwest	254	22·8	21·4	21·3	20·3	23·3
South	408	36·7	37·1	37·2	37·7	35·8
West	238	21·4	23·4	23·5	23·9	22·1

χ^2 test comparing percentages of meat reducers and non-reducers: *$P < 0.05$, **$P < 0.01$.

STAKEHOLDER PARTNERSHIPS

One strategy with which meat alternative producers have approached market penetration is stakeholder partnerships. By partnering with a well-known brand to supply their products under familiar brands, the firms are able to partially overcome some of the barriers to alternative meat consumption (discussed in detail later in this paper). Two of the largest firms, Beyond Meat and Impossible Foods, have partnered with a variety of food industry stakeholders in the United States. For example, Beyond Meat has partnered with Dunkin Donuts as the producer of Beyond Sausage patties for Dunkin's Beyond Sausage Sandwich. This partnership has been growth-inducing: after launching the

sandwich in November 2020, Dunkin announced that it had seen same-store sales rise by 2.8% during its fourth quarter, attributing the growth to Beyond Meat sandwiches and cold brew/espresso sales (Manning 2021).

Another large partnership was announced by Beyond Meat in 2021, after they were able to secure "multi-year deals" as suppliers for McDonald's and Yum Brands (owner of KFC, Taco Bell, and Pizza Hut), some of the largest global fast-food brands. McDonald's plans to launch an entire "McPlant" section of their menu, including a burger for which Beyond Meat will be the exclusive supplier. For Yum Brands stores, Beyond Meat will develop new and exclusive items after originally supplying Pizza Hut with meatless "Italian Sausage" crumbles (Sandler 2021).

PRODUCTION TECHNOLOGIES

The technologies used in production of plant-based meats can be subdivided into three key characteristics of meat to be imitated: structure, appearance, and flavor (He et al. 2020).

Structure

The most important part of production is imitating meat's structure, because the "characteristic and dominant feature of consumable meat is its fibrous structure and texture" (He et al. 2020). There are two processing techniques to create the correct structure for plant-based meats, which are bottom-up and top-down. Bottom-up techniques combine different components to create the final product whereas top-down techniques imitate meat's texture through the formation of biopolymer blends. The most common strategy used by current producers is top-down extrusion for its scalability and

consistent functionality. Extrusion, a process often used to make pasta, consists of a "food mixture" being driven through a die, receiving pressure and heat, and then being cut to size. New production technologies are also in development, including but not limited to shear cell technology, wet spinning, electrospinning, mixing with hydrocolloids, and ice/freeze structuring (He et al. 2020; Kazir and Livney 2021).

Appearance

Another important characteristic of food is its appearance, which can easily be the first thing its consumer notices about it. Modern plant-based meats imitate the color of meat even during the cooking process: Beyond Meat adds beet juice to achieve raw beef's red color, while Impossible Foods went so far as to include soy leghemoglobin to almost exactly imitate the blood found in meat (He et al. 2020). They produce this molecule with genetically modified yeast (Juneja 2020).

Flavor

The flavor of meat is very complicated and stems from a wide assortment of compounds that undergo the Maillard reaction and lipid degradation to yield the final flavor; while Maillard reactions and lipid degradation can also occur in plant-based meats, the differences between compounds found in them and in meat have proved difficult to overcome (He et al. 2020). The same leghemoglobin that Impossible Foods includes for color also provides a bloody and meat-like taste to the end product.

