EVALUATING THE POTENTIAL FOR PLANT-BASED MEAT TO CAPTURE THE U.S. MEAT MARKET

BY

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THESIS

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ABSTRACT

This thesis describes factors influencing the meatless meat industry's potential to expand, and it estimates the U.S. beef market's response to competition from plant-based meat products. The first part of the analysis provides an overview of the meatless meat industry and outlines factors that influence the new industry's potential to capture market from the U.S. livestock industry. These factors include consumer sensory acceptance of and willingness to pay for meatless meat products, technical feasibility of producing the products at scale, the economic feasibility of pricing them competitively with meat, and how the U.S. livestock market and U.S. agriculture lobbyists will respond to the new competition. Next, the analysis provides an empirical analysis of one of these factors – the U.S. livestock market's response to competition from plant-based meat, using an examination of how competition between plant-based meat and ground beef would affect the entire beef market. The analysis estimates price changes for ground beef, fed steer, and choice and select beef markets using price elasticities and historic beef price data from 2013-2019. Joint-product theory and an OLS regression of historic beef prices indicate that these beef markets are linked, so plant-based meat's competition with ground beef will affect supply and prices in the fed steer and choice/select markets. Beef price estimates are calculated for different scenarios in which plant-based meat captures 5% to 25% of the ground beef market. It is estimated that ground beef prices will drop 2.10% to 4.00% if plant-based meat takes 5% of its market, and its price elasticity of supply and demand would be -1.25 in the new market equilibrium.

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CHAPTER 1: INTRODUCTION

The emergent meatless meat industry has sparked interest among consumers, investors, farmers, and meat companies alike. The question many are asking is, to what extent will meatless meat replace animal meat in the American diet? Agricultural researchers have identified a number of factors that will influence meatless meat's competition with livestock: consumer acceptability of the products, whether the industry can produce the products at scale, how the industry prices its products, and how regulatory bodies will treat plant-based meat. Another factor, yet to be researched, is how the livestock industry will respond to competition from meatless meat. The objective of this thesis is to outline the challenges that meatless meat will face in competition with the livestock industry, and to use a case study of the beef industry to estimate price and supply changes that could occur if plant-based meat captured some of its market.

Understanding the potential for meatless meat to capture sales from the livestock industry will be valuable to stakeholders in both industries. This analysis can be used by meatless meat companies to strategize and anticipate challenges from the livestock industry. Investors in meatless meat also would benefit to know that growing the plant-based meat is not a matter of funding alone – external factors, especially competition from livestock, will slow and eventually could stymie its growth. Livestock stakeholders, meanwhile, can use this information to understand the degree to which meatless meat threatens their industry, and to understand their leverage points for competing with it. Farmers, especially, can use the pricing information to anticipate how plant-based meat would affect their revenue.

This analysis is separated into two parts. The first part describes the meatless meat industry, academic literature about the industry and factors influencing its expansion, and how the livestock industry will likely respond to and challenge competition from it. These are covered in Chapter 2 – "Description of the Meatless Meat Industry", Chapter 3 – "Literature Review of Consumer Acceptability and Economic Feasibility of Meatless Meat", and Chapter 4 – "Livestock Industry's Response to Meatless Meat." The second part of the analysis is a case study of the U.S. beef market and how its prices and supply would react to competition from plant-based meat. The case study anticipates that plant-based meat will compete as a substitute for ground beef, but this competition will generate a price response not only in the ground beef market, but in the fed steer and premium beef markets as well. This is because ground beef is produced jointly with higher-end cuts, and the joint nature of the products will impact price response. The case study uses beef price elasticities and historical beef price data to estimate how beef prices would change if plant-based meat captures varying portions of the market. This analysis is presented in Chapter 5, "Case Study of Plant-Based Competition with Ground Beef." Finally, Chapter 6, "Results and Conclusions", summarizes the likely response from the livestock industry to plant-based meat, whether the response would change in cases of other meatless meat products, and opportunities for future research on this topic.

In Chapter 5, two assumptions about plant-based meat and animal meat products guide the analysis. The first assumption is that plant-based meat is a viable substitute for ground meat, but not for other, more valuable cuts of meat. No doubt the plant-based meat industry would like to expand its product portfolio to include other cuts of meat, but the products that are currently available on the market resemble ground meat. The second

assumption is that animal meat is a joint product. A single livestock animal produces many different cuts of meat, and the supply of one cut of meat cannot be adjusted without adjusting the supply of all the other cuts. This means that plant-based meat cannot compete with the livestock industry on a product-by-product basis, but on an industry-level basis, because all other joint meat products will respond to competition with ground meat.

CHAPTER 2: BACKGROUND ON THE MEATLESS MEAT INDUSTRY

In the U.S. and Western Europe, agri-food systems are changing in response to consumer preferences for foods that appear to be healthier and better for the welfare of animals and the environment. Although these regions have the most sophisticated and efficient commercial livestock industries in the world, these industries have come under criticism for their natural resource consumption and greenhouse gas emissions.[1] Additionally, the Dietary Guidelines for Americans states that the average American adult consumes too much meat, which contributes to weight gain and associated diseases like cancer and heart disease (U.S. Department of Health and Human Services, 2015). This position combined with the realization that consumption choices can help mitigate environmental decay and improve animal welfare, has increased the market for goods that claim healthy and environmentally conscious attributes.

The emerging 'meatless meat' industry is a part of this trend, with more than 50 start-up companies currently in the market (Good Food Institute, 2019). The stated mission of many of these start-ups is to fully supplant animal-based meat in order to end the commercial livestock industry and its environmental footprint. The market for these products is currently valued at $14 billion (Theurer et al., 2019) and Barclays predicted that the market would expand to $140 billion in the next decade, capturing 10% of the globe's $1.4 trillion meat industry (2019).

The meatless meat industry produces two categories of products: plant-based meat and lab-grown meat. Both of these products are distinct from alternative meat products

[1] According to the U.S. Environmental Protection Agency, agriculture and livestock accounted for 10% of U.S. greenhouse gas emissions in 2019.

such as veggie burgers or tofurkey because they are formulated to look, smell, and taste like animal meat. These products, then, can be understood as direct substitutes for meat. Their nutritional profiles are also designed to resemble those of meat. The plant-based meat products are currently on the market in the U.S. and Europe and Asia, but the lab-grown products are not projected to reach retail for at least another three years (Kateman, 2020).

The market for plant-based meat is populated by both start-ups and large meat companies.[2] Of the start-ups, there are three main competitors in the U.S. market. The first is Beyond Meat, a U.S.-based public company founded in 2009 and currently valued at $4.8 billion (Franklin & Sen, 2019). Beyond Burger currently offers five meatless meat products: Beyond Burger, Beyond Beef, Beyond Sausage, and Beyond Beef Crumbles. It also is in the process of developing a chicken product, which it piloted with Kentucky Fried Chicken (KFC, 2019). Its beef-imitation products are made from a mixture of pea, mung beans, and rice, and their red color and juicy texture – mimicking the bloodiness of meat – come from beets, pomegranates, and coconut oil. Beyond Burger's products are sold at more than 58,000 locations in the U.S, including fast-food franchises: Dunkin', Carl's Jr., Subway, A&W, Denny's, Hardee's, TGI Friday's, and Epic Burger. Its other outlets include grocery stores, hotels, movie theaters, bars, amusement parks, research institutes, and universities. Impossible Meat is the second company which sells plant-based meat products. It is a private company founded in 2011, and the company was valued at $777 million as of November 2019 (Franklin & Sen, 2019). Impossible Meat currently has two products

[2] The Good Food Institute published a comprehensive chart of plant-based meat companies and their products in its 2019 report, *Plant-Based Meat, Eggs, and Dairy: U.S. State of the Industry Report.*

(Impossible Burger and Impossible Sausage) on the market and one product in the R&D phase (Impossible Pork). Its main product, "Impossible Burger," is mostly made from soy protein concentrate, coconut oil, and sunflower oil. It uses soy leghemoglobin, a compound derived from soybean, to imitate the animal protein "heme," which carries iron in the bloodstream and gives meat its juiciness (Impossible Foods, 2020). Impossible Meat sells its products at more than 17,000 locations in the U.S., which include more than 7,200 Burger King locations. The company started selling its products in grocery stores in California and the East Coast in 2019 and currently sells at 150 retail locations (Watson, 2020). It intends to have its products available at grocery stores in all regions of the U.S. by mid-2020. Its products are also sold in Hong Kong, Singapore, and Macau. The third plant-based meat start-up is The Meatless Farm Company. Based in the U.K., its formula and product offerings are similar to that of Beyond Meat. It is the exclusive provider of plant-based meat to Whole Foods, and its products are also available in the United Arab Emirates, Canada, China, and Europe (Meatless Farm, 2020).

