Evaluating the supply chain of animal protein-based pet food ingredients and international trade of pet food

by

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Abstract

The overarching theme of this thesis research is economics and management of pet food. This paper is split into two area of focus, looking at the supply of pet food ingredients and international trade of pet food. These areas are related as pet food trade can have an effect on the domestic production of pet food, and therefore the need for ingredients. Pet food is a growing industry and can benefit from increased research into the economics of trade and supply chain characteristics of the industry.

The first section of this thesis evaluates the supply chain of animal protein-based ingredients used in pet food and how they flow from human food production to pet food manufacturers. It utilizes predominantly qualitative research methods to shed light on major players and transaction characteristics along the pet food supply chain, as well as identifies constraints and potential growth opportunities in the supply chain. It is important to understand the supply chain of pet food ingredients as the volume of animal protein-based pet food ingredients required grows. The systematic literature review revealed a lack of publicly available research studies offering a detailed analysis of the pet food supply chain. This thesis contributes to filling this gap on pet food analysis in agribusiness and economics literature.

The second section of this thesis's utilizes quantitative research methods to evaluate the effect that regional trade agreements (RTAs) have on the trade of pet food. This was evaluated using a fixed effects gravity model. Here we show that RTAs have a significant positive effect on pet food trade, however there are factors missing from the model that also affect the trade of pet food. Previously, pet food trade has not been heavily evaluated in academic literature. This thesis provides a starting point for the economic analysis of pet food trade which is going to

become a more important area in the future as this industry is continues to grow and become more globalized.

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Section 1 - Supply Chain Analysis

Chapter 1 - Introduction and Objectives

1.1 Introduction

The pet food industry is rapidly growing both in the US and globally. In the US, annual expenditure on pet food and treats grew from $20.46 billion in 2012 to a projected $44.1 billion in 2021, equaling a 115.54% increase in nine years (Bedford using US APPA, 2021). Looking at global pet food sales value, it has increased from 60.1 billion USD in 2012 to 102.9 billion USD in 2021, equaling a 71.21% increase in nine years (Frimpong, 2021). The growth in pet food expenditure is displayed in **Figure 1**. As the pet food industry continues to grow, the availability of ingredients needs to increase to keep up with the growth in pet food sold (Million Insights, 2020).

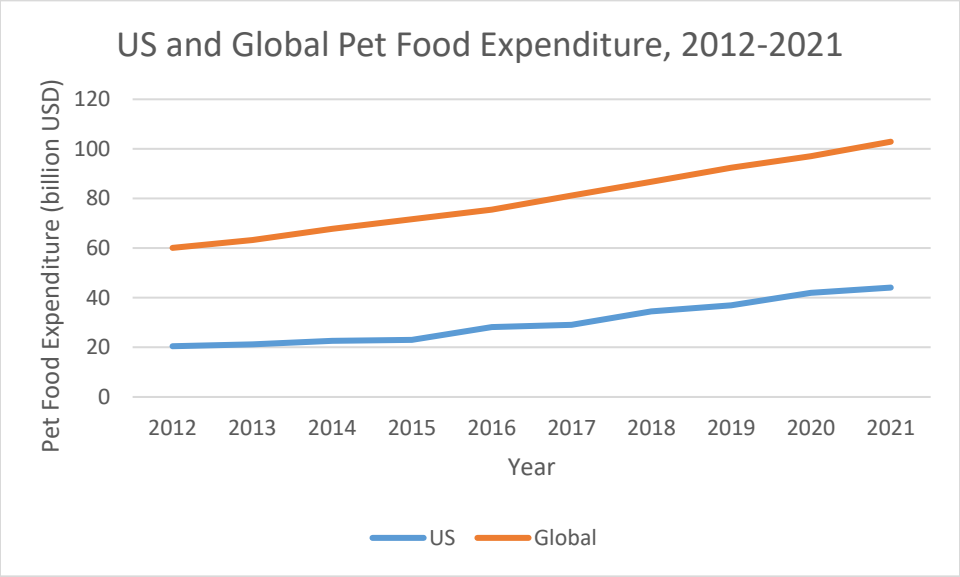
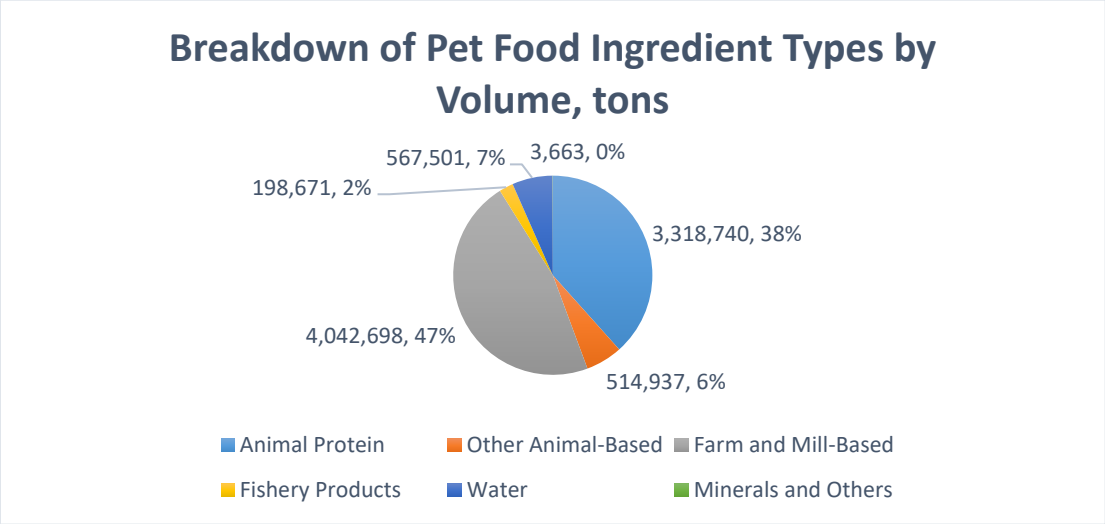


Figure 1. Pet Food Expenditure, 2012-2021

Source: Bedford using US APPA, 2021; Frimpong, 2021

According to Decision Innovation Solutions (DIS) using Nielsen (2020), the main categories of ingredients in pet food are farm and mill-based products, meat and poultry products, rendered protein meals, water, fishery products, broth from animal and poultry products, and minerals and others. Animal-based ingredients consisting of meat and poultry products (both fresh/frozen meat, organ meats, byproducts, and fats), and rendered protein meals, make up 38.4% of the ingredients used in US pet food in 2018 by volume and 51.5% by value making animal protein a significant ingredient. (DIS using Nielsen, 2020). The breakdown of pet food ingredient types by volume and value is shown in **Figure 2**.



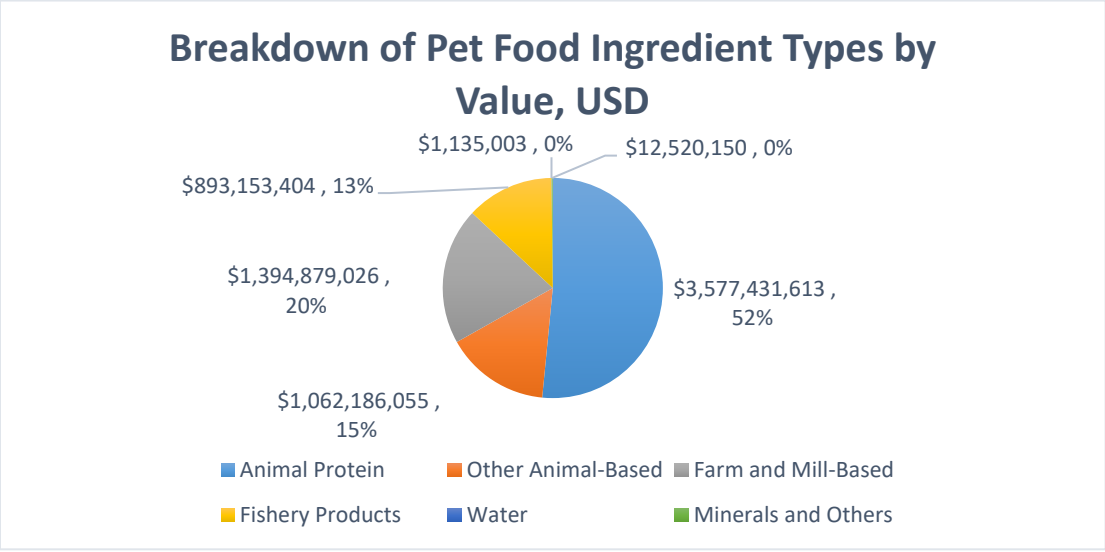


Figure 2. Pet Food Ingredients by Volume and Value

Source: DIS using Nielsen, 2020

There are two ways for the increased need of protein ingredients to be met. Either by making better use of existing protein sources or increasing the use of other protein sources, such as plant or novel proteins (Alonzo, 2016). One way to expand the use of current protein sources is through increasing the use of rendered proteins and byproducts from livestock (Alonzo, 2016). According to the NARA (n.d.) about 50% of animals are inedible for human consumption, so rendering acts as a way to recycle these parts of the animal into things like pet food. Novel proteins are simply protein types that are not commonly used in pet foods, such as kangaroo, alligator, and bison (Tractor Supply Co, n.d.; Wall, 2016; Wall, b2018). Challenges with using novel proteins include properly educating consumers on the ingredient, consumer acceptance, regulatory challenges, and financial feasibility (Wall, 2016; Wall, a2018; Phillips-Donaldson, 2016). Another supply challenge was addressed by Dr. Greg Aldrich in a Petfood Forum TV interview where he spoke about the need for novel proteins to have an established human food supply chain that pet food would fit alongside (Aldrich, 2018). To avoid issues with novel ingredients, making better use of current sources might be able to be accomplished with a better understanding of the supply chain. The pet food ingredient industry is important to analyze because as the industry grows, there needs to be a better understanding of the supply chain to help keep up with the increase in need for protein ingredients.