Cultured Meat

Cultured meat does not require the consideration of many of the factors listed above for plant-based meat production, because the end product is nearly identical to

animal meat. But it does require new production technologies not seen before, and as such is still largely in a state of research and development, with a single exception of one dish in one restaurant in Singapore (Grunwald 2021). According to Josh Tetrick, CEO of Eat Just (the company selling cultured meat in Singapore), production of cultured meat is highly capital-intensive, but as production is scaled up and the cost of growth media decreases, production costs will plummet; the company currently uses a bioreactor with a capacity of 1,000 liters, but plans for the future include a 500,000 liter reactor. Growth media for cultured meat contains the nutrients that cells require to grow; currently, the most popular medium is fetal bovine serum, a liquid taken from pregnant cows before slaughter (Choudhury et al. 2020). This liquid is highly expensive and can make up nearly 80% of production costs for cultured meat, so substitutes are being explored, such as microbial fermentation that produces recombinant growth proteins or entirely plant-based liquids with the necessary nutrients (Choudhury et al. 2020).

Due to its research and development stage, cultured meat's production costs are still prohibitively high: the dish in Singapore includes 4 nuggets and is sold for $23, but the production of just one nugget currently costs around $90, so the firm is losing money on every sale. However, others claim to have lowered costs significantly: for example, an Israeli startup by the name of Future Meat claims to have lowered the cost of producing a quarter-pound chicken breast to $7.50 (Grunwald 2021). Some firms have been able to substitute fetal bovine serum completely for great cost savings, and Choudhury et al. suggest that for others that don't use fetal bovine serum, lowering input grades from pharmaceutical grade to food grade could reap significant cost savings for producers (Choudhury et al. 2020). If such cost savings can be realized and improved by economies

of scale and scope, production costs will fall and cultured meat may be more commercially viable.

INGREDIENTS FOR PLANT-BASED MEAT ALTERNATIVES

Current producers of plant-based meats use a variety of ingredients to simulate meat, falling into the categories of proteins, fats, carbohydrates, fibers, and vitamins/minerals (Juneja 2020). The most common protein sources are soybeans and peas, but also include hydrolysed vegetable protein, mycoprotein, and almonds (He et al. 2020; Juneja 2020). Fats come from a variety of oils, including vegetable, canola, sunflower, coconut, and others; carbohydrates come from potatoes, tapioca, rice, sweet potatoes, flour, and others; and fibers come from brown rice, lentils, black beans, and others. Some products are also supplemented with vitamins and minerals, including iron, vitamin B12, or zinc (Juneja 2020).

NUTRITIONAL VALUE OF MEAT ALTERNATIVES

Current meat alternative products share a relatively similar nutritional profile with traditional meat. When seven plant-based burgers (Beyond Meat, Nestle Sweet Earth, Impossible Foods, Tyson Raised and Rooted, Beyond the Butcher, Lightlife, Smithfield) were compared to 80% lean ground beef burgers, the total calorie, fat, and protein contents were quite similar (Edge and Garrett 2020). However, the sodium content in meat alternative products was significantly higher than in traditional meat. Additionally, the protein sources found in plant-based alternatives were less digestible than that of traditional meat, at least according to the DIASS system (Edge and Garrett 2020).

Traditional meat contained a wider variety of vitamins and minerals than did the plant-based products examined, while the plant-based products contained more fiber.

BEYOND MEAT

Beyond Meat is one of the most successful manufacturers of meat alternatives. As of April 2021. they produce meatballs, breakfast sausages, burgers, ground “beef”, bratwurst-style sausages, and “beef” crumbles (Beyond Meat 2021). The breakfast sausages, bratwurst-style sausages, and crumbles are sold in several varieties with different seasoning options. According to their website, consumers can purchase their products in ShopRite, Giant, Safeway, Sprouts, Target, Publix, Ingles, and Walmart. Alternatively, their products can also be found in restaurants including TGI Fridays, BurgerFi, Bareburger, VeggieGrill, Carl’s Jr, A&W, Del Taco, and Dunkin Donuts(https://www.beyondmeat.com/where-to-find/). Since Beyond Meat is publicly traded, financial statement data is available. In 2020, Beyond Meat had revenues of nearly $325 million, but ended with a loss of $52.8 million. In 2017, 2018, 2019, and 2020 respectively, loss per share was $5.57, $4.75, $0.29, and $0.85. Though 2020 results appear worse than previous year results, the company cites COVID-19 closures of restaurants as the reason for an increased year-over-year loss and states that it remains optimistic for the future.