Large, established meat companies are also entering the plant-based meat market. Companies such as Tyson, ADM, JBS, Kellogg's, and Nestlé have developed brands for their plant-based products: Raised and Rooted (Tyson), MorningStar Farms and Ozo (JBS), Marfrig (ADM), Gardein (Conagra Brands), Boca (acquired by Kraft-Heinz), Sweet Earth and Awesome Burger (Nestlé) (Good Food Institute, 2019).

For lab-grown meat, the Good Food Institute reports that there are nearly fifty start-ups globally working on cultivated meat products, 19 of which are in the U.S., the rest in 15 other countries (Good Food Institute, 2019).[3] Singapore is the first and only country to

[3] Please note that this figure also includes start-ups that focus on lab-grown seafood.

approve commercial sale of the products, certifying Eat Just, a U.S. company, to sell chicken nuggets made with lab-grown meat in December 2020 (Oi, 2020). The largest lab-grown meat company in the U.S. is Memphis Meats, which has raised $180 million from investors (Weiner-Bronner, 2020). Memphis Meats has successfully grown beef meatballs and cuts of chicken and duck from cell culture. Another prominent one is Aleph Farms, an Israeli company that specializes in growing steaks currently valued at $14 million (Lewis, 2020). It garnered attention in 2019 when it successfully grew a steak on the international space station, to demonstrate how its production process uses few natural resources (Yeung, 2019). Mosa Meats, a Dutch start-up, grew the world's first piece of meat from cow cells, based on research funded by Google at Maastricht University (Mosa Meat, 2020).

The basic method employed by many of these start-ups involves taking starter cells from an animal biopsy or embryo and cultivating them into myocytes, muscle cells, along with fat and tissue cells. These are then proliferated in a liquid medium in a piece of equipment called a bioreactor, and these cells are grown around micro-scaffolding in order to form cuts of meat. There is variation to this general approach, such as the degree to which animal cells are used in the process. The starter cells can be taken from animal embryos or biopsies, but there is also an 'animal-free' method which involves creating a piece of animal DNA (using DNA code stored in genome databases) and inserting it into a non-animal host organism (Waschulin & Specht, 2018). Similarly, the medium in which the cells grow typically has been fetal bovine serum, but formulations without animal components are also under development (2018).

In addition to these companies, many independent research institutes and lobbyist groups have been founded to build a research foundation, curry government regulatory

favor, capture investors' attention, and sway public opinion for the meatless meat industry. These include the Cellular Agriculture Society, New Harvest, the Good Food Institute, the Modern Agriculture Foundation, and Food Frontier. Moreover, the Good Food Institute identifies 7 countries as leaders in plant-based meant innovation: Brazil, Canada, Germany, Israel, the Netherlands, the U.K., and the U.S. (Good Food Institute, 2019).

In summary, meatless meat companies have generated a lot of excitement, not only because of their novel products, but also because they appear to address pressing social issues, namely climate change. The market is crowded with start-ups, and the nascent industry also has the backing of investors, policy makers, and researchers who are united around the goal of eliminating the livestock industry and its associated environmental footprint. Plant-based meat is more advanced in its product development, with a number of products already available at restaurants and grocery stores. Lab-grown meat is still in the R&D phase for the most part and is not expected to reach market in the U.S. for years. Although plant-based meat is more developed than lab-grown meat, lab-grown meat has demonstrated greater capabilities at mimicking a greater variety of meat cuts. As will be discussed in Chapters 5 and 6, this capability will be essential for competing with livestock successfully.

CHAPTER 3: LITERATURE REVIEW OF CONSUMER ACCEPTABILITY AND ECONOMIC FEASIBILITY OF MEATLESS MEAT

For the meatless meat industry to grow, and for the companies to achieve their stated missions, there are two criteria that will determine success. The first is consumer acceptability – the meatless meat products must be formulated and marketed in such a way that consumers perceive them to be acceptable substitutes for animal-based meat. The second is economic feasibility – the companies must be able to produce the products in such a way that they can achieve price parity with animal-based meat. This chapter investigates both of these topics in order to describe the potential for how much of the meat market the meatless meat industry will capture in the U.S.

3.1 Consumer Acceptability

In order for the meatless meat industry to achieve its stated goal of supplanting the meat market, consumers must accept the products as substitutes for meat. Researchers started surveying consumers on this question approximately five years ago, and initial findings suggest that approximately 25-30%[4] of customers are willing to do so.

Studies about the acceptability of meatless meat ask two types of questions: 1) would consumers be willing to regularly eat meatless meat products, and 2) what is consumers' willingness to pay for these products.[5] The majority of the studies concern North American and European consumers. Because meatless meat products are not yet

[4] This figure is an approximate mean of the findings from consumer preference surveys. It also implies an expanded market for meat products, since alternative meats will also cause new consumers who were not purchasing meat to begin to purchase meat alternative products (Lusk, 2020). The state of the research does not yet point to a specific breakdown of what proportion of the alternative meat market will be cross overs from animal meat, and what proportion will be completely new consumers.

[5] It is important to note that another genre of studies focuses on consumers' sensory acceptability of meatless meat products. The studies surveyed in this article assume that meatless meat products taste the same as meat.

widely available on the market, the studies have relied on hypothetical choice scenarios related to purchasing meat.

For lab-grown meat, the current research estimates consumer willingness to substitute to be anywhere between 5% and 32%. Three studies surveyed U.S. consumers on this question. One study reported that 32.6% would be willing to regularly eat lab-grown meat, and 31.5% would be willing to substitute it for animal meat (Wilks & Phillips, 2017). A second study, which incorporated consumers' willingness to pay along with consumers' willingness to substitute, found that 17.2% of consumers would substitute lab-grown meat for regular meat if it cost the same and was the only meat alternative on the market. That number would go down to 10.6% if plant-based meat was available, and further down to 7.9% if both substitutes cost a dollar more than meat (Slade, 2018). A similar study which incorporated marketing messages found that only 5% of consumers would opt for lab-grown meat when given the choice between beef, plant-based beef, lab-grown beef, or no purchase (Van Loo et al., 2019).

The substitutability rate is higher for plant-based meat, though research findings still range widely. An online survey found that nearly 33% of U.S. consumers reported that they would be extremely likely to purchase plant-based meat, and another 41.8% were slightly or moderately likely, if it was widely available on the market (Bryant et al., 2019). A different survey found that 24.7% of U.S. consumers would substitute plant-based meat for beef if it was the only meat alternative on the market and cost the same price as beef (Slade, 2018). This share would drop to 20.5% if lab-grown meat was also offered at the same price on the market, and would further drop to 14% if both alternatives were $1 more than animal meat (2018). In the study about marketing messages, 23% of people

opted for plant-based meats, and various marketing messages did not change this proportion of the market (Van Loo et al., 2019).

This initial research suggests that a significant population in the U.S. and Europe would switch to meatless meat if it was widely available on the market and priced competitively with animal meat. For plant-based meat, 20-33% of consumers would use it as a meat substitute if it was priced competitively with meat. For lab-grown meat, research suggests that 5-17% of consumers would make the switch. Since these two products would be competitive with each other, the estimate for total meatless meat market share is somewhere between 25% and 30%. Still, these initial studies suggest that the majority of U.S. consumers are not willing to substitute these products for animal meat, even if they did cost the same. Notably, during the early months of the pandemic when grocery stores across the U.S. faced meat shortages, sales of plant-based meat did not go up, despite the increased incentive to substitute (Lusk, 2020).

It is important to remember that these figures do not reflect consumer sentiment as influenced by commercial marketing. A couple of the studies considered subjects' behavior changes after exposure to certain marketing messages, but they do not simulate the influence of repeated exposure to attractive advertisements. Still, these studies offer initial insights about consumers' reactions to marketing messages. The survey referenced previously exposed American online shoppers to four different types of information about the products: the product descriptions (beef, plant-based meat made from pea protein, plant-based meat made from "animal-like" protein, or lab-grown meat), brand names ("Certified Angus Beef," "Beyond Meat," "Impossible Burger," and "Memphis Meats"), claims about products' environmental impact, and details of the technology used to create the

products. The study found that exposure to brand names compelled 8% of consumers to switch from their original choice of meatless meat to beef. The messages regarding environmental impact and technology compelled a small percentage of people who originally opted not to purchase any product to purchase a meatless meat product.