Because the rise in the pet food industry happened so quickly, literature has not been able to keep up and the information available to inform decision makers in the industry is limited. There are three main branches of literature regarding the pet food supply chain that look at: formulation (pet food types and ingredients), consumer trends (shifting consumer preferences), and players in pet food production (pet food manufacturers, renderers, ingredient brokers, etc.).

However, there is not sufficient information on the details of the animal protein ingredient supply chain (defining the supply chain, interaction between supply chain members, how ingredients move through the supply chain, volumes produced at each supply chain step, and market structure of each sector). Filling in these gaps will provide the information needed for researchers and decision makers to effectively inform them about the pet food ingredient supply chain and ingredient procurement.

1.2 Problem Statement

The pet food industry is growing fast which creates demand for a consistent and reliable supply of ingredients. This is complicated by shifting consumer preferences towards different ingredient types and increased interest in sustainability. Dynamic changes in the industry create a need for decision makers and researchers in the pet food industry to have access to information on the supply of pet food ingredients and demand of finished pet food. In order to make decisions, they need access to reliable information and research about the animal protein ingredient supply chain.

1.3 Research Objectives

This research aims to fill the current gap in literature on the movement of animal protein from the human food supply chain to pet food manufacturing. The purpose of this thesis is to present a comprehensive analysis of animal-based protein supply for pet food industry. Specific objectives include: (i) compare growth rates of the supply for the animal-based protein and US produced pet food based on trends in animal slaughter for human consumption, (ii) mapping the supply chain and describing the flow of animal protein from the human food supply chain to use in pet food manufacturing, and (iii) highlight and discuss potential supply chain constraints and bottlenecks, as well as the areas of untapped potential and growth opportunities. The analysis

will include information on key players, ingredient types, available volumes, and transaction characteristics.

1.4 Overview of Methods

The supply chain research was primarily qualitative as it involved mapping and evaluating the supply chain for animal protein used in pet food. This analysis was achieved through a review of secondary data/information and discussions with subject matter experts to confirm and enhance the findings. There is also a quantitative aspect to look at the change in availability of animal protein volumes from the human supply chain to pet food over time and evaluate how changes in the volume of animals produced for human food will impact the supply of animal protein for pet food.

1.5 Overview of Key Results and Main Contributions

The new insights generated by this thesis will shed light on fast-evolving pet food supply chain and the flow of animal protein-based ingredients from the human food supply chain to the pet food industry. An extensive literature review has revealed that there is a significant gap in the agribusiness literature on the pet food industry in general and the pet food ingredient supply chain in particular. The results of this study will contribute to filling that gap in three ways: (i) the detailed supply chain analysis will provide a complete overview of pet food supply chain structure, main stages, and key players, (ii) the findings highlighting supply chain inefficiencies, major constraints, and key bottlenecks, as well as the untapped supply potential and opportunities for growth can be used to inform industry decisions on input procurement, product, and marketing strategies, (iii) the findings and propositions generated by this study will help highlight the gaps in the literature and the need for agribusiness research insights in pet food.

Chapter 2 - Background: Animal-Based Protein Ingredients

2.1 Forces Driving Demand for Animal-Based Protein

Animal-based protein has uses in many different industries. Much of the animal-based protein that isn't used for human consumption goes to rendering before being used in other industries. From rendering, animal protein is used in livestock feed, pet food, fertilizer and more. Since anywhere from one-third to one-half of animals produced are consumed by humans this creates a significant market for the byproducts (Meeker & Hamilton, 2006; NARA, n.d.).

Animal-based protein is growing in importance as its demand is increasing. As the population grows, there will be an increase in demand for food. By 2050, the population is expected to grow to 9.7 billion leading to a large increase in the demand for food (UN News, 2019). There will also be a rise in incomes in developing countries leading to a shift away from grain products towards animal protein (Hawkes, Harris, & Gillespie, 2017). These factors will contribute to an increase in demand for animal-based proteins. A comparison of the growth in population and the growth in animals (beef, pork, and chicken) produced for human consumption globally is displayed in **Figure 3** (United Nations, 2019; OECD, 2021). As animal protein production grows, this will increase the availability of animal protein for use in pet food.

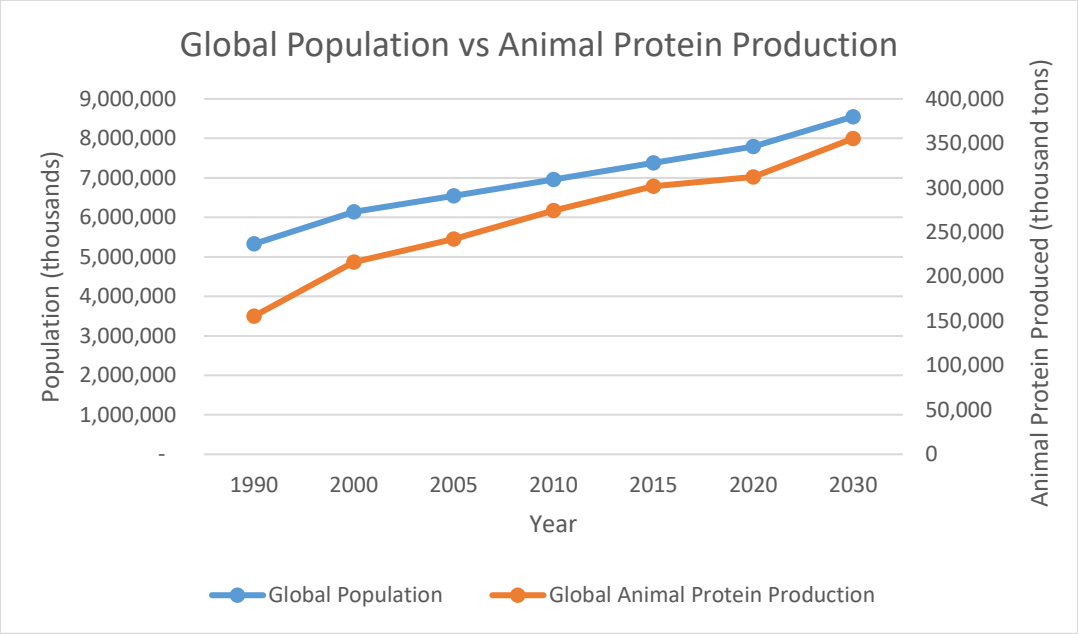


Figure 3. Change in Global Population vs Animal Protein Production, 1990-2030
Source: United Nations, 2019; OECD, 2021

The statement that the demand for animal-based protein ingredients for pet food is increasing is supported by the increase in pet food sales globally by volume and value over the past decade (Frimpong, 2021). As far as the composition of pet food goes, animal protein makes up a significant portion in both volume and value (DIS using Nielson, 2020). Although there is no data available on the change in average protein content in pet food over time, according to industry experts it has been increasing over time (Aldrich, 2022). This is important because as the demand for pet food continues to increase, there needs to be enough animal protein available for the ingredients to avoid the need to substitute to different ingredients. Therefore, it is necessary to identify whether the production of livestock is increasing at a rate fast enough to keep up with the growing need for animal protein-based ingredients for pet food.

2.2 Ways to Increase Animal-Based Protein Ingredient Supply

The two ways to increase the supply of animal-based protein ingredients used in pet food are to i) capture more from the existing supply sources or ii) switch to alternative sources of

protein. Challenges currently exist for both of these options. To date there is not a detailed supply chain illustrating how animal protein moves from the human food supply chain to use in pet food. This can cause inefficiencies and bottlenecks when those in the industry are only evaluating the steps they are involved in. Alternative sources of protein to animal-based are plant-based or novel proteins. A short-term problem with changing ingredients in pet food are the fact that pet food formulas are “fixed”. This means that ingredients cannot be exchanged without requiring a change to the label (Aldrich, 2021). Issues with switching to plant-based protein include the requirement of animal protein in cats’ diets for their health and consumer preferences for animal protein (Berry, 2019). The challenges associated with identifying and relying on novel protein sources for pet food production include inadequate or underdeveloped supply chains that pet food can fit alongside (Aldrich, 2018).

The challenge with increasing the availability of animal protein-based ingredients can be addressed by conducting a detailed supply chain analysis to provide a complete overview of the pet food supply chain structure, main stages, and key players. Understanding the supply chain will allow for an analysis of supply chain inefficiencies and untapped supply potential that would allow for growth. There are many different factors from the Covid-19 pandemic, pet food and animal protein slaughter growth rates, challenges with alternative protein sources that point to the importance of understanding the supply chain of animal protein-based pet food ingredients.