IMPOSSIBLE FOODS

Impossible Foods is another of the most successful producers of meat alternatives. As of April 2021, they produce breakfast sausages, burgers, ground “beef”, and ground

"pork". According to their website, consumers can buy their products at Target, Walmart, Kroger, Wegmans, Safeway, and others. Additionally, they can be found in restaurants such as Burger King, Starbucks, Red Robin, White Castle, Qdoba, and others. Unfortunately, Impossible Foods is a privately held company, so financial statement data is not publicly available.

CURRENT INNOVATIONS

Plant-based meat and cultured meat are on the market or mostly through the R&D process, but there also are current innovations in meat alternatives- products that are a long ways from the market, but are still interesting and worth discussing.

Solar Foods

Solar Foods is a Finnish start-up that has created a revolutionary process in which single-cell microbes are fed hydrogen and carbon dioxide to produce proteins. As of April 2021, the firm has secured $12 million in a loan from the Finnish Climate Fund and plans to use it to build a commercial-size production facility. According to Solar Foods, their product, named Solein, has a carbon footprint that is 80% less than that of plant protein and 99% less than that of meat (Scott 2021).

3D Printed Meat

3D printed meat is currently under research and development by several firms. However, it faces the same challenges as plant-based meat: it is difficult to imitate meat's

texture, taste, nutrition, and appearance, even through the printing process (Ramachandraiah 2021).

SECTION II: BARRIERS TO ADOPTION OF MEAT SUBSTITUTES

Unfortunately for producers of meat substitutes, consumers prefer to eat conventional meat. Even when prompted towards accepting lab-grown or plant-based meat, one study found that consumers still expected conventional meat to make up most of their protein intake in the future and that it would be their preferred source over plant-based or lab-grown alternatives (Bryant et al. 2019). Another study found that consumers have higher willingness to pay for beef products over plant-based or lab-grown, and that when given the choice between burgers made from each type, conventional meat would have a market share of 72%, while plant-based had 23% and lab grown had 5% (Van Loo et al. 2020), which is in line with a similar choice experiment that found market shares of 65% for beef, 21% for plant-based, and 11% for lab-grown (Slade 2018). Given these results, it is clear that most consumers prefer conventional beef over plant-based or lab-grown alternatives when choosing between them, a significant barrier that producers of meat substitutes must overcome. The following section will discuss the variety of barriers to adoption of meat substitutes that contribute to consumers' preference for conventional meat: taste, nutrition, convenience, expense, law and regulatory, perceived (un)naturalness, and culture.

CONSUMER PREFERENCE FOR MEAT TASTE

Taste is one of the most important factors to most consumers when choosing a protein source (Webster 2021; Stubbs et al. 2018). Unfortunately, many people consider plant-based meat to have poor flavor (Blanco-Gutiérrez et al. 2020). One study found that when asked why they don't try new plant-based protein sources, 41% of participants said

that they wouldn't like the taste (Clark and Bogdan 2019). This study also contained some notably harsh quotes about meat alternatives: one participant said "...These products are invariably GROSS". Given the importance of taste when selecting protein sources and that consumers find the taste of plant-based choices to be inadequate, it is clear that the taste of plant-based alternatives is a barrier to their adoption.

NUTRITION

Another factor consumers consider when purchasing protein sources is its nutritional value. While plant-based substitutes contain similar amounts of calories, protein, and iron to meat products, they tend to be significantly higher in sodium and sometimes contain additives like flavorings, binding agents, and coloring (Santo et al. 2020). For example, one study found that 36.3% of participants refused to try new plant protein sources because they were too high in sodium (Clark and Bogdan 2019). Santo also notes that replacement of meat with substitutes does not necessarily make the meal healthy, because the meat substitute may still be served with unhealthy side items, and that the consumption of ultra-processed foods such as meat substitutes is associated with higher caloric consumption, weight gain, and adverse long-term health impacts.