Research studies also provide insights about the reasons for consumers' aversion to meatless meat products. A 2019 study (Bryant et al., 2019) focused on which marketing messages improve consumers' perceptions of lab-grown meat, which lags behind plant-based meat in hypothetical consumer acceptability. Consumers were presented with four different messages about meat: "Clean meat is natural," "Conventional meat is unnatural," "Naturalness is not important," or a fourth about lab-grown meat's benefits without mention of natural qualities. The researchers found that only the message "conventional meat is unnatural" improved consumers' perceptions of lab-grown meat and their willingness to pay more for lab-grown meat over regular meat. The researchers also went so far as to say that marketing attempts to change consumers' opinions about the "naturalness" of lab-grown meat would be futile, based on their findings. Two other studies, by the Institute for Environmental Decisions (Siegrist et al., 2018) and Ghent University (Verbeke et al., 2015), support these findings, suggesting that the main roadblock to greater acceptability of lab-grown meat is that consumers perceived lab-grown meat as unnatural and therefore disgusting (Siegrist et al., 2018).

In 2020, the Good Food Institute published a report to predict the dynamism of consumer acceptability in response to mass marketing. The report applied Diffusion of Innovation Theory to predict the rate at which reluctant consumers will switch to meatless meat. This theory categorizes a population into different groups based on their willingness

to adopt an innovation, and states that the groups will adopt an innovation sequentially, on the condition that the innovation is "perceived to be of lower social or economic costs, that provide a good fit with values and current practices, and [is] of low complexity" (Encyclopedia Britannica, 2016). The report uses data from a 2019 study by Bryant et al. to predict that 18-33% of the population will be 'early adopters' of meatless meat products, with this segment's demographics disproportionately male, Millennial, Hispanic, urban, politically liberal, educated, and higher income in relation to the rest of the population (Szejda and Urbanovich, 2020). The report also asserts that the entire population will eventually adopt meatless meat, which could be an overconfident application of Diffusion of Innovation Theory. The Theory is contingent on certain aspects of the innovation, including cost and consumers' values, and there have been plenty of innovations which have not been adopted by the entire population.

3.2 Economic Feasibility

The meatless meat industry's ability to price its products competitively with animal meat is the second key to its success. The high rate of estimated consumer acceptability depends on the price parity with animal meat, and achieving price parity depends on the industry's ability to scale up production. Currently plant-based meat prices are approximately $1 above hamburgers when sold at restaurants,[6] and up to three times the price of animal meat when sold in grocery stores.[7] However, in response to animal-meat shortages during the COVID-19 pandemic, both Beyond Meat and Impossible Meat lowered

[6] In downtown Chicago, a Whopper meal at Burger King goes for $8.09 while an Impossible Whopper meal $8.59. In Springfield, IL, they go for $7.29 and $8.29 respectively. At Hardee's in Springfield, the Beyond Burger goes for $7.34 while a regular burger of the same size goes for $6.57. (March 2020 prices)

[7] At a grocery store in Champaign, Illinois, Beyond Meat is offered at $5.99/8oz. Impossible Meat made its grocery store debut in California in August 2019, where it went for $8.99 per pound, which was three times that of a pound of beef.

their prices (McClain, 2020) (Watson, 2020). Lab-grown meat is not yet available on the market so the retail price is not yet set. The research to grow the first hamburger cost 250,000€ (Mosa Meat, 2020), and with the current technology it costs more than $15,000 to grow a kilogram of meat in a lab (Specht, 2020). Business press estimates of the initial market price for lab-grown meat – projected to hit the market in 2021-2022 – range from $10 to $50 per pound (Lucas, 2019) (Axworthy, 2019) (Purdy, 2019).

The market capture permitted by consumer acceptability hinges on the industry's ability to develop production technologies which produce sundry cuts of meat at competitive prices. According to the Good Food Institute, the industry has just "scratched the surface" of optimizing its production process, with the ultimate goal being a more efficient conversion of raw material calories to consumable calories (Allen, 2018). A popular technique involves a high moisture twin-screw extrusion process, which creates new covalent bonds among the plant proteins, forming fibers akin to meat (Wild et al., 2014). These fibers are then used as the main ingredient in the product, with flavorings and further processing to create a final product. An advantage of plant-based meat is that it can have a longer shelf life than animal meat (Kyriakopoulou et al., 2019).

The cellular agriculture industry faces major technical hurdles to scaling and commercializing lab-grown meat products. Cuts of meat have been grown successfully in laboratory environments, but the technology has not yet been developed that would manufacture lab-grown meat on a large scale. The prototypes of the equipment that would be used for large-scale lab-grown meat come from the lab-grown therapeutics industry (Specht et al., 2018), which grows organs individually. To this end, the lab-grown meat industry needs to develop equipment for commercial production, such as a bioreactor for

the controlled growth of large volumes of cells, and micro-scaffolding for the structure of different cuts of meat (Stephens et al., 2018). Bioengineering research also needs to enhance the industry's ability to control cell differentiation, as well as develop cost-effective formulas for cell growth media. According to a production analysis conducted by the Good Food Institute, the cell growth medium accounts for 55% to 95% of the marginal production costs (Specht, 2020). It is also important to note that different types of media are needed to grow different types of animal cells, and that the same type of medium may not work for the entire growing process of a piece of meat (Bhat et al., 2014).

Start-ups and research institutes are mobilized to tackle each of these challenges. The Good Food Institute has produced models for cell media production which would reduce the cost from $400 per liter, the market price, to $0.24 - $40.94 per liter (Specht, 2020) if produced in-house.[8] A group of researchers at Northwestern University recently developed a formula for a stem cell medium which can be produced at 97% less cost than the market varieties (Kuo, 2019). The world's first industrial factory of lab-grown meat is scheduled to start operation in the Netherlands in 2020, a joint venture between Mosa Meats, Nutreco, and Low Capital Carbon (Mosa Meat, 2020). Based on the high level of investment and the projections of start-up companies and research institutes, it is highly likely that lab-grown meat will become available in the U.S. in the next decade. The USDA and the FDA are poised to oversee its production in the U.S., planning to split regulation between its two production phases. The question remains whether the industry can reduce the costs of production by scaling and innovating, because there is no evidence that it has overcome the technical barriers to doing so yet.

[8] These models assume 20,000L of this medium to grow 3,500 kg of meat (Specht 2020).

In summary, consumer acceptability and economic feasibility are two factors which will influence the meatless meat industry's ability to expand and compete with livestock. Current consumer acceptability studies rely on hypothetical choice scenarios for these products, and initial findings present a range of acceptance levels among consumers. For plant-based and lab-grown meat combined, current research estimates that consumer acceptability would be approximately 25-30%, if the products are priced competitively with their meat substitutes. The studies have found that more consumers are willing to substitute plant-based meat for meat than they are willing to substitute lab-grown meat. However, these findings reflect the opinions of consumers who have not yet been exposed to mass marketing or initial cultural adoption of the products, which likely would increase acceptability levels. In terms of economic feasibility, plant-based meat and lab-grown mean claim but have not yet proven that they will be able to price their products competitively with meat. Production costs for plant-based meat and lab-grown meat are not publicly available, for current or for at-scale production scenarios. Plant-based meat is more developed than lab-grown meat in that it already produces its products commercially, but the industry is still investigating ways to optimize production to drive down prices. Lab-grown meat faces higher hurdles in that its production process is more technically involved and requires further research and the development of new equipment to apply stem cell growth techniques to commercial food production. The heightened scientific and public interest in this pursuit will accelerate R&D in order to see if commercial-scale production of lab-grown meat is possible.

CHAPTER 4: THE LIVESTOCK INDUSTRY'S RESPONSE TO MEATLESS MEAT

Plant-based meat already comprises 1.4% of total 'meat' sales in the United States, and this market experienced rapid growth over the course of the past year (Good Food Institute, 2021). As meatless meat takes aim at the animal meat market, the question remains how much of the meat market it can capture. It is unlikely that the industry will not steadily capture the entire meat market in the way it intends to, because the livestock and feed industries will respond dynamically to this new competition, and their response eventually could stall meatless meat's growth. This chapter provides an overview of ways the livestock industry likely will respond to competition from meatless meat.