2.3 Additional Need for Pet Food Supply Chain Research

The pet food industry has not escaped the supply chain challenges caused by the Covid-19 pandemic disrupting businesses across many industries. Supply chain challenges involving ingredients, labor, and transportation have been key issues impacting the pet food industry. These issues will likely be exacerbated in 2022 by government mandates and tax incentives

involving renewable diesel production. According to Juan Gomez, global director for Alltech, "the pandemic has highlighted the fragility and vulnerabilities of the supply chain." In order to identify ways to overcome the challenges in the supply chain, a comprehensive understanding of the supply chain is required (Beaton, 2022).

Bryan Jaffe, managing director of Cascadia Capital, offered similar views on the pandemic highlighting supply chain issues, "what was once perceived to be transitory is looking increasingly systemic." The supply chain issues do not appear to be going away soon and require an evaluation throughout the entire system to identify solutions. Looking at animal protein, chicken has increased 87% in costs along with an increase in production labor costs of 3.4% per hour for the 12-month period ending August 2021 according to Jaffe. These cost increases were significant as chicken is the most common source of protein used in pet food. Consumers are going to feel the effects of these cost increases as 82% of companies surveyed by Cascadia said they will be passing the increases on to consumers. Although there are continued growth projections for pet food, supply chain issues could affect the ability to meet this growth (Phillips-Donaldson, 2021).

The supply challenges seen during the Covid-19 pandemic highlight the importance of understanding how animal-protein moves through the supply chain from production for human food to use in pet food and other co-product uses. Having a full picture of the supply chain will provide the information necessary to help manufacturers rebuild a more resilient supply chain regarding where and how they are sourcing their animal-protein ingredients.

Chapter 3 - Literature Review

3.1 Academic Literature

A thorough review of academic literature in agribusiness and agricultural economics journals shows a gap in the literature covering animal-based protein used in pet food. The American Journal of Agricultural Economics (AJAE), Applied Economics Perspectives and Policy (AEPP), Journal of Agricultural Economics (JAE), Agribusiness, and International Food and Agribusiness Management Review (IFAMR) journals were evaluated by searching each journal from 2000 to 2021 for keywords, such as pet, pet food, animal protein, and animal byproducts.

There is some literature available that covers the fact that byproducts from human food production are being used in pet food (Reithmayer et. al, 2020; Mathews & McConnell, 2012). Martinez-Garmenda & Anderson (2005) and ShalekBriski et al (2020) give examples of less common animal protein ingredients being used in pet food, such as tuna and kangaroo. However, these articles do not go into detail on the supply chain transactions involved with this movement of ingredients. Kimle (2010) provides some insight into the transaction costs involved between one pet food manufacturer and their ingredient supplier, but outside of this article, the literature available on transaction characteristics between ingredient suppliers and pet food manufacturers is very limited.

There are a few published papers that cover information on the volumes of ingredients being used in pet food. For example, Bernstein & Skully (2003) mentioned that 5% of beef offal imports go into pet food production in the EU. Mathews & McConnell (2012) estimated that 25% of meat and bone meal was used for pet food in 2000.

There was mention of pet food in a handful of articles, however, none of these articles were focused on pet food or animal-based protein used in pet food. For example, Houser, et al (2018) and Henson & Mazzocchi (2002) looked at pet food in relation to BSE. Overall, the academic literature in agribusiness and agricultural economics does not currently provide insights into how animal protein moves through the supply chain into pet food use.

It is understandable that the literature on animal protein in pet food is currently lacking in agribusiness and agricultural economics journals, as pet food has likely been considered a topic related to the animal science and nutrition field or is considered an unimportant discretionary market without factoring its contribution to the economy.

3.2 Disciplinary Literature

Next, journals focused on companion animal nutrition and health discipline were evaluated for information on how animal protein is sourced for pet food. Journals used include the Journal of Animal Physiology and Animal Nutrition, Journal of Animal Science, Veterinary Clinics of North America: Small Animal Practice, Food Safety Management, Advances in Nutrition, Global Environmental Change, Annual Review of Animal Biosciences, and Waste Management.

There were a few papers in this sector that briefly covered the idea that pet food is using the same ingredient streams as the human food supply and provided simplified overviews of the pet food ingredient supply chain (Acuff, et al, 2021; Carrion & Thompson, 2014; Swanson, 2013). However, these were very general evaluations of animal protein going from human food into pet food. These articles do not go into detail regarding the specific players, ingredient processing, and interactions involved in the movement of animal protein from the human supply chain into pet food. The IBIS World has a report on the pet food production that provides a good

overview of the supply chain and players involved. However, this report only provides generalized information on ingredients and does not go into the specific steps involved in moving animal protein from human food to use in pet food (Diment, a2021).

Instead, these journals primarily focus on scientific aspects of animal protein-based pet food ingredients, such as how processing effects animal proteins (Chang, 2014; Perez-Calvo, 2010; Spitze, 2003), quality of different animal protein ingredients in pet food (Tjernsbekk, 2017; Hervera, 2009), and animal protein in pet food's impact on the environment (Acuff et al, 2021; Kim, et al, 2019; Alexander et al, 2020; Mosna et al, 2021). This leaves a gap in the literature evaluating how animal protein ingredients move through the supply chain.

3.3 Non-Academic Literature

Nonacademic literature, such as industry and company websites, provides a large and well-established source of information on pet food and the animal-based protein being used. The three main segments of information in this literature evaluate pet food formulation (AAFCO, n.d., Aldrich, 2006), consumer trends (Avis, 2020; Wethal, 2021; Wall, a2021; Wall, a2018; Martin, 2019), and players in pet food manufacturing (WATT Global Media, a n.d.; WATT Global Media, b n.d.; Pet Food Institute; 2020; NARA, 2021). However, this literature is missing information on the supply chain of pet food ingredients, such as the interaction between major players, how the ingredients move through each stage of production, the volumes of ingredients used, and the market structure of each supply chain sector.

3.4 Literature Gap

There is an abundance of literature available through academic and nonacademic sources that covers information on the animal protein ingredients that make up pet food and their scientific properties, pet food trends, and players involved in pet food production. However,

there is a gap in the literature pertaining to the flow of animal protein through the supply chain, their volumes at each stage, and details on the interactions between players.

As the pet food industry and need for ingredients are rapidly growing, this leads to an increased need for this gap in literature to be filled. For decision makers in the pet food industry to make informed decisions on the ingredients used and their procurement, information on the overall flow of pet food ingredients through the supply chain is a necessity.

Chapter 4 - Methodology

4.1 Quantitative Methods

4.1.1 Animal-Based Protein Ingredient Availability Analysis

Goal: To determine if animal protein production is growing at a rate fast enough to meet the growing needs animal-based protein in pet food.

Data Needed: The data needed includes the growth rate of animal-based protein needed for pet food and growth rate of animal protein sources for pet food. These exact measurements are not currently available, so reasonable proxies will be used. The change in volume of pet food produced in the US will be used in place of the growth rate of animal protein needed for pet food, assuming that the proportion of animal protein as a proportion of total protein in pet food will remain stable over time and volume increase. Live slaughter weight data from USDA will be used to estimate the growth rate of animal protein available for use in pet food.

Proxy for change in volume of pet food produced in the US

Goal: There is clear evidence that the value of pet food sales is increasing in the US. A corresponding question is how the volume of pet food produced in the US has changed over time. This is important because the volume of ingredients is what is driving the volume of ingredients needed to produce pet food.

Data Needed: There is no data readily available regarding the annual volume of pet food produced in the US, so it must be estimated.

Data Used: There is information available on US dollar sales of pet food, US pet food import values, units of pet food sold in the US, and price per unit of pet food. This information can be used to estimate how many units of pet food have been produced annually in the US. There is

also no specification on what a unit of pet food is, but for the purposes of this thesis it is good enough to illustrate the change in pet food volume assuming a unit remains constant over time.

Calculations:

1) Estimate the value of pet food sold in the US that was produced in the US.

$$US\ produced\ pet\ food\ value = US\ pet\ food\ sales - US\ pet\ food\ imports\ value$$

2) Estimate missing values on price per unit of pet food for 1997-2012 using the average annual inflation rate of pet food of 2%.

$$price\ per\ unit\ Year_{i-1} = price\ per\ unit\ Year_i * 0.98$$

3) Estimate the units of US produced pet food sold each year.

$$Year_i\ US\ produced\ pet\ food\ units\ sold\ = \frac{Year_i\ US\ produced\ pet\ food\ sales}{Year_i\ price\ per\ unit\ of\ pet\ food}$$

4) Estimate the growth rate of US produced pet food indexed to 2001.

$$\frac{Year_i\ US\ produced\ pet\ food\ units\ sold}{2001\ US\ produced\ pet\ food\ units\ sold} * 100$$

Proxy for change in animal protein available for use in pet food

Goal: Illustrate the growth rate of livestock slaughtered for human consumption in the US. This is important because pet food derives their animal protein ingredients from the livestock for human food supply chain. Therefore, the growth rate of livestock slaughtered for human consumption shows the growth of animal protein available for use in pet food.