The ingredients found in meat substitutes could have adverse nutritional effects. To those that carry food allergies, plant-based meat substitutes may be unsuitable as they are often made from soy, wheat, and peas (which cause reactions in some people with peanut allergies). There also exist concerns about the health of additives: For example, Santo discusses the effects of heme iron, an ingredient added specifically to the Impossible Foods burger in the form of soy leghemoglobin, which the company claims to

be molecularly identical to the heme found in animal meat after being cooked. While this heme helps Impossible Foods to overcome the taste barrier, it may have adverse health effects, as animal heme from red meat is associated with health risks such as type 2 diabetes, cardiovascular disease, colorectal cancer, and lung cancer. If Impossible Foods' heme is truly identical to animal heme after being cooked, it may carry the same health risks as animal protein. Alternatively, Santo notes that heme iron is one of the most easily absorbed iron sources and therefore may provide health benefits to those concerned with iron deficiency. But other additives are considered potentially harmful as well. For example, carrageenan, a popular food additive, has historically seen much debate over its safety and potential to cause digestive issues or absorb heavy metals during its growth in seawater.

Some nutrients are better sourced or only sourced from animal proteins, creating a significant barrier to meat substitutes that wish to replicate the nutritional profile of traditional meat. Vitamins A, B12, D, K2, along with minerals like iron or zinc and certain fatty acids fall into this category, and provide important benefits for tissue development and regeneration (van Vliet et al. 2020).

Worsening the nutritional barrier to adoption of meat substitutes, some consumers perceive that alternative proteins are less healthy than meat substitutes (Stubbs et al. 2018).

CONVENIENCE, INFORMATION, AND UNFAMILIARITY

Another barrier to consumer adoption of meat substitutes is the convenience of obtaining and preparing them. Consumers perceive that such foods represent a significant

change and thus require new and complicated cooking, recipes, and information, and also that they will be difficult to find in restaurants (Féher et al. 2020; Graça et al. 2019).

Information about meat substitutes is also sometimes difficult for consumers to evaluate due to poor grocery store placement and promotion: stores dedicate more than four times as much shelf space to animal products as they do to alternatives, provide fewer promotions for alternatives than for animal products, and locate meat alternatives inconsistently in produce or organic sections as opposed to meat sections, causing consumers to have difficulty finding them and remark that placement is inconsistent or confusing (Gravely and Fraser 2018).

Another barrier to information comes as a consequence of the typical culture found in innovative food companies. One study notes that the secrecy involved in typical Silicon Valley food technology companies can make it difficult or impossible for consumers to evaluate the products they produce and the processes through which they are produced (Guthman and Biltekoff 2020).

A simpler information barrier to the adoption of meat substitutes is that there is a general lack of familiarity among consumers with such products. In fact, many consumers may be unaware that they even exist. For example, one study found that in the US, 36.4% of participants were entirely unfamiliar with plant-based meat and 57.3% were entirely unfamiliar with lab-grown meat, while 23.1% of participants were slightly familiar with plant-based meat and 17.8% were slightly familiar with lab-grown meat (Bryant et al. 2019). This complete or somewhat unfamiliarity with meat substitute products is a significant barrier to their adoption.

EXPENSE

Another barrier to consumer adoption of meat alternatives is their cost. Though alternatives are a competitive market, their market share remains small and most cost more than conventional meat (Santo et al. 2020). In one study, 38.3% of participants indicated that they don't increase their consumption of protein alternatives due to the cost premium over meat (Clark and Bogdan 2019). Many other sources also include price as a significant barrier to the adoption of meat alternatives (Fehér et al. 2020; Blanco-Gutiérrez et al. 2020; Maynard 2020; Stubbs et al. 2018).