As shown by consumer willingness-to-pay surveys cited in Chapter 3, the cost of meatless meat will be an important determinant of the size of its market. The more cost competitive meatless meat is, the more market share it will take. The industry aims to achieve price parity with animal meat, but its ability to drive down cost remains to be seen. If it does achieve price parity, consumer acceptability studies suggest that the initial market share will be 25-30%. These figures assume the expansion of the market itself, because meatless meat draws in customers who would otherwise not purchase meat at all.

If the industry does achieve price parity with meat, however, expect a dynamic response from the livestock industry. The livestock industry will be able to respond strategically to meatless meat; even without the competition posed by meatless meat, the industry has been becoming increasingly efficient, thanks to advances in livestock breeding and feed formulation. Because of the size and sophistication of the industry, livestock will be able to lower its prices to undercut meatless meat, breaking the market equilibrium. The

pressure from meatless meat also will spur livestock innovation in an already sophisticated agricultural research industry, increasing livestock's capacity to undercut meatless meat.

The commercial agriculture industry is closely linked with the livestock industry, and it, too, will respond to the growth of the meatless meat market. Corn and soybean are staples of livestock diets, and livestock feed is the number one use of U.S. corn and soy worldwide (United Soybean Board, 2020). Commercial agriculture is also becoming increasingly efficient as plant breeders and agronomists increase crop yields annually. If demand for livestock dips, in the short run farmers will face lower commodity prices as a result of their increased supply. These lower prices would feed into declining livestock prices, which again would make it more difficult for meatless meat to compete with livestock in the short run. This increased competition would cause price sensitive consumers who had switched to meatless meat because of lower prices to return to animal meat.

The variety of meat cuts offered by meatless meat also will affect meat prices. There are dozens of different cuts of meat, and currently meatless meat offers only a few of them, namely, the lower end meats such as ground meat. Limited offerings of meatless meat cuts will distort animal meat prices because the livestock industry cannot adjust its supply of certain cuts while demand for other cuts remains steady – animal meat cuts are joint products. Price competition would result. In this scenario, conventional ground meat prices would drop far below the prices that meatless meat can offer because there would be a surplus and livestock cannot readily adjust its supply if demand for other cuts of meat remains constant. Meatless meat would then have to compete with those dropped prices.

This competition would benefit consumers, but it could imperil meatless meat's strategy of undercutting the price of animal meat.

Besides adjusting price, the livestock industry likely will challenge some of the claims made by meatless meat. For example, it will challenge the claim that meatless meat products are nutritionally superior, pointing out that plant-based meat is highly processed, and highly processed foods have been linked to obesity and other health problems (Hall et al., 2019). Similarly, the livestock industry could criticize lab-grown meat the same way that GMOs have been criticized. Although there is no immediate evidence that consuming these products contributes to poor health, the potential health side effects of consuming these products long-term are not yet known. Livestock also may seek to distinguish itself from meatless meat by defining itself as 'natural,' a quality in food highly valued by U.S. consumers (Consumer Reports, 2016). Finally, livestock may conduct its own life cycle analyses to reckon with the environmental claims against it (see Appendix A for a discussion of life cycle analyses related to plant-based meat), or it may invest in practices which improve its perception among environmentalists. For example, commercial agriculture's main source of greenhouse gas emissions is nitrogen fertilizer; with precision agriculture technologies, significantly reducing these emissions is within reach.

The agricultural lobby will backstop the livestock industry's competition with meatless meat. Though agriculture comprises only 1% of the U.S. economy (USDA Economic Research Service, 2020), the agricultural industry commands political sway disproportionate to its share of GDP because it provides an essential good (food) and its trade strengthens diplomatic relations with numerous key economies. The rising demand for 'natural' products also compels government support for smaller farms. For these

purposes the U.S. Department of Agriculture subsidizes the production of key commodities, and agriculture industry associations, such as the National Corn Growers Association, American Soybean Association, and National Cattlemen's Beef Association, maintain lobbyists in Washington to protect their interests. These institutions are likely to push regulations that protect livestock and agriculture as meatless meat enters the market. Already in Missouri, the state legislature passed a bill in 2018 prohibiting food companies from labeling products as "meat" if the products do not come from livestock or poultry (Tsang, 2018).[9] Prompted by Big Ag, the USDA, the FDA, and state governments will likely introduce further regulations which support the livestock industry in its competition with meatless meat.

Beyond impacts on U.S. agriculture, the growth of the meatless meat market also will have consequences on emerging economies. As the world's population grows to 10 billion by 2050, demand for meat will rise, but the majority of that demand will come from population growth in African and South Asian cities. Currently meatless meat's target market is wealthy economies, which still experience annual growth in meat consumption, but the real need for protein nutrition in the coming decades will come from the Global South. Traditionally the growth of domestic livestock industries is a key step in a country's economic development and food security, but if meatless meat reduces demand for livestock in the U.S., American farmers will look abroad for markets for their corn and soy. This could have a detrimental effect on the economic development of poor countries – an increased dependency on food imports could stifle economic growth, and a drop in key

[9] The Animal Defense Fund, the Good Food Institute, the American Civil Liberties Union, and the company Tofurkey, filed a lawsuit against the state of Missouri over this law. Litigation continues.

commodity prices also could reduce the food security of agrarian-based economies. Meatless meat would not achieve its intended environmental impact if U.S. livestock was simply redirected to new markets. Yet if meatless meat does target emerging markets in the Global South, can its sophisticated production processes be conducted in resource-poor environments? As an industry oriented towards a sustainable future, meatless meat will need to consider the global implications of its challenge to the livestock industry.

CHAPTER 5: PRICE RESPONSE IN THE GROUND BEEF MARKET

As mentioned in the last chapter, one of livestock's responses to competition from meatless meat will be to adjust prices, and the first price response would come from the ground meat market. Other price responses will occur, but this chapter will focus on the ground meat price response using the beef market as an example. The ground beef market was chosen for examination because the plant-based meat industry's entry point into the meat market was ground beef, with products like Impossible Burger and Beyond Burger. Ground beef is also a useful case study because it illustrates how meat is a joint product – production of one cut of meat necessarily involves the production of other cuts. This means that a shift in the ground beef market will affect the markets for choice and select cuts of meat, so anticipating beef market response to meatless meat also requires a consideration of the price, supply, and demand of other, more valuable cuts of beef. An examination of ground beef as a joint product illustrates how meat markets more generally will be difficult to penetrate.

This examination provides an analysis of the economics of ground beef with the goal of describing price, supply, and demand responses within the market for all cuts of beef, if plant-based meat cuts demand for ground beef. An OLS regression using time series data of beef prices is used to quantify the relationships between fed steer, ground beef, and choice/select prices, as well as the implied changes when there is a disruption in the ground beef market. Pre-COVID market data from 2013-2019 is used, and it is assumed that this data reflects equilibrium in the beef market, so that it can be used to estimate potential price responses when plant-based meat disrupts the equilibrium. This examination also relies on price elasticities taken from recent literature about beef

markets, which will be used to estimate beef price responses to changes in supply and demand. Finally, it is assumed that plant-based foods will change the price elasticities in the ground beef market, but will not change the price elasticities for fed steers or other cuts of beef. This is because plant-based meat directly disrupts the ground beef market, and fed steer and choice/select markets react to that disruption.

The first section of this chapter (5.1) describes the beef industry in the U.S. and details the fed steer, ground beef, and choice/select beef markets. Section 5.2 outlines joint product theory and how it relates to beef production. Section 5.3 presents a time series dataset of historic beef prices in the U.S. Section 5.4 models the relationship between fed steer, ground beef, and choice/select prices using an OLS regression. Section 5.5 explains how plant-based meat would ripple through the entire beef market and quantifies price responses to plant-based meat from the three different beef markets using price elasticity estimates from recent literature. Section 5.6 estimates ground beef prices in a new equilibrium in which plant-based meat captures varying percentages of the ground beef market.

5.1.1 Overview of U.S. Beef Market

According to five-year averages from 2015 to 2019, the U.S.'s beef industry is the largest in the world, accounting for 19.33% of total global beef production (USDA Foreign Agricultural Service, 2019). Beef is also the greatest source of revenue for the U.S. agricultural sector, accounting for 18% of agricultural commodity cash receipts (USDA/Economic Research Service, 2021). At the beginning of 2020, the U.S. herd contained 94.4 million beef cattle (USDA/Economic Research Service, 2021). There are

approximately 727,906 beef farms and 26,586 feed lots in the country, which are concentrated in the Great Plains states (NCBA, 2021).