Data Needed: The data needed for this analysis includes annual live weight of cattle, hogs, chickens, and turkeys slaughtered in the US. These four species were chosen because they constitute the majority of animal protein found in pet food.

Data Used: Data is available on the annual live weight slaughter of all four species from the USDA for 2001 to 2020.

Calculations:

1) Estimate the annual growth rate of animal protein slaughter indexed to 2001.

$$\frac{Year_i\ live\ weight}{2001\ live\ weight} * 100$$

4.2 Qualitative Methods

4.2.1 Supply Chain Mapping Analysis

Mapping the supply chain of animal protein in pet food is essential to understanding how animal protein flows from human food to its use in pet food. The supply chain has been mapped using secondary and primary insights.

First, an understanding of the supply chain steps of animal protein for human use was gathered by conducting secondary research online in consultation with subject matter experts to verify the information found. Next, a list of the different byproducts generated from each stage of animal protein production was compiled through secondary research online.

With the animal protein for human use section of the supply chain mapped out, it had to be determined where the byproducts from human food production went next. Petfoodindustry.com provides a list of pet food ingredient suppliers. The suppliers were sorted to only look at those who handle animal protein. These suppliers were evaluated for what specific ingredients they produced/sold by visiting each suppliers' website. Then, the activities by each ingredient supplier were grouped into "like" categories for simplicity when creating the supply chain graphic. After grouping the ingredient suppliers into categories, a list of pet food ingredients generated by each category was created. Finally, subject matter experts were consulted to gain a better understanding of the different intermediary processing activities of pet food ingredients and verify that no details were missed.

The final product from using these methods is a comprehensive supply chain graphic on how animal protein pet food ingredients flow from the human food supply chain into pet food use.

Chapter 5 - Data

5.1 Qualitative Data

The qualitative data needed to conduct the supply chain research included the types of animal protein ingredients used in pet food, the companies involved in pet food ingredient manufacturing, the activities involved in pet food ingredient production, interaction between supply chain members, and ingredient types produced by each supply chain member.

Information on the types of animal protein used in pet food is available from a variety of sources including previous studies and AAFCO. The companies involved in pet food manufacturing such as ingredient suppliers and manufacturers are available from petfoodindustry.com. Finding the interaction between supply chain members is not readily available and required discussions with subject matter experts. The types of ingredients produced by different supply chain members were available on company websites.

5.2 Quantitative Data

The quantitative data needed to conduct this research included information on the change in the quantity of animals produced for human consumption over time, proportion of animals produced for human use that end up in pet food, the number/size of companies in each activity of the supply chain, and volumes of ingredients produced by each supply chain activity. Some of this information is not readily available and must be estimated.

Data on the number of animals produced each year are available through the USDA. There is no information readily available on the proportion of animals that end up in pet food. However, this number can be estimated by species using dressing percentages and volume of live weight of animals produced. The number and size of some companies are available through petfoodindustry.com and other market analyses such as IBISWorld. Decision Innovation

Solutions (DIS) using Nielsen (2020) provides some of the most detailed information available on the composition of pet food sold in the US by the volume of ingredients across the overall industry.

Chapter 6 - Analysis

6.1 Objective One: Animal-Based Protein Ingredient Availability Analysis

6.1.1 Change in Pet Food Produced in the US

The increased need for pet food is supported by the increase in pet food sold by both volume and value. In the US, expenditure on pet food and treats has increased 122% from 2011 to 2021 (Bedford using US APPA, 2021). The growth in pet food produced in the US can be seen by looking at the increase in the number of units of pet food produced in the US from 495.78 million in 2001 to 830.24 million units in 2019 displayed in **Figure 4**. Based on the source used for the average price per unit of pet food, one unit of pet food is equal to one kilogram of pet food (Gibbons using US BLS, 2021; The Observatory of Economic Complexity (OEC), n.d.; Statista, n.d., US BLS, n.d.). A similar trend can be seen globally with a 61.6% increase in dollar sales of pet food and a 45.1% increase in volume sold from 2012 to 2020 (Frimpong, 2021). This growth is fueled by increased pet ownership and humanization trends (e.g. pet is treated as a member of a family) and is expected to continue into the future (Frimpong, 2021).

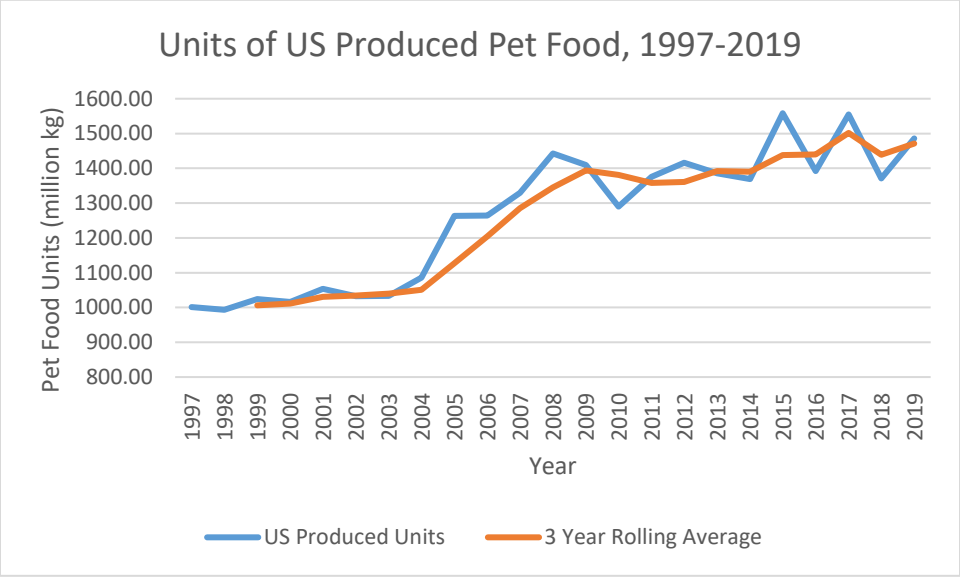


Figure 4. Change in Pet Food Units Produced in the US, 1997-2019

Source: Gibbons using US BLS (2021); The Observatory of Economic Complexity (OEC) (n.d.); Statista, (n.d.); US BLS, (n.d.)

Now that it can be seen how the volume of pet food produced is changing over time and the importance that animal protein-based ingredients play in pet food, it makes sense to look at how the availability of animal protein for pet food is going to change over time. In order to meet this increasing demand for pet food, the availability of pet food ingredients will have to increase (Million Insights, 2020). According to data from DIS using Nielsen (2020), animal-based protein ingredients made up 38% of the ingredients used in US pet food from the 52-week period before June 2019 by volume and 52% of the ingredients by value. This shows that animal protein-based ingredients make up a significant component of pet food that will need to increase in availability in order to keep up with the growing need for ingredients driven by an increase in units of pet food produced.

6.1.2 Factors Affecting Supply of Animal Protein

The supply of animal-based protein in pet food is predominantly derived from animal slaughter for human consumption. Historical data on animal slaughter in the US can be found from the USDA. Live weight at slaughter was the variable chosen to evaluate because the ingredients derived from animal slaughter are typically the parts not used for human consumption (the parts of the animal not included in the dressing percentage). The change in total live weight slaughtered for commercial cattle, commercial hogs, chickens, and turkeys is shown in **Figure 5**. These species were chosen as they are the main sources of animal proteins used in pet food (DIS using Nielsen, 2020). Commercial cattle and hogs were chosen because they make up over 90% of cattle and hogs slaughtered (USDA NASS, 2021c).

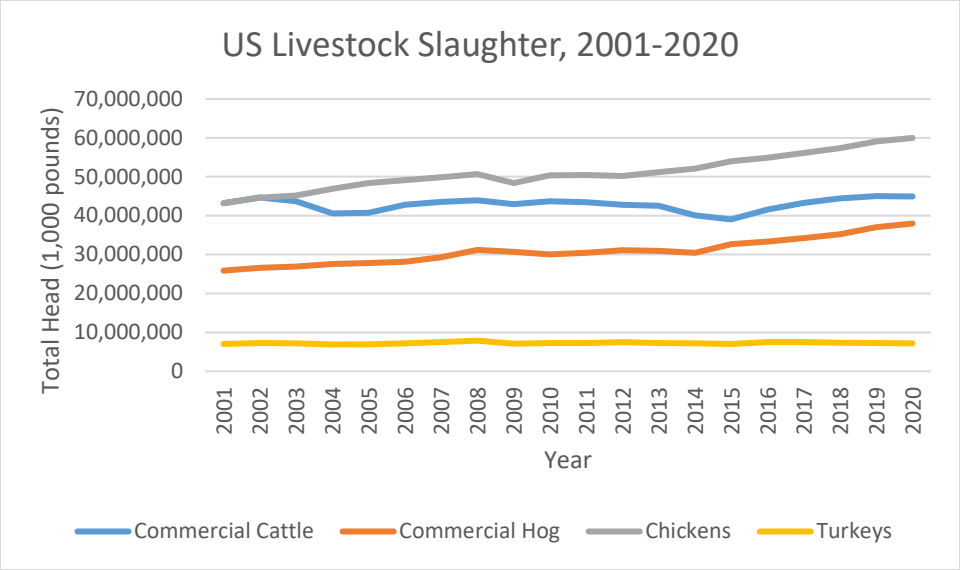


Figure 5. Livestock Slaughtered by Live Weight in the US, 2001-2020

Source: USDA NASS, 2002-2021

6.1.3 Comparison of Animal Protein Availability and Pet Food Growth

A comparison of the growth rates of US pet food production and US animal slaughter for human consumption can be done to determine if animal protein availability is growing fast enough to keep up with the growth in pet food. The units of pet food produced in the US have been growing at a faster rate than animals slaughtered for human consumption as seen in **Figure 6**. This is significant because if these growth rates continue there will be a point where there are no longer enough animal protein-based ingredients available to meet the needs of pet food production.