LAW AND REGULATION

The popularity of meat alternative products has led meat producers and stakeholders to pursue various strategic countermeasures, including institutional level countermeasures like legislation. One way in which this has manifested is in regards to labeling: in July 2019, there were bills introduced in 25 states and several already passed in states including South Carolina to regulate the labeling of meat alternative products (Watson 2019). The legislation made it illegal for producers to label nontraditional products with traditional terms such as "beef", "milk", or similar terms, even when qualifiers like "plant-based" or others were included. It was largely introduced with the stated motivation of "preventing consumer confusion". However, research shows that consumers are not confused by this labeling.

A 2020 study shows that consumers understand labels like "plant-based bologna" to mean free of meat (Gleckel 2020). The same study discusses how the argument of preventing consumer confusion is sourced from a survey conducted by the National

Cattlemen's Beef Association (NCBA) that claimed to demonstrate confusion among nearly 40% of consumers about whether "plant-based beef" was made from animal meat. However, Gleckel describes that the survey was not published nor peer-reviewed and that its stated results are misleading through mischaracterizing responses, and finds that in reality, 93% of consumers from the NCBA survey were not confused by such labels.

Cultured meat specifically faces a significant barrier of regulatory approval. It is not approved for human consumption in any country in the world except for Singapore (Grunwald 2021), which presents a large barrier to those firms working to commercialize it.

PERCEIVED (UN)NATURALNESS

Another barrier to the adoption of meat substitutes is that consumers perceive them as unnatural and/or overly processed. Naturalness is an important criteria for consumer selection of foods, including for plant-based protein sources: "natural" and "organic" are two of the top three most important labels on plant protein to consumers (Webster 2021). One study found that 37.6% of consumers indicated that they wouldn't try new plant protein sources because they were too processed (Clark and Bogdan 2019). The consumer attitude towards new food technologies is often strongly shaped by the perceived naturalness of them, which can be shaped by a variety of metrics, including sensory elements like taste and texture or by appearance and aesthetic. Consumers often draw conclusions about the product's safety or healthfulness from this perception of it (Slade 2018). This affects plant-based meat and cultured meat in similar ways, where both are evaluated by the perceived complexity of the production process and by the final

product's appearance and sensory qualities. In one Canadian study, several participants had harshly negative perceptions toward meat alternatives, responding "It's FAKE FOOD", "I won't eat any food pretending to be something else", and that meat alternatives "pretend to be meat… These products are invariably GROSS" (Clark and Bogdan 2019). While firms that produce plant-based meat substitutes can argue that their production process is somewhat similar to household cooking, producers of cultured meat are not afforded the same opportunity and face a significant barrier to perceived naturalness due to their entirely novel production process.

Part of the perceived unnaturalness of meat alternatives can be described as food neophobia, a phenomenon in which consumers find new food technologies to be unpalatable. Several authors list food neophobia as a significant barrier to adoption of meat substitutes (Graça et al. 2019; Bryant et al. 2019; Clark and Bogdan 2019).

Beyond the perceived artificialness of processed products, other consumers believe that it is natural for humans to eat meat and unnatural to remove it from the diet (Beverland 2014). The consumption of meat has strong ties to human identity and human history and is an important part of human culture, as I will discuss in the next section.

CULTURAL BARRIERS

Foods are inherently cultural: they possess meaning for people and play roles in personal and group identities (Mintz and Du Bois 2002). One such food is meat: it is common knowledge that meat is a staple food included in cultural dishes worldwide, and is a source of key flavors for many cultural foods. This presents a barrier to adoption of meat substitutes, because consumers may perceive cultural foods prepared with

nontraditional meat substitutes as diluted, weakened, or inauthentic due to the presence of "fake meat".

Additionally, other cultural issues like social norms and gender roles present barriers to the adoption of meat substitutes.