Over the past five years, the U.S. produced on average 29,646 million pounds of beef and imported an additional 3,086 million pounds (Table 1). U.S. consumers also consume more beef than anyone else in the world. The 5-year average was 26,194 million metric tons, which accounts for a quarter of total global consumption (USDA/FAS). The 5-year average for per-capita annual beef consumption was 56.4 pounds of retail weight (Figure 1). Over the past two decades meat demand has remained relatively stable, with a compound annual growth rate of -0.03% (USDA/FAS). The U.S. is a net importer of beef in terms of volume, but a net exporter of beef in terms of value. The U.S. imports lean ground beef in order to dilute its fattier trim supply to create leaner blends of ground beef, while it exports the more valuable choice and select cuts of beef (Speer, 2019).

5.1.2 Slaughter Market

From 2016-2020, on average 32,423 heads of cattle were slaughtered in the U.S. annually. Table 2 displays the breakdown of animal type in total slaughter. 51.42% were steers (male animals raised for slaughter), 28.04% were heifers (female animals raised for slaughter), 9.28% were beef cows (female animals raised for breeding and slaughter), 9.60% were dairy cows (female cows raised for dairy production), and 1.65% were bulls and stags (uncastrated and late castrated male animals, respectively). The industry is designed to optimize production of choice and select carcasses.

The slaughter market cannot adjust supply quickly in response to change in demand because of cattle life cycles. The herd size fluctuates every 8-12 years as farmers grow or cull their herd in response to market and environmental factors (USDA/ERS). Cattle

lifecycles last 1-2 years. The first stage of the production is called cow-calf operations, where calves are born to herds of beef cows on pasture land. Calves are weaned off their mothers after 3-7 months; next they are sent to pasture or pens to feed for 3-4 months. Finally, the animals are sent to feed lots for fattening prior to slaughter. Time in a feed lot can last 90-300 days. The beef carcass is processed into several hundred basic wholesale products, which are then fabricated into several thousand products differentiated by brand and consumer specifications (Peel, 2021).

5.1.3 Ground Beef Market

The ground beef supply in the U.S. comes from three main sources– the beef industry, the dairy industry, and imports from Australia, Canada, Mexico, New Zealand, and Brazil (Ishmael, 2020). Ground beef is a 'subprimal' cut of beef, meaning that it is lower quality meat. Thirty-eight percent of a steer's carcass is sub-primal meat, which can be processed into ground beef and stew meat (American Angus Association). Ground beef comes in many different blends – 70%, 80%, 90% lean – which are created from fattier trimmings blended with leaner trimmings (Ishmael, 2020). In general, fattier trimmings come from fed cattle, and leaner trimmings come from dairy cows and imports. Table 3 displays the proportionate contributions of these sources to ground beef supply. Trimmings from fed cattle contribute 43% of total supply, domestic cows (mostly dairy cows) contribute 27%, imports contribute 26%, and trimmings from domestic bulls (uncastrated males used for breeding) contribute 4%.

It is estimated that 45% (Ishmael, 2020) to 62% (Rabobank, 2014) of the beef that Americans eat is ground beef. Demand for ground beef has grown over the past forty years, as convenience and leanness attributes became more valuable to American consumers

(Rabobank, 2014). As a result of this shift in preferences, the U.S. relies on imports of lean beef trimmings to meet demand for ground beef. U.S. beef animals are optimized for choice and select cut production instead of ground beef production. With the recent increase in ground beef demand, it has been argued that the beef industry no longer produces an optimal ratio of prime to sub-prime cuts for the U.S. market (Rabobank, 2014).

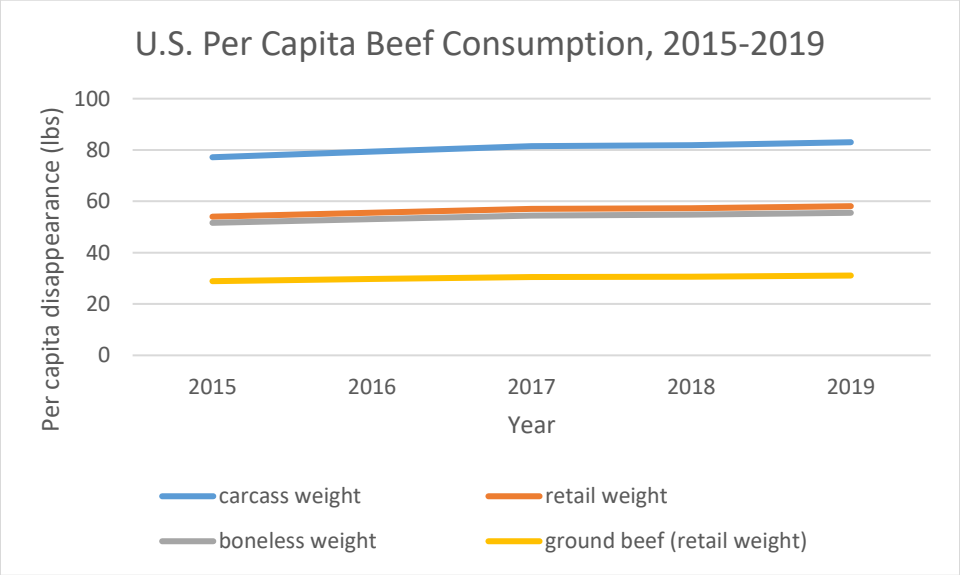
Competition with the U.S. beef market, and especially the ground beef market, will be difficult for a number of reasons. For one, it is the largest in the world, and for another, demand for ground beef is higher than for any other beef product. The supply side of the market poses additional challenges to competitors. As a joint product, the supply for ground beef cannot be adjusted without adjusting supply of other cuts of beef. Cattle life cycles also make it difficult for the industry to adjust supply quickly, which means that it would first undercut plant-based meat prices for years before reducing supply of ground beef. And the fact that ground beef supply comes from multiple sources complicates supply adjustments even further. Dairy cows contribute nearly 10% to total U.S. ground beef supply. However, sales of dairy cattle likely have little impact on the dairy industry. Beef imports pose a similar challenge, since they do not affect U.S. beef farmers' revenue. So a fixed supply of ground beef will be on the market regardless of beef prices or customer demand, which will give the beef industry an advantage in a pricing competition with plant-based meat.

Table 1: U.S. Supply and Disappearance for Beef, million lbs CWE, 5-year average (2015-2019)

Year	**2015**	**2016**	**2017**	**2018**	**2019**	**5-year average**
Total Year End Supply	23,760	25,288	26,250	26,938	27,224	25,892
Beginning Stocks	591	683	757	649	662	668
Imports	3,368	3,012	2,993	2,998	3,058	3,086
Total Supply	27,719	28,983	30,000	30,585	30,944	29,646
Exports	2,267	2,557	2,859	3,160	3,026	2,774
Ending Stocks	683	757	649	662	642	679
Total Disappearance	24,769	25,669	26,492	26,764	27,275	26,194

Source: USDA/ERS Beef Supply & Disappearance Dataset

Figure 1: U.S. per capita beef consumption, lbs (2015-2019)



Source: USDA/ERS Beef Supply & Disappearance Dataset

Table 2. Cattle Slaughter in the U.S., 5-year average, 2016-2020

Animal Type:	**Number of Heads Slaughtered:**	**Share of Total:**
Steers	16,673.2	51.42%
Heifers	9,091.7	28.04%
Beef Cows	3,009.4	9.28%
Dairy Cows	3,112.3	9.60%
Bulls and Stags	536.2	1.65%
Total Cattle:	32,422.7	100.00%

Source: USDA/ERS

Table 3: Estimated Trim Used in U.S. Ground Beef Production

Source	**Pounds, billions**	**Percent of Total**
Fed Cattle	3.622	43%
Domestic cow trim	2.297	27%
Imported lean trim	2.220	26%
Bull trim	0.366	4%
Total	8.505	100%

Source: Beef Magazine

5.2 Joint Product Theory

Market responses to plant-based meat can be explained with joint product theory. Beef products are joint products – production of a certain cut of beef involves the production of other cuts of beef, because all cuts come from a single allocable factor, a beef carcass (see Beattie and Taylor (2009) for a discussion of joint product theory). More specifically, ground beef is jointly produced with choice and select cuts of beef. The joint production of ground beef and choice/select cuts is modeled by a fixed factor production function:

$$F(y_1, y_2, x_1) = 0$$

Where y_1 and y_2 are the beef product outputs (ground beef and choice/select cuts) and x_1 is the allocable factor (steer carcass). The production of choice cuts (y_1) is a function of the prime part of the steer carcass ($x_{1.1}$) and the production of ground beef (y_2).

$$Y_1 = f(y_2, x_{1.1})$$

And the production of ground beef (y_2) is a function of the sub-prime part of the steer carcass ($x_{1.2}$) and the production of choice cuts (y_1).

$$Y_2 = f(y_1, x_{1.2})$$

This function can be made more specific to joint production of beef considering that only a certain part of the steer carcass can be turned into choice and select cuts – approximately 62%, according to the American Angus Association – while the entire carcass could be processed into ground beef (though optimally only 38% of the carcass would be used for ground beef).

$$Y_1 = f(y_2, 0.62x_1)$$

$$Y_2 = f(y_1, 0.38x_1)$$

In summary, joint product theory indicates that the supply, prices, and demand for choice and select cuts of beef will respond to changes in supply, prices, and demand for ground beef.