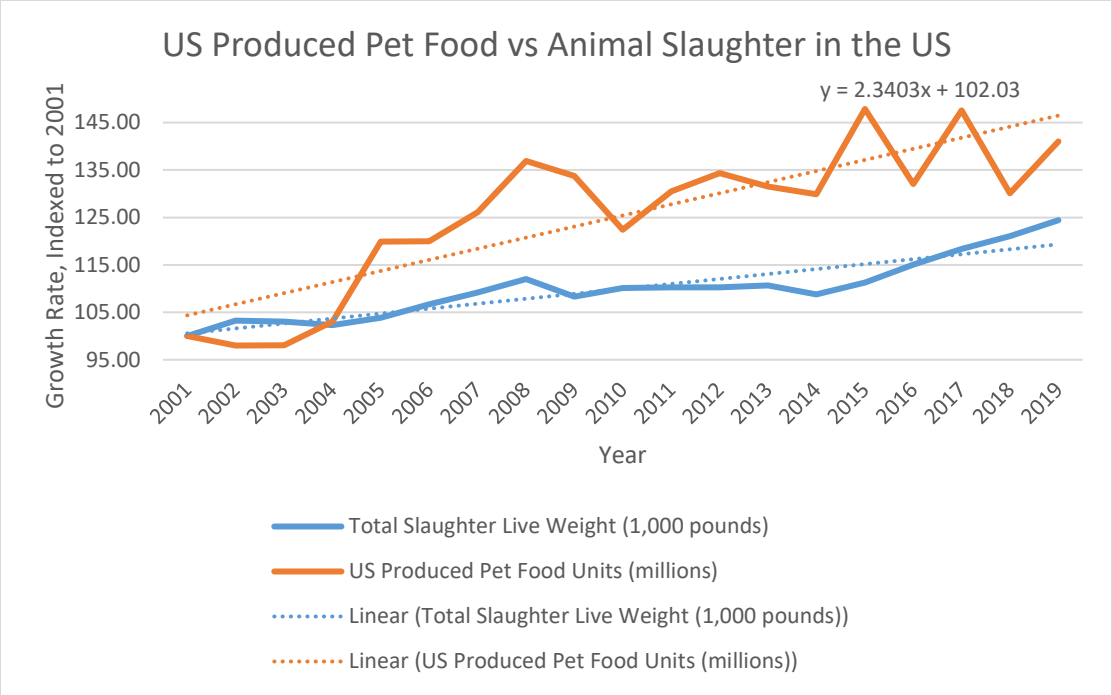


Figure 6. US Animal Pet Food Produced vs US Animal Slaughter

Source: *Gibbons using US BLS (2021); The Observatory of Economic Complexity (OEC) (n.d.); Statista, (n.d.); US BLS, (n.d.); USDA NASS, 2002-2020*

Now that we can see that the availability of animal protein for pet food is not growing at a fast enough rate to keep up with the growth in pet food; it is important to understand the supply chain currently being used. If a better understanding of the supply chain can uncover ways to use the current sources of animal protein more efficiently, this can alleviate future strain without forcing manufacturers to switch to alternative sources of proteins with unestablished supply chains.

6.2 Objective Two: Supply Chain Mapping Analysis

The supply chain for animal protein used in pet food is derived from the human food supply chain including animal production, slaughter, processing, packaging, and retailers. Byproducts are generated at each step of the human food supply chain and then flow to pet food ingredient processing steps including rendering, upcycling, meat handling, or further processing.

The finished pet food ingredients generated by these processors can then be sold to pet food manufacturers either directly or through brokers. A map of the supply chain of animal protein used in pet food is displayed in **Figure 7**. This section of the thesis evaluates each supply chain function.

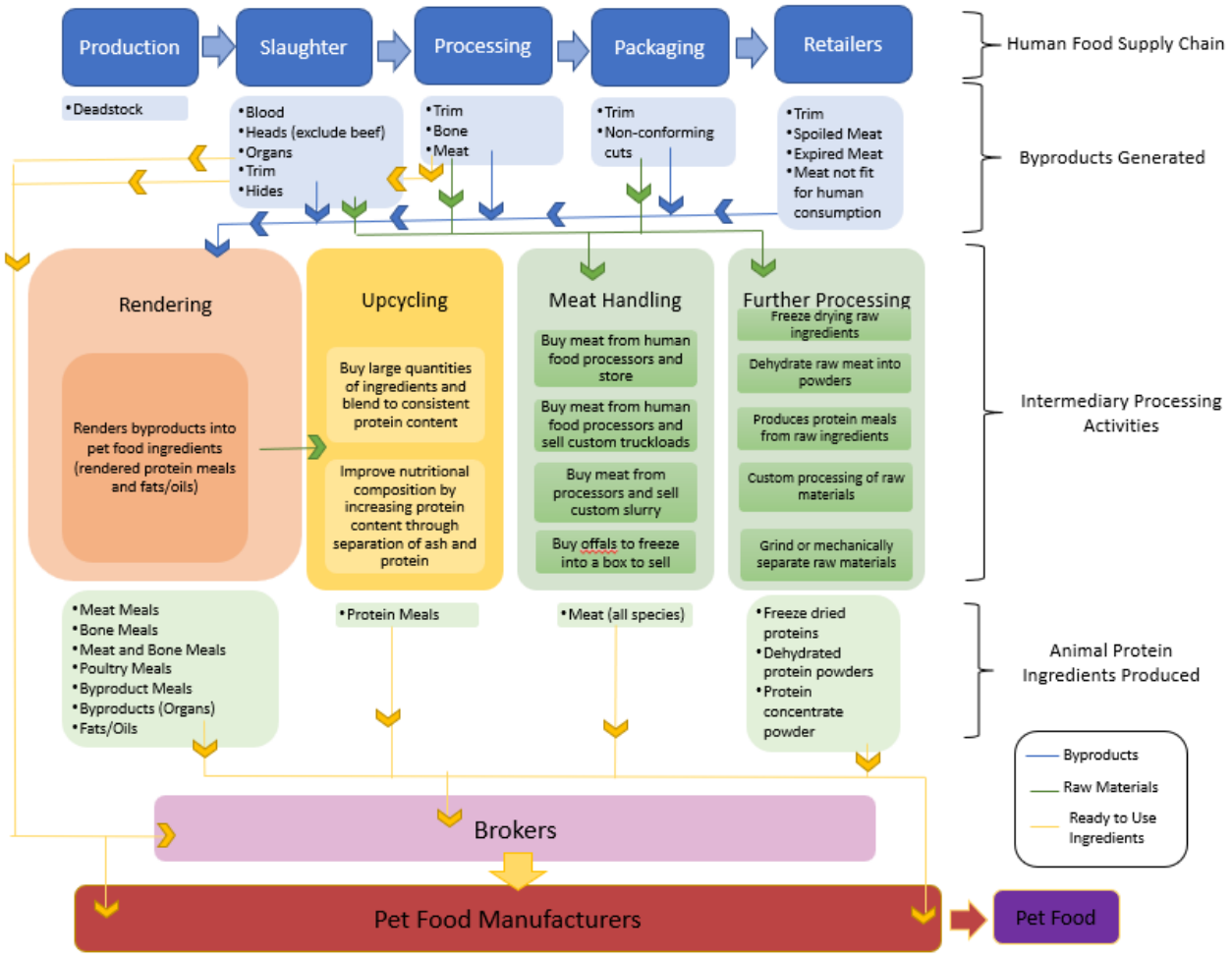


Figure 7. Flow of Animal-Based Protein Pet Food Ingredients from the Human Food Supply Chain to Pet Food

6.2.1 Animal Production

The process of producing animal protein for human consumption begins with animal production at the farms that raise animals for slaughter. The animal production sector can be broken into groups by species. This thesis will focus on cattle, hogs, chickens, and turkeys

because those are the most common species used in pet food products (Association of American Feed Control Officials (AAFCO), n.d.; DIS using Nielsen, 2020). Trends in animal production are important to understand because the number of animals produced determines the amount of animal protein that can be produced and available for slaughter.