Social Norms

Because most Western people eat meat, the adoption of meat substitutes can be perceived as abnormal or unusual, and as a violation of social norms. Eating is part of social norms, and the way that people eat affects the way others perceive them and their affiliations with social groups, which creates an ingroup and outgroup situation among meat eaters and meat substitute eaters (Cheah et al. 2020; De Groeve et al. 2019). Historically, vegetarian diets have been associated by the American public with nutritional deficiency, muscular and protein deficiency, and other negative stereotypes, and such perceptions continue today (Feher et al. 2020). These negative stereotypes toward vegetarian diets apply by extension to meat substitutes, and as such present a barrier to their adoption through social norms and the potential for negative perception by others.

While meat eaters view those that follow vegetarian diets in an overall positive manner, they view them in a less favorable manner than they view meat eaters, and such negative views are amplified when the moral or cultural identities of meat-eaters are challenged (De Groeve et al. 2019). The amplification of anti-vegetarian bias in situations where meat-eating culture is challenged creates a direct barrier to the adoption of meat substitutes when vegetarians promote them. However, if in an effort to overcome

anti-vegetarian bias meat-eaters were to promote meat substitutes, this could create an adverse unintended consequence of perceived inconsistency among the meat-eating group (De Groeve et al. 2019), and potentially an even less effective message than before. Regardless of the promoter's diet, the social norms of eating meat are a significant barrier to the adoption of meat substitutes.

Gender

Gender is another aspect that influences the adoption of meat substitutes. People establish their identities partially through food consumption, and gendered foods are an important part of such identity establishment, particularly in gender identity. Sobal (2006) argues that meat, especially red meat, has a particularly gendered consumption in the minds of western men. As examples, he offers that men sometimes claim that meals are incomplete without meat or not "real" meals, that they dominate barbecuing competitions in which meat is cooked, and that they are the typical participants in eating competitions that often feature meat foods like hot dogs. The masculinization of meat partially stems from how it represents the act of hunting, a common masculine activity. Through hunting and killing animals, men can demonstrate their power, violence towards, and control over other species, reinforcing their power and therefore masculinity, all while providing food for their families and demonstrating virility and strength. Though most modern men do not hunt and kill all of the animals that provide the meat they eat, the consumption of meat is still a symbolic and traditional masculine activity (Sobal 2006). Part of meat's role in masculinity also originates from its nutritional role. Meat is high in protein, a key nutrient for the maintenance and growth of muscle tissue, and fat, a calorie-dense nutrient

that can facilitate a person's increase in size. Since muscle mass and size are also components of masculinity, meat's nutritional properties and role can also be tied to meat's role in masculinity.

SECTION III: OVERCOMING BARRIERS TO ADOPTION

In this section, I will discuss ways that firms could or are currently working to overcome the barriers to the adoption of meat substitutes: taste, nutrition, convenience, expense, law and regulatory, perceived (un)naturalness, and culture.

OVERCOMING THE TASTE BARRIER

Some consumers believe that the taste of meat alternatives is worse than that of conventional meat. One way that firms are overcoming this barrier is through stakeholder partnerships, in which consumers are able to see that the meat substitutes, especially those from Beyond Meat and Impossible Foods, can be quite similar to meat when incorporated into their favorite fast-food meals, such as burgers from Burger King, breakfast sandwiches from Dunkin Donuts, or other stakeholder partnerships. Impossible Foods and Beyond Meat were some of the first firms to work on research and development to overcome the taste barrier, especially because from my own personal experience, there were very few palatable meat alternative burgers before theirs, and definitely weren't any that resembled meat in any real way other than shape of the burger. Their research and development efforts to find ingredients to mimic the flavor of meat are an excellent example of response to this barrier. Impossible Foods' soy leghemoglobin ingredient, for example, overcomes this barrier by incorporating something they claim is chemically identical to heme found in animal meat after being cooked (He et al. 2020).