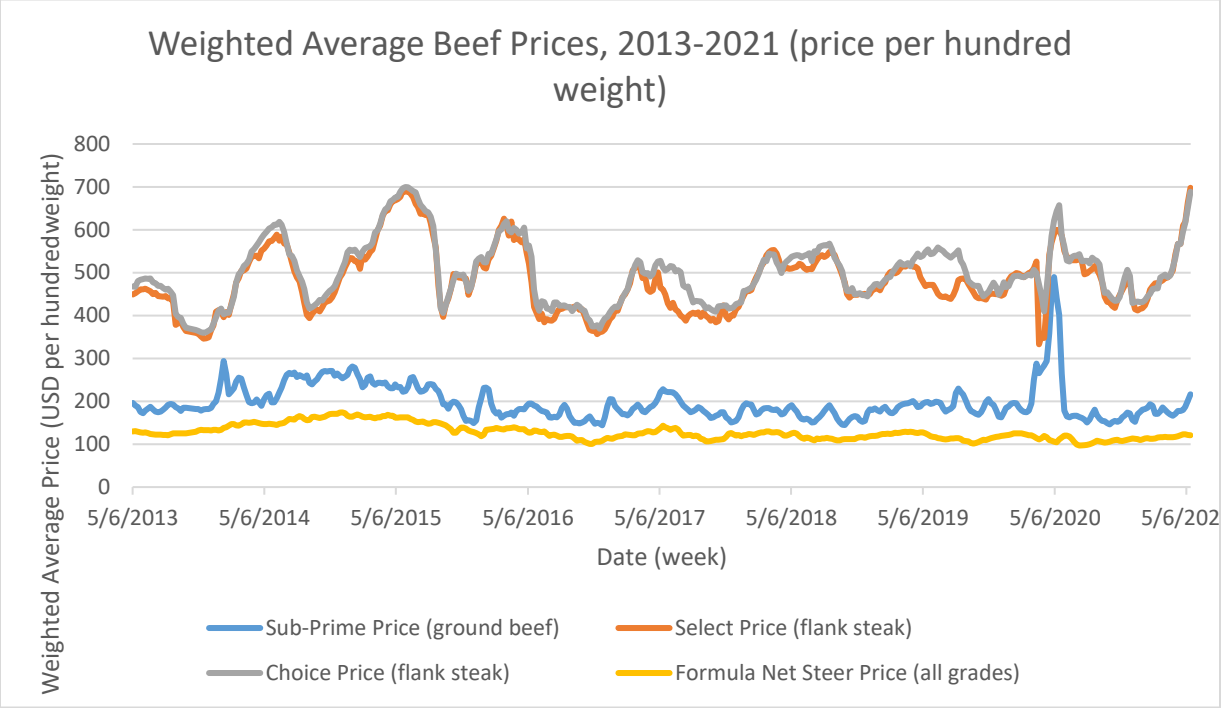
5.3 Historical Relationships between fed steer, ground beef, and choice/select prices

Estimating beef market response to plant-based meat using depends on the assumption that the beef market is in equilibrium prior to the entry of plant-based meat. Historical relationships between fed cattle, ground beef, and choice/select prices can be used to support this assumption. Figure 3 displays a time series graph of these prices from 2013-2021. Select and choice steak prices are highly correlated and fluctuated up to $350 per hundredweight each year for the past eight years. Their compound annual growth rate (CAGR) over the past eight years has been 5.66% and -4.96%, respectively. Ground beef prices are not strongly correlated with steak or steer prices and they fluctuated less, only

by approximately $150 per hundredweight over the course of the past eight years. Its CAGR has been 1.23%. Fed steer prices varied the least, only by about $75 per hundredweight over the course of the last eight years, and its CAGR was -0.88%. The COVID-19 lockdown in spring 2020 resulted in price spikes for ground beef and price drops for steak, but the prices quickly returned to pre-lockdown levels within a few months. Because no significant deviations from price patterns are observed prior to the COVID-19 market shock, it is assumed that the 2013-2019 time series represents the beef market in equilibrium.

The data comes from the USDA Agricultural Marketing Service's MPR Datamart, which is a database for time series pricing data on meat and dairy consumer products. The time series data used for this study are the prices from formulated sales of national weekly boxed beef cuts. The prices range from the week of May 6, 2013 to the week of May 6, 2021. The pricing data for three beef cuts are included in the model, each one representing choice, select, or sub-prime cuts of beef: flank steak (choice), flank steak (select), and ground beef (81% lean). The steer price is a National Weekly Direct Slaughter price for all steer grades, formula net purchase type.

Figure 3: Weighted Average Beef Prices, 2013-2021



Source: MPR Datamart

5.4 Estimating Beef Price Relationships Using OLS & Historic Beef Prices

Using the data above, this section quantifies the influence that ground beef and choice/select prices have on the fed steer price using an OLS Regression. The relationships of retail beef prices to feedlot prices can be used to estimate the prices of fed cattle, ground beef, and choice/select cuts in equilibrium after a shift in supply or demand. The price estimates provided by the OLS model are useful because they estimate prices changes in one market considering the prices in the other two linked markets. The OLS model permits an estimate of beef prices in a new equilibrium, assuming that the relationship of retail to farm beef prices stays the same.

The relationships of retail to farm beef prices are determined by the Ordinary Least Sums model:

$$P_{fs} = a + b * P_{\text{ground beef}} + c * P_{\text{choice/select}}$$

Where steak and ground beef prices are a function of steer price: P_{fs} = price of fed steer, $P_{ground\ beef}$ = price of ground beef, and $P_{choice/select}$ = aggregated average price of choice and select steak. The prices of choice and select steak prices were combined in a single variable in order to avoid multicollinearity between the two variables.

A regression was run on this model using the beef price data from 2013-2019. Price data from 2020-2021 was dropped from the dataset because the price volatility during the onset of the COVID-19 pandemic caused heteroskedacticity in the model (even after a log transformation), which violated the assumption of constant variance among residuals for an OLS regression. A log transformation was again necessary for the model using the 2013-2019 data in order to create constant variance among residuals in the regression.

Table 4: Transformed Regression Coefficients

Coefficient	**Estimate**	**Standard Error**	**Significance**
Intercept	4.3531266155	0.03137	< 2e-16
Ground Beef	0.0013319110	0.0001302	<2e-16
Choice/Select Aggregate	0.0004613277	0.00005825	8.45e-12

Each variable is significant at the 0.05 level and the goodness of fit (adjusted R-squared) is 0.6873, meaning that 68.73% of variability in steer price can be explained by the model.

Correlation between the independent variables was tested; ground beef and the choice/select aggregate are only correlated by 33.91%. A Durbin-Watson test was conducted on the model to test for autocorrelation; the test statistic was 0.078501, significant at the 0.05 level, meaning that there is positive autocorrelation in the model and the price data used in the model can be used to estimate future prices. Finally, a Breusch-Pagan test was conducted on the transformed model to test for heteroskedasticity. The test

statistic was below 0.05, indicating that heteroskedacticity cannot be assumed in the model.

Interpretation of the log-transformed multiple regression requires taking the inverse of the coefficients using exponentiation, see Table 5. A one unit (unit = USD per hundredweight) increase in the price of ground beef will yield a 0.13% increase in the fed steer price, and a unit increase in the choice/select average price will yield a 0.46% increase in the price of fed steer. The intercept 77.72 is the estimated geometric mean of the outcome variable, the fed steer price.