Cattle

Looking at annual cattle inventory, the number of cattle and calves in the US has declined by 16.438 million head (-14.78%) between 1980 and 2019 (USDA NASS, 2020a). Beef cattle production has followed a similar trend, decreasing by 5.417 million head (-14.6%) between 1980 and 2019 (USDA NASS, 2020a). Although the number of cattle produced has decreased over time, the average weight/cow has also been increasing meaning that fewer cows today can produce the same amount of meat as more cows in the past (Hamilton, 2011). In 2020, there was an estimated 94.413 million head of cattle and calves in inventory with an estimated 31.31 million head being beef cows in the United States (USDA NASS, 2020a). Beef production is expected to decrease 2% in 2022 due to droughts and high feed cost (USDA ERS, 2021). The change in annual cattle and calves inventory vs beef cow inventory from 1980 to 2019 is presented in **Figure 8**.

Hogs

Market hog inventory has gone through periods of increase and decline since 1980, but overall has grown by 17,232.5 thousand head (+31.14%) between 1980 and 2019 (USDA NASS, 2020a). In 2019, there was an estimated 77,337 thousand total hogs and pigs in inventory, out of which 70,876 were market hogs and pigs (USDA NASS, 2020a). Pork production is expected to increase 1.3% in 2022 to meet consumer demand (USDA ERS, 2021). The change in annual market hog inventory from 1980 to 2019 is shown in **Figure 8**.

Chickens

Broiler production has increased steadily since 1980, with an increase of 5,075,089 thousand head (+128.05%) between 1980 and 2018 (USDA NASS, 2020a). In 2019, there was an estimated 9,177,200 thousand head of broilers produced in the US (USDA NASS, 2020a). The change in annual broiler production between 1980 and 2018 is displayed in **Figure 8**.

Turkeys

Turkey production has also been following an increasing production trend with an increase of 72,757 thousand head (+44.03%) between 1980 and 2018 (USDA NASS, 2020a). In 2019, there was an estimated 229,000 thousand head of turkeys produced in the US (USDA NASS, 2020a). Annual turkey production between 1980 and 2018 is shown in **Figure 8**. Both broiler (+0.9%) and turkey production (+0.6%) are expected to increase in 2022. This is likely driven by increased consumer demand (USDA ERS, 2021).

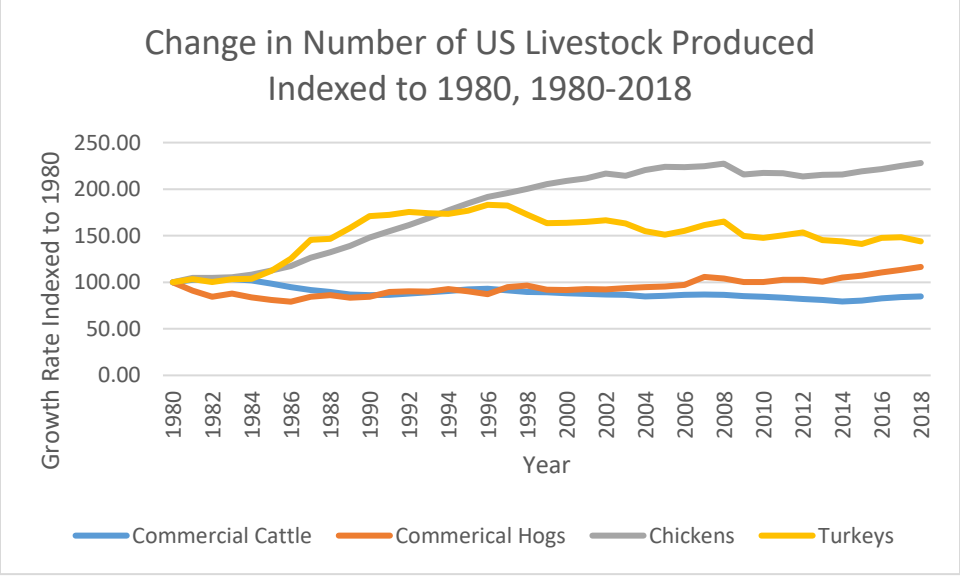


Figure 8. US Livestock Production, 1980-2018

Source: USDA NASS, 1981-2019

Beef cattle production takes place in multiple steps including cow/calf operations, stocker/backgrounders, and feedlots. Out of the total 882,692 cattle and calf operations in the United States, 802,317 are considered cow/calf, stocker/backgrounder farms or ranches, 28,180 are feedlots, and 54,599 are dairy herds (National Cattlemen's Beef Association (NCBA), n.d.). According to the 2012 Census of Agriculture, there were 21,687 farms with primary production in hog and pig production. A majority of farms were family/individuals (83%), followed by corporation (8%), partnership (7%), and other (2%) (USDA NASS, 2014). According to the 2017 Census of Agriculture, there were 164,099 poultry farms in the US. (USDA NASS, 2020b). There were an estimated 2,500 farms producing turkeys in the US in 2020 (National Turkey Federation, n.d.). The animal production sector is a low concentrated industry because it has no large market leaders, instead production is spread across many companies.

6.2.2 Slaughter

The next stage in the production of animal protein is the slaughtering of the animals produced in the first stage. Looking at the trends in animals slaughtered is important because it provides an idea of how many animals are being slaughtered annually for human consumption. This is important in regard to animal protein for pet food because it is unlikely that more animals will be produced solely for use in pet food. Therefore, the animal protein available for pet food is dependent on the livestock produced for human consumption.

The FSIS requires federal inspection of slaughterers unless the business qualifies for an exemption. Slaughterers are exempt if they are slaughtering livestock for personal use or providing custom slaughtering. Custom slaughtering exemptions are allowed if the products from the livestock are returned to the livestock owner for personal use, so the slaughterer processes the livestock and returns the finished products to the owner (USDA FSIS, 2018). This report will

focus primarily on federally inspected businesses as they slaughtered 98.1% of cattle, 97.9% of calves, and 99.4% of hogs in 2020 (USDA NASS, 2021c).

Cattle

In 2020, there were a total of 32,886.3 thousand head of cattle slaughtered, a decrease of 2.29% from 2019. Out of the cattle slaughtered in 2020, 32,785.7 thousand head (99.67%) were commercially slaughtered, and 100.6 thousand head (0.03%) were slaughtered on farms (USDA NASS, 2021c). The total head of commercial cattle slaughtered annually from 2001-2020 is displayed in **Figure 9.**

Hogs

In 2020, there were a total of 131,639 thousand head of hogs slaughtered, which equals a 1.27% increase from 2019. Out of the hogs slaughtered in 2020, 131,563 thousand head (99.94%) were commercially slaughtered, and 76 thousand head (0.06%) were slaughtered on farms (USDA NASS, 2021c). The total head of hogs slaughtered annually from 2001 to 2020 is displayed in **Figure 9**.

Chickens

There was a total of 9,346,660 thousand head of federally inspected chickens slaughtered in 2020, which is a 0.08% increase from 2019. Chickens are stratified into young and mature categories with young chicken making up 9,229,801 thousand head (98.75%) and mature chicken making up 116,859 thousand head (1.25%) of the chickens slaughtered in 2020 (USDA NASS, 2021d). The annual slaughter of chickens from 2001 to 2020 is shown in **Figure 9**.

Turkeys

There were 223,003 thousand head of federally inspected turkeys slaughtered in 2020, which was a 2.05% decrease from 2019. Turkeys are broken down into young and old categories

with young turkeys making up 221,323 thousand hand (99.25%) and old turkeys making up 1,680 thousand head (0.75%) (USDA NASS, 2021d). The annual slaughter of turkeys from 2001 to 2020 is shown in **Figure 9**.

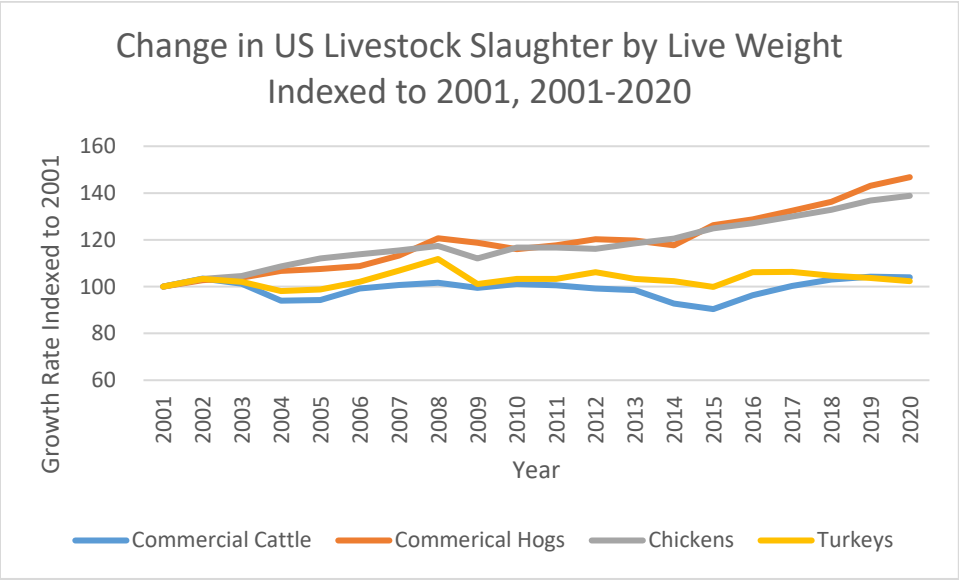


Figure 9. US Livestock Slaughter, 2001-2020

Source: USDA NASS, 2001-2020

In 2021, there were 858 slaughter plants under federal inspection. This is a 2.75% increase from the 835 federally inspected slaughter plants in 2020. There were also 1,917 slaughter plants not under federal inspection bringing the total slaughter plants to 2,775 (USDA NASS, 2021c). There were 683 federally inspected plants slaughtering cattle in 2020. Out of these plants, 13 accounted for 54% of the total cattle slaughtered (USDA NASS, 2021c). There were 621 federally inspected plant slaughtering hogs in 2020. Out of these plants, 14 accounted for 58% of the total hogs slaughtered (USDA NASS, 2021c). In 2019, there was an estimated 370 federally inspected plants slaughtering poultry in the US (USDA NASS, 2021d). Although there are a large number of slaughter plants, a small number are responsible for a significant percentage of slaughter.