OVERCOMING THE NUTRITION BARRIER

The nutritional barrier is a difficult one to overcome. Plant-based meats, in particular, are ultra processed foods and as such are generally not considered as healthful as less processed foods. Unfortunately, this part of the nutrition barrier is unlikely to be overcome, because without complex production processes, plant-based meat that mimics the flavor and texture of meat does not exist. While cultured meat does come about from an unfamiliar and complex process, the end result is real meat cells, and therefore carries the same nutritional profile as traditional meat, making the nutrition barrier somewhat less pronounced for cultured meat.

However, conventional meat is also considered by some to be harmful to human health. Makers of plant-based meats already stress the advantages of plant-based foods over animal foods in their marketing, which is one way in which they work to overcome this barrier.

OVERCOMING THE CONVENIENCE, INFORMATION, AND FAMILIARITY BARRIERS

The convenience, information, and familiarity barriers have been lowering over time as meat substitutes proliferate and more people become familiar with them, the recipes they are used in, and the ways they are cooked. As with the taste barrier, stakeholder partnerships are a major way in which firms can overcome this barrier, because familiar stakeholders are already frequented by consumers and can provide the introduction to meat substitute products such as plant-based hamburger patties or breakfast sausages. Additionally, stakeholder partnerships with nationwide or global

restaurant brands help make meat alternatives more accessible by providing a source for them throughout diverse geographic locations.

OVERCOMING THE EXPENSE BARRIER

The expense barrier, like the convenience barrier, will lower greatly over time as meat alternatives grow in popularity. Firms that produce such products, as they increase production levels and gain market power, will benefit from the economies of scale and scope as well as learning curve effects to lower their production costs significantly. This is already happening with major industry players like Impossible Foods, who recently elected to lower the prices of their products across the board, first in 2020 to wholesale restaurant distributors through a price cut of 15%, then again for those same distributors by an additional 15% in 2021, and most recently, a 20% price reduction for grocery stores, hoping to pass the savings to shoppers (Woodside 2021). According to Impossible, this price cut is not in response to slowing sales, but instead due to improving economies of scale and as part of their eventual goal to undercut the price of conventional meat.

As another, less optimistic example, Burger King elected to lower the price of their Impossible Whopper, contrastingly in a response to slowing sales (Bloomberg 2020). It is yet unclear whether this has helped them increase sales. However, in the future, given how much cheaper production is for plant-based meat than for conventional meat, it may well be (as per Impossible Foods' stated goal) that meat alternative products cost significantly less than their conventional counterparts, which would constitute a true overcoming of the expense barrier.

OVERCOMING THE LAW AND REGULATORY BARRIERS

The law and regulatory barriers have had significant effects on the way in which many meat alternative products are sold. For example, many products insert apostrophes into or otherwise modify the wording on their packaging to comply with regulation on labeling while still trying to convey the products they are meant to replace, such as the pot pie made with Gardein "Be'f" in Figure 2 below.

Figure 2: Marie Callender's Meatless "Be'f" Pot Pie

Though compliance through such modification of familiar words is how some firms are currently overcoming the regulatory labeling barrier, other organizations are actively engaging in lawsuits against the states that have passed such legislation. For

example, The Good Foods institute initiated one such lawsuit against the state of Missouri (Watson 2019).

Another major regulatory barrier is for cultured meat specifically, in that it is not legal to sell in any country in the world except for Singapore. To overcome this barrier, firms will have to demonstrate to local food regulating authorities, such as the USDA in the United States, that cultured meat is safe for human consumption.

OVERCOMING THE PERCEIVED (UN)NATURALNESS BARRIER

The perception of meat alternatives as unnatural or overly processed is another difficult barrier to overcome, and is difficult especially because meat alternative products are inherently quite processed and unnatural foods: plant-based meats are made from complex sets of ingredients, and cultured meat is grown in the lab in a way many would consider entirely separated from nature. While cultured meat is not yet on the market, manufacturers of plant-based meats such as Beyond Meat have worked to partially overcome this barrier.