Table 5: Exponentiated Regression Coefficients

Coefficient	**Exponentiated Estimate**
Intercept	77.721087
Ground Beef	1.001333
Choice/Select Aggregate	1.00461

5.5 Market Response Estimates Using Beef Price Elasticities

Now that the relationships between the three beef markets have been established, this section presents price elasticities for ground beef, fed steer, and steak (a proxy for choice/select) markets and uses them to estimate a change in price as a result of a certain change in supply or demand. This information is used to describe how plant-based competition with ground beef would ripple through the entire beef market. In section 5f, this information is integrated with the findings of 5d to make a final estimate of the effect of plant-based meat on beef.

The following method is used to describe the beef market response to plant-based meat, using price elasticities:

1. Calculate the ground beef price that would result from a drop in demand of X%.

   a. ***Equation X****: Price elasticity of supply for ground beef = % change in quantity ground beef supplied/ % change in ground beef price. Assume that steer supply drops proportionately to the drop in demand for ground beef.*

2. Calculate the fed cattle price that would result from a supply cut of X%.
   a. ***Equation Y****: Price elasticity of fed cattle supply = % change in quantity of fed cattle supplied/% change in fed cattle price.*
3. Calculate the choice price that would result from a cut in fed cattle supply:
   a. ***Equation Z:*** *Price elasticity of choice beef cut = % quantity of choice cuts supplied/% change in choice cut price.*

Part 1:

The first step is to calculate the ground beef prices that would result from cuts in demand. To do this, the price elasticity of supply for beef, Equation X, is used. A decrease in demand for ground beef would lead to a surplus of the product, which would lead to a price cut. Table 5 displays the change in price that would result from changes in demand for ground beef. The figures are calculated using an estimate of price elasticity of demand as a substitute for price elasticity of supply. (The reason for this is that the beef market literature has many estimates of price elasticity of demand for different cuts of beef, but not price elasticities of supply. In the short term with a surplus of ground beef, it is fair to assume that the prices of ground beef would adjust according to price elasticity of demand, because the price changes would prompt consumers to respond proportionately and return the market to equilibrium.)

Lusk and Tonsor (2016) provide own and cross-price elasticities of demand for different cuts of beef, see Table 6. They calculated own and cross- price elasticities of

demand for different cuts of beef, and they separated price elasticities by low, medium, and high income responses and by price increases and decreases. For a generalized response of ground beef prices to plant-based meat, the calculations in Table 5 use the medium income elasticity for a price response in ground beef. Ground beef has a negative own price elasticity of demand, which means that it is a normal good. As an estimate for price elasticity of supply, -2.377 means that a 2.377% increase in ground beef supply means a price decrease by 1%.

Table 6: Arc Elasticities of Demand for Price Increases and Decreases of Ground Beef and Steak, by Income Level:

Income Level		Price Increase		Price Decrease	
		Ground Beef	Steak	Ground Beef	Steak
Low	Ground Beef	-1.959	0.184	-2.511	0.280
	Steak	0.375	-1.738	0.478	-2.652
Medium	Ground Beef	-1.834	0.373	-2.377	0.514
	Steak	0.344	-1.836	0.441	-2.606
High	Ground Beef	-1.703	0.459	-2.075	0.548
	Steak	0.253	-1.674	0.307	-2.061

Source: Lusk & Tonsor 2016

Table 7: Short-Run Responses of Ground Beef Prices to Ground Beef Demand:

% Change in Demand	**% Change in Supply**	**Price Change to Ground Beef**
-5%	+5%	-2.10%
-10%	+10%	-4.21%
-15%	+15%	-6.31%
-20%	+20%	-8.41%
-25%	+25%	-10.52%

Part 2:

A key assumption of this model is that a drop in ground beef supply would mean a proportionate drop in steer supply. Ground beef is a joint product, which means that the steer carcass is optimally divided into different cuts of beef, and only 38% of a steer carcass can be made into ground beef. This means that beef butchers cannot use more of the steer

for choice or select cuts as ground beef demand declines, so if the market requires that they cut ground beef supply by 10%, they will have to cut steer supply – and other cuts of beef – by 10% as well.

Another assumption is that the dairy industry will not react to the drop in the demand for ground beef. The dairy industry contributes to the ground beef supply, but ground beef is a side product of dairy production and does not contribute significantly to dairy farms' revenue. For this reason, dairy farms will not adjust the size of their herd in the way that beef farms are expected to do. Instead, it is possible that the U.S. would reduce beef imports, since dairy beef and imported beef are leaner and used to cut fattier steer beef into leaner blends preferred by consumers.

Part 3:

The next step is to calculate how feeder cattle prices would respond to a cut in supply. Jeong (2019) provides the most current price elasticities for fed and feeder cattle in the U.S. beef market. See Table 8. Fed cattle are steers which have been fattened in a feedlot and are ready for slaughter. Feeder Cattle are steers and heifers that have been weaned from their mothers and are ready to be sold to a feedlot.

Table 8: Estimated Long Run Price Elasticities of Fed and Feeder Cattle Supply:

Product	**Fed Cattle Price**	**Feeder Cattle Price**
Fed Cattle Supply (short run)	1.813	-0.877
Fed Cattle Supply (long run)	4.13	-2.166

Source: Jeong, 2019

Fed cattle have a positive price elasticity of supply, which means that supply increases as price increases and contracts as price decreases. The elasticity is greater in the long run

than in the short run, which means that supply would contract more in response to a 1% decrease in price over the long term than it can in the short term. This makes sense for cattle supply, since supply in the industry is bound to annual growth cycles of the animals and the age at which the farmer chooses to slaughter the animal.

Table 9 displays the change in fed cattle prices that would result from different cuts in fed cattle supply. These figures were calculated using Equation X and the long run price elasticity of fed cattle supply.

Table 9: Long Run Responses of Fed Cattle Price to Fed Cattle Supply:

% Change in Supply	**% Change in Price**
-5%	-1.21%
-10%	-2.42%
-15%	-3.63%
-20%	-4.84%
-25%	-6.05%

Part 4:

Finally, how would the price of choice and select cuts of meat respond to a drop in steer supply? Since the plant-based meat industry has not yet developed products which could be substitutes for choice and select cuts of beef, the assumption is that the demand for these cuts would remain the same while the demand for ground beef drops. In the face of a supply cut, choice and select cuts of beef would increase in price. This change is calculated using Equation Z and the price elasticities again from Lusk and Tonsor (2016) in Table 6. In this case, the own-price elasticity of demand for steak (in response to a price increase) is used to estimate how the price of choice cuts will react to a shortage. See Table 10.

Table 10: Long Run Responses of Steak Price to Steak Supply:

% Change in Demand	% Change in Supply	Price Change to Steak
0%	-5%	2.72%
0%	-10%	5.45%
0%	-15%	8.17%
0%	-20%	10.89%
0%	-25%	13.62%

In summary, because ground beef is a joint product, changes in its market would affect the fed steer and choice/select cut markets as well. The price elasticities for each product, as estimated by recent studies about U.S. beef markets, can be used to quantify price changes across all three markets, under the assumption that the entire beef market was in equilibrium prior to plant-based meat entry. These calculations indicate that the decrease in fed steer price would be less than the decrease in the price of ground beef, and the increase in choice/select prices would be greater than the decrease in both the fed steer and ground beef prices. This suggests that in the long term, the fed steer price could actually increase as a result of plant-based meat competition with ground beef.

5.6 Accounting Identity for Ground Beef Price Estimates

This section combines the price relationships from section 5d with the price elasticities from section 5e to estimate the price drop in ground beef that would result from competition with plant-based meat. This method builds upon the ground beef price estimates made in section 5e by calculating a new price elasticity for ground beef. This new price elasticity will reflect the new market equilibrium for ground beef after plant-based meat establishes itself in the U.S. meat market.

The model's estimates from section 5d can be used to create an accounting identity that reflects the historical relationship between beef prices, and can be used to estimate

prices in a new equilibrium after a shift in supply or demand. This accounting identity is represented by the equation:

$$P_{\text{ground beef}}^{**} = \frac{Pfs* - a - c * Pchoice/select*}{b}$$

Where P_{fs}^{*} = fed steer price given change in quantity supplied, $P_{choice/select}^{*}$ = average choice/select steak price given a change in quantity supplied, and $P_{\text{ground beef}}^{**}$ = ground beef price given change in quantity supplied or demanded.