Although the number of animals slaughtered in the US is increasing, we know from Section 6.1 that it is not growing at a fast enough rate to keep up with pet food. Using average dressing percentages, the volume of animal protein available for use in pet food can be estimated. This would be the maximum animal protein available, not what is actually being used. It would also be an overestimate since the byproducts from slaughter have uses in other industries, are not 100% protein, there are also bones, fats, etc., and lose weight during processing. The change in estimated volumes available are displayed in **Figure 10**.

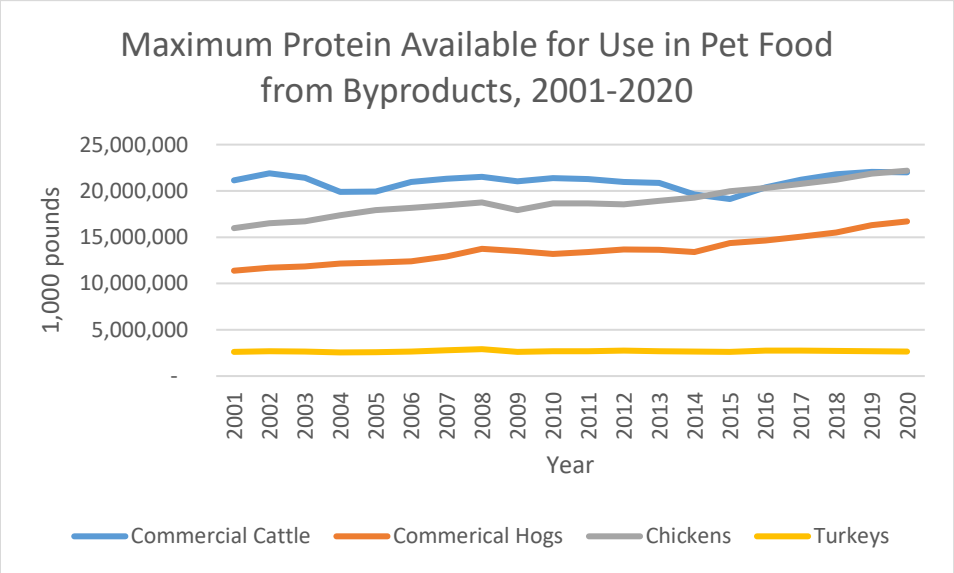


Figure 10. Estimated Protein Available for Use in Pet Food, 2001-2020

Source: USDA NASS, 2002-2021; Tyler 2021

6.2.3 Processing

According to IBISWorld, the meat and poultry processing industry involves slaughtering, processing, and rendering (Schulman, 2021). This is likely because these functions are closely related and often done by the same companies. However, for the purposes of this report these functions are divided because different products and byproduct ingredients used in pet food come from each activity. For this report, meat and poultry processing is considered breaking down the primals and subprimals into cuts for retail sale.

The change in processed meat ready for human consumption shows similar trends to animal slaughter. This can be seen by comparing the meat produced from each species annually as seen in **Figure 11.**

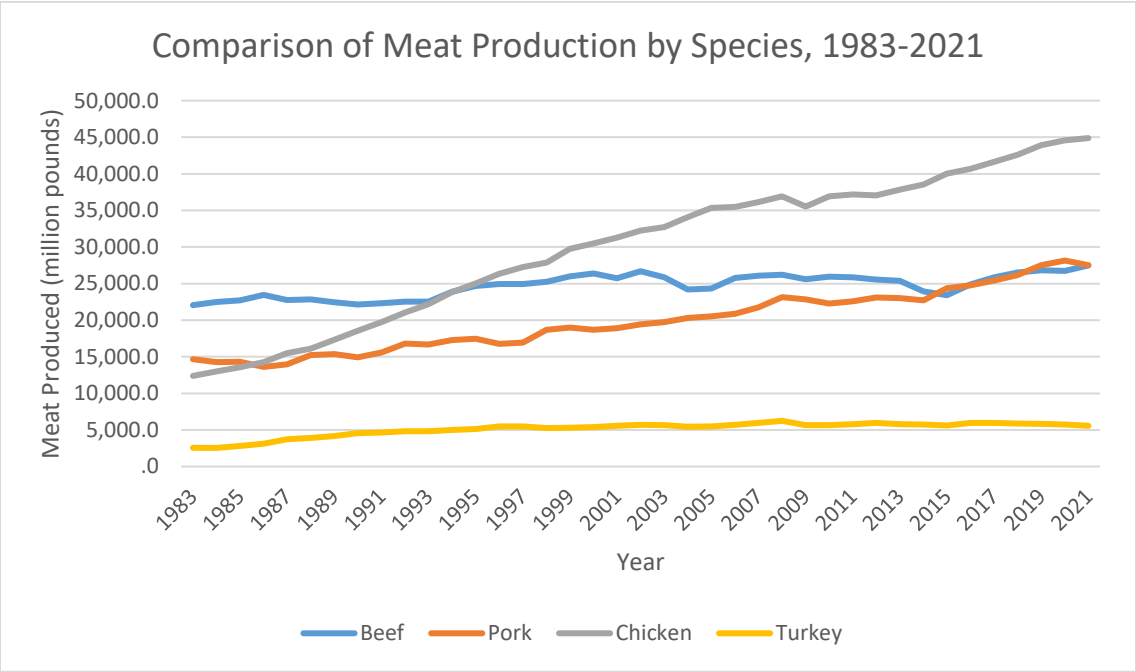


Figure 11. Comparison of Meat Produced by Species, 1983-2021

Source: USDA ERS, 2022

There are approximately 5,486 companies involved in meat processing in the US. Despite the large number of companies, four companies make up approximately 52% of the market share by revenue. The four major meat processing companies are JBS USA Holdings Inc., Tyson Foods Inc., Cargill Incorporated, and Smithfield Foods Inc. The market share for each major company is displayed in **Figure 12.** JBS USA is involved in beef, pork, sheep, and lamb processing. Tyson has four segments, including chicken, beef, pork, and prepared foods. Tyson is very vertically integrated in their chicken segment with involvement from breeding all the way to food production, marketing, and transportation. Cargill processes cattle and poultry. They are

no longer involved in pork because they sold that business segment to JBS USA. In addition, Smithfield is a very large player in pork processing (Schulman, 2021).

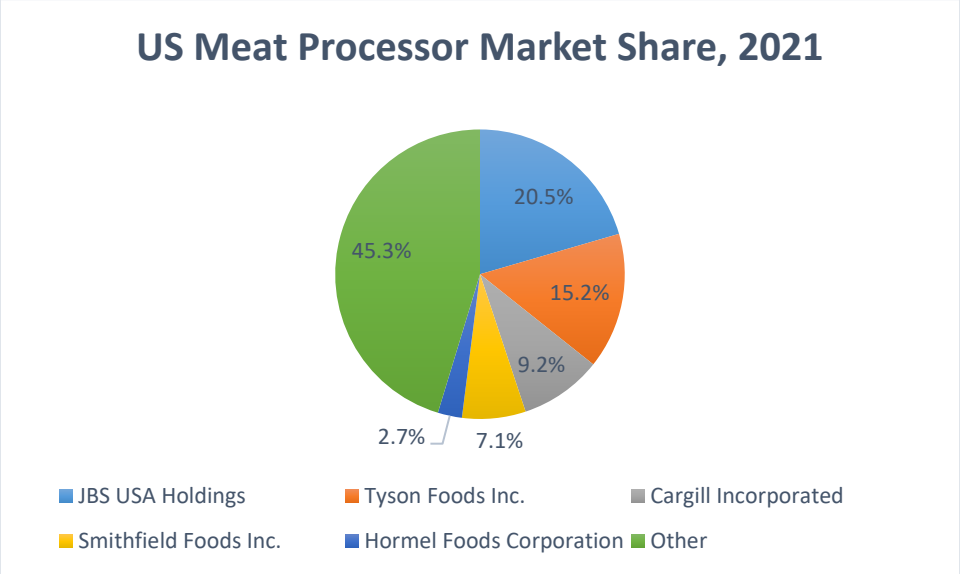


Figure 12. Meat Processor Market Concentration, 2021

Source: Schulman, 2021

6.2.4 Rendering

Rendering is the process of recycling the parts of the animal not consumed by humans, such as blood, fat, and byproducts into products used in other industries such as biofuels, pet food, livestock feed, and aquaculture feed. There are two kinds of rendering businesses, integrated and independent. Integrated rendering plants are meat processing companies that have their own rendering facilities to process the byproducts generated. Independent renderers are those that collect and process byproducts from many sources, rather than being owned by a meat processing company (Jekanowski, 2011). Annually, there are approximately 16 million tons of rendered products produced annually in the US and Canada (NARA, n.d.). Out of animals produced for human consumption, approximately 49% of raw materials from cattle, 37% from

poultry, and 44% from swine are not used in human consumption. Rendering provides the opportunity for these materials to be used elsewhere (Tyler, 2021).