On Beyond Meat's website, they have a page dedicated to the ingredients found in their products that seems to overtly stress naturalness. The page features high-resolution close-up photos of familiar ingredients, some in natural-looking wooden bowls, such as beets, peas, rice, salt and others. Captions also reference naturalness, with one saying "Our food is simple. Made from plants. With no GMOs". On the same page, Beyond Meat describes their production process in an attack on the perceived processed nature of their product, stating that "Our process uses basic elements of cooking- heating, cooling,

pressure and mixing- to give the protein from plants a taste and texture that's just like meat" (Beyond Meat 2021).

OVERCOMING THE CULTURAL BARRIERS

Cultural barriers to adoption of meat substitutes are also difficult to overcome- meat consumption is ingrained in most human cultures however defined, and humans have been eating meat for so many years that to some, a change is unthinkable. The social norms component of the cultural barrier will decrease in significance as more people begin to eat meat substitutes and it becomes less unusual to do so. Stakeholder partnerships again come to mind as a way in which firms can work to overcome a barrier, because foods from well-known businesses like Burger King are already considered socially normal.

Some firms have applied marketing campaigns to partially overcome the gender barrier. For example, Field Roast, a maker of plant-based meats, released an ad in November 2020 that appears similar, based on personal experience, to ads historically published about meat or fast food restaurants. The ad is voiced over by a man with a deep voice, while rock music plays in the background and the narrator states..."We're for the bold- the daring- the kitchen creators and flavor trailblazers" (Field Roast 2020). The ad also features Field Roast products in grills and smokers, traditionally masculine appliances. It concludes.."Get ready to make taste happen", in an appeal to forceful masculinity.

This ad can also be interpreted as an attempt to redefine male gender norms so they can include meat alternatives. With the deep voice, rock music, focus on boldness,

grilling and smoking, and appeal to forcefulness, it implies that men can still be “manly” without eating traditional meat while also keeping in place these other parts of the traditional male gender norm.

CONCLUSION

Overall, meat alternative products face significant challenges to their adoption. However, firms are working to overcome those challenges, and the market's quick growth, increasing number of competitors, and growth in major stakeholder partnerships paint an optimistic picture of the future for meat substitutes. As firms like Beyond Meat and Impossibile Foods make meat alternatives mainstream, consumers will see them in a better light. Stakeholder partnerships have seen success so far, and new and exciting partnerships such as Beyond Meat's partnerships with McDonalds and Yum Brands, some of the largest restaurant chains in the world, appear promising and if successful will push meat alternatives even further into the mainstream.

On the other hand, significant barriers still exist for meat alternatives. The meat industry has a lot of money and a strong incentive to fight against the success of meat alternatives, and are already winning some battles such as regulation on labeling alternative products. But these same stakeholders also face a major opportunity to enter production of meat alternatives, with many already having done so or invested in firms that do so.

This paper was inspired by my own personal experience as a vegetarian for more than four years. I find that many of the barriers and information discussed hit close to home in regards to what I've heard from friends and coworkers about meat alternatives. In regards to my own personal experience, I've gone from microwaving horrible, rubbery, soy patties alone at home to ordering delicious, juicy, and meaty Beyond Meat burgers from restaurants with friends. It has been fascinating (and relieving) to watch the explosive growth of meat alternative products in quantity and quality during my weekly

trips to grocery stores like Wal-Mart. Over time, I've watched the sections of meat alternative products grow from a small number of terrible options to entire aisles filled with delicious choices.

Current events, such as the Biden administration's new climate plan to reduce US emissions and Bill Gates' suggestion that "all rich countries should switch to synthetic beef", have effects that remain to be seen. Overall, it appears that the meat alternative industry faces significant barriers but remains successful, and I remain optimistic for its future growth amid continuing technological innovation and strategic responses to the barriers described above.

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