Five-year averages of beef prices (2015-2019), listed in Table 11, are used to test the model. Shifts in the price of beef as a result of competition from plant-based meat can be estimated using this model: see Table 12 for price estimates of ground beef.

Table 11: Beef Prices, 5-year average (2015-2019)

Product	**Price (per hundredweight CWE)**
Fed steer	$126.53
Ground Beef	$187.87
Steak (choice/select aggregate)	$495.82

Table 12: Estimated Beef Prices from Model: Ground Beef Price as Output

% change in ground beef demand	**Ground Beef Price**	**steer Price**	**steak Price**
-5%	$180.36	$125.00	$509.31
-10%	$166.42	$123.47	$522.84
-15%	$152.38	$121.94	$536.33
-20%	$138.22	$120.41	$549.81
-25%	$123.92	$118.87	$563.35

In comparison with the price elasticities from the literature, the OLS accounting identity estimates a greater price drop to ground beef when fed steer and choice/select market linkages are considered. Using these two sources, this analysis expects that ground beef prices will drop between 2.10% and 4.00% if its market shrinks by 5%. The low end of the range comes from the price elasticity of demand estimated by Lusk & Tonsor (2020), and the high end of the range comes from the OLS regression, implying a new price

elasticity of supply and demand for ground beef: -1.25. This new figure means that ground beef is still an elastic good because its quantity supplied/demanded changes more than the price change, but it is less elastic than Lusk & Tonsor's estimate. This elasticity estimate is different from Lusk & Tonsor's because it reflects the linkage between ground beef and other beef markets. The model implies that the ground beef market, and its price elasticities, will change when plant-based meat enters the market. However, the model also assumes that the steer and steak price elasticities will remain the same, since plant-based meat will not be competing directly with them. The beef market will have to reach a new equilibrium after plant-based meat's growth stalls. Table 13 displays the differences in price change in ground beef according to the old and new price elasticity, representing the old and new market equilibria for ground beef, before and after plant-based meat.

Table 13: Old and New Market Equilibria for Ground Beef, before and after Plant-Based Meat

% Change in Demand	**% Change in Supply**	**Price Change to Ground Beef (Old Equilibrium (-2.377)**	**Price Change to Ground Beef, New Equilibrium (-1.25)**
-5%	+5%	-2.10%	-3.997%
-10%	+10%	-4.21%	-7.994%
-15%	+15%	-6.31%	-11.991%
-20%	+20%	-8.41%	-15.988%
-25%	+25%	-10.52%	-19.985%

When considering these results, it is also important to consider the assumptions made in the analysis. Three key assumptions were made in this analysis: the first was that the demand change in the ground beef market would spur a proportionate supply change in fed steer and choice/select markets. The second assumption was that the markets of the three beef products are linked, which was corroborated by historical price data and the

OLS Regression on that data, as well as by joint product theory. The third assumption was that the historical data used in the analysis reflected a market in equilibrium, and the market will be in equilibrium when plant-based meat enters the market. Pricing data from the COVID-19 pandemic was not incorporated in the model, and it is assumed that the relationships between the three beef markets will remain the same in a post-COVID, restabilized market.

CHAPTER 6: SUMMARY AND CONCLUSIONS

This thesis evaluated the potential for the plant-based meat industry to capture market from the U.S. livestock industry. The plant-based meat industry has emerged in light of widespread criticism of the livestock industry, especially about its environmental impacts. Claiming to produce a product superior to meat in terms of nutrition, taste, and environmental impact, plant-based meat companies intend to capture as much of the meat market as possible, in order to reform the commercial food system and reduce natural resource degradation.

To fully understand the implications that this new product would have on the U.S. food system, it is important to consider the factors that would drive and limit its growth. This analysis identified the main factors as consumer acceptability and willingness-to-pay, economic feasibility of producing the products at scale and pricing them competitively with meat, and the livestock industry's response to competition in terms of marketing campaigns, lobbying campaigns, and price competition. On average current studies about consumer acceptability of meatless meat estimate that 25-30% of the U.S. market would switch to meatless meat if it achieved price parity with meat. This is not yet a viable scenario, however, because both plant-based meat and lab-grown meat have not yet optimized production in order to market their products widely, at competitive prices. Finally, this figure does not consider the reaction from the livestock industry that would occur if meatless meat began to take its market. The second part of this analysis illustrated livestock's initial price response to this competition, focusing on plant-based competition with ground beef because it is expected that this would be the first market that the competition would occur in.

In summary, the livestock industry's response to competition from plant-based meat will challenge plant-based meat's expansion. Since ground beef is a joint product, the ground beef market is linked to both the steer and choice and select beef markets. If plant-based meat captures part of the market from ground beef, ground beef prices will decrease, prompting a supply cut and price cut in the fed steer market. In turn, assuming that demand for choice and select cuts stay the same, their prices will increase as a result of a reduction in supply in the fed steer market. This new equilibrium in the beef market will make it more difficult for plant-based meat to compete with beef, since ground beef will undercut the price of plant-based meat.

Further studies about the livestock industry's response to plant-based meat could challenge these assumptions: additional details about beef farmers' revenue sources could provide a better estimate of how farmers would adjust supply in response to a drop in the fed steer market. The linkages of the beef markets, as well as consumer behavior, could have changed as a result of the pandemic, in which case post-COVID market prices would need to be used to estimate new price elasticities and a new model. Future research also could characterize lab-grown meat's competition with the livestock industry. Plant-based meat only produces viable substitutes for ground meat, but lab-grown meat has demonstrated the capability to grow steak. If it is able to scale up and drive down its production costs, the lab-grown meat industry could complement plant-based meat's competition with livestock; this partnership would be better suited to complete with joint-products such as beef.

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USDA/Economic Research Service, Livestock & Meat Domestic Data

APPENDIX A: MEATLESS MEAT & ENVIRONMENTAL SUSTAINABILITY

The marketing strategy of many start-ups focuses on the sustainability of their production process compared to that of the conventional meat industry. Marketing messages compare the resource use of conventional meat and livestock meat and suggest that the globe cannot withstand the livestock industry much longer. Memphis Meats claims "same great taste, better for the planet." Impossible Meats says that its products "require way less land and water than cows, and produce a fraction of the emissions." Beyond Meat's website says, "we hope our plant-based meats allow you and your family to eat more, not less of the traditional dishes you love, while feeling great about the health, sustainability, and animal welfare benefits of plant protein." Mosa Meat's website states, "By 2050, global meat demand will be 70% higher than today's level. Our planet simply doesn't have enough land or water to produce this much meat using animals. And trying to do so would devastate the environment." Aleph Farms claims that it is "leaving a better legacy for future generations by establishing a responsible and sustainable food system."

These claims are backed by independent research, as well as research funded by meatless meat companies and advocacy groups. Life cycle analyses (LCAs) are used to compare the environmental impact of meatless and animal meat products; the overall finding of these LCAs is that both plant-based and cell-based meat products (Tuomisto & Joost Teixeira de Mattos, 2011) use considerably less energy, water, and land than animal meat, and their production emits considerably less pollution and greenhouse gases into the environment. For example, Beyond Meat commissioned the University of Michigan Center for Sustainable Systems to conduct a life cycle analysis of a 4 oz. Beyond Burger product in comparison with a 4oz. ground beef patty. The analysis considered the raw material supply

(including the production of agricultural crops), processing and packaging operations, cold storage, distribution, and disposal of packaging materials, and used four indicators to determine environmental impact: greenhouse gas emissions, energy use, land use, and water. The analysis found that the production of a Beyond Burger patty results in 9.25 times less greenhouse gas emissions, 1.87 times less energy, 12.67 times less land, and nearly 200 times less water. Impossible Meat also commissioned the research consulting firm Quantis to produce a life cycle analysis of its product. This study compared 1 kg of Impossible Burger with 1 kg of beef within the same system bounds and found that Impossible Burger used 87% less water, 96% less land, 89% "global warming potential" (greenhouse gas emissions), and 92% less "aquatic eutrophication potential" (discharge of nutrients to waterways which cause algae blooms) (Quantis, 2019). Similar findings were reported in a life cycle analysis funded by the Dutch Consumers' Association (Blonk Consultants, 2017) and a study conducted by Wageningen University (Zhu & Ierland, 2004). However, a 2010 study conducted by researchers at the Swedish Institute for Biotechnology found that processing peas into a vegetarian meat product takes the same amount of energy as the processing for the equivalent product made from animal meat (Davis et al., 2010).