Ansen Pond, Ph.D., head of food safety, quality and regulatory for Pilgrims/JBS USA provided some information on the quantity of rendered ingredients being used in pet food. There are 8.9 million tons of rendered protein meals produced annually in the US. Out of this, 1.5 million tons of rendered protein meals, or 16.85%, were used in pet food. Looking at meat, poultry, and organ byproducts, there were 1.83 million tons used in pet food directly from slaughtering (Tyler, 2021). According to Informa Economics (2011) out of the rendered ingredients produced in the US and Canada, 31% of rendered proteins and 15% of rendered fats that are produced were used in pet food (Meeker & Meisinger, 2015). The volume of raw materials available for rendering varies based on the volume of livestock and poultry slaughtered annually (Jekanowski, 2011).

The main products produced through rendering are fats and proteins. Meat and bone meal (MBM) is the top protein product from rendering, however its value and use changes based on the raw material from which it is made. For example, ruminant meat and bone meal cannot be used back into ruminant feed. The common uses of rendered protein produced include livestock, poultry, and aquaculture feed, and pet food. Poultry feed uses 39% of the rendered protein produced followed by pet food at 31%. Pet food is the largest user of poultry by-product meal and non-ruminant mammalian MBM, however pet food does not use blood meal. Cattle feed is the largest user of blood meal but overall, only uses a small share from total rendered proteins produced. Cattle feed also uses a significant volume of feather meal (Jekanowski, 2011).

There are approximately 300 rendering plants in North America, with 156 plants being active members of the NARA in 2021 (Meeker & Hamilton, 2006; NARA, 2021). Integrated

renderers process approximately 48% of the raw materials. These raw materials come from the meat processing companies they are affiliated with. Independent renderers process the other 52% of raw materials. The raw materials processed by independent renderers include restaurant grease (10%), grocery/butcher scraps (7%), and slaughter byproducts (83%) (Jekanowski, 2011).

According to IBISWorld, the two main rendering companies in the US are Darling International Inc., and Tyson Foods Inc. holding 47.3% and 46.5% market share respectively. Tyson's market share was increased through the acquisition of American Proteins Inc. in 2018. Baker Commodities Inc. is another renderer holding 1.9% of the market share (Diment, b2021). The market share for each major player is displayed in **Figure 13**.

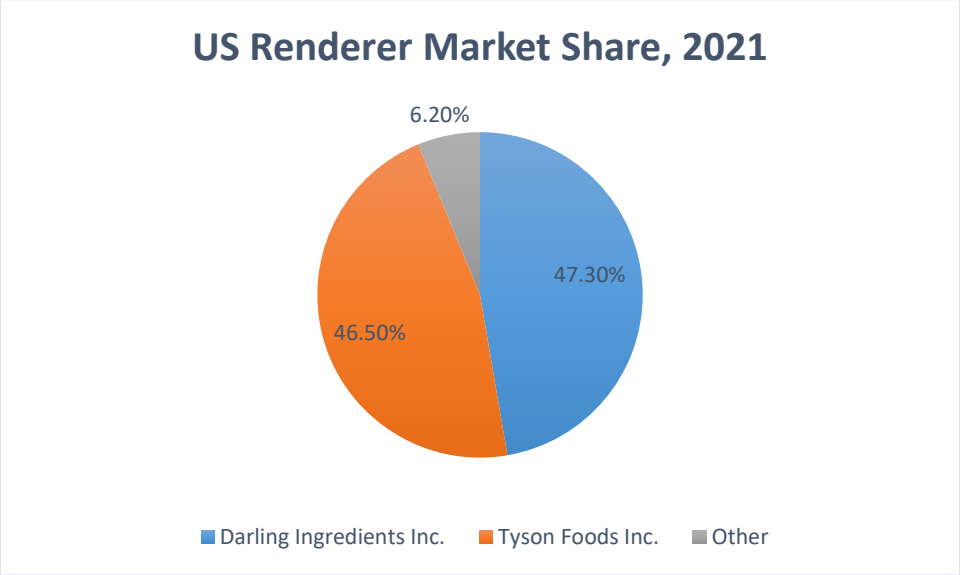


Figure 13. Renderer Market Concentration, 2021
Source: Diment, b2021

Although IBISWorld reported two rendering companies holding over 90% of the market share for rendering, further research and consultation with industry members indicates this is likely not the case. According to Jekanowski, 2011, independent renderers process approximately 48% of rendered material. This category would include Tyson Foods Inc. which

according to IBISWorld has 46.5% market share. It is unlikely that the other independent renderers process less than 3% of the leftover market share. To demonstrate this, Cargill and JBS are both large meat processing company that have integrated rendering plants according to the NARA 2021 membership list. Collectively, JBS and Cargill have a higher market share in meat processing, so it is unlikely that Tyson's market share in rendering is 15 times larger than Cargill and JBS's combined market share.

6.2.5 Upcycling

Upcycling involves taking the protein meals created during rendering and increasing their value through additional processing. This processing includes buying large quantities of rendered protein and blending it to a consistent protein content or improving the nutritional composition of the protein meal by separating the ash from protein. The ingredients generated from upcycling are higher value protein meals than those generated from renderers. (Aldrich, 2021).

Wilbur Ellis is an example of a company that provides ingredient grinding, screening and blending to add value to protein meals (Wilbur-Ellis, n.d.). Northland Choice offers custom blending of ingredients to meet needs such as increased protein content (Northland Choice, n.d.).

6.2.6 Meat-Handling

Meat handlers are companies that buy, store, or minimally process meat. For example, some companies simply buy meat directly from human food processors and store it before selling. Others will buy meat from human food processors to sell custom truckloads. Other companies will do something similar but with a meat slurry. Finally, some companies will buy offals from human food processors to box and sell to pet food manufacturers. The ingredients generated from meat handling include a variety of frozen meat and meat slurry (Aldrich, 2021).

IQI Trusted is an example of a company involved in meat handling. This company imports protein that isn't found in the US and minimally processes them through repackaging and adding antioxidants (Industry Stakeholder, 2022). Ingredients Online takes possession of ingredients, places them in storage, and facilitates sales to pet food manufacturers (Industry Stakeholder, 2022). Omaha Cold Storage is another company that buys and stores meat before reselling (Aldrich, 2021). Bill Barr & Company sources ingredients from many places and has warehouses across the country to store ingredients before selling to pet food manufacturers (Bill Barr & Company).

6.2.7 Further Processing

The final category of intermediate processing activities are further processors that take raw materials or pet food ingredients and put them through significant additional processing before selling them. Some of the ingredients generated from further processing include freeze dried proteins, dehydrated protein powders, protein concentrate powders, and mechanically separated proteins (Aldrich, 2021).

Companies involved in this sector include Petsource, ADF, 3D Corporate Solutions, SRC Milling, Boyer Valley Co., and Northland Choice. Petsource is an example of an ingredient processor that makes freeze-dried ingredients (Scoular, n.d.). ADF and 3D Corporate Solutions take raw materials and converts them into a meat powder (Nutrios, n.d.; 3D Corporate Solutions, n.d.). There are many companies that convert raw ingredients into protein meals including SRC Milling and Boyer Valley Co. (SRC Milling, n.d.; Boyer Valley, n.d.).

6.2.8 Brokers

Brokers act as a middleman that facilitate the trade of pet food ingredients between an ingredient supplier and pet food manufacturer without ever taking physical possession of the

ingredient (Aldrich, 2021). For example, North Central Companies is involved in global ingredient sourcing working to bring buyers and sellers together (North Central Companies, n.d.). There are also companies that source ingredients, take possession, and then resell without additional processing; examples of this are IQI and BHJ (IQI, n.d.; BHJ, n.d.).

6.2.9 Pet Food Manufacturers

Pet food manufacturers are the companies that buy ingredients and produce finished pet food products. There are a variety of kinds of pet food being produced including dry, wet, semi moist, and treats. The pet food produced by manufacturers is ready for sale through retail channels (Diment, a2021).

There are 516 FDA-registered pet food manufacturing facilities in the US. The states with the most pet food manufacturing facilities are Pennsylvania (59), Michigan (33), Wisconsin (28), Minnesota (26), Nebraska (26), and Washington (26). However, just because these states have high numbers of production facilities, does not mean they are producing the largest volume of pet food as the size of facilities can vary widely (DIS, 2017).

According to the Pet Food Institute (PFI), their 21 producer members produced 98% of all pet food and treats in the United States in 2020 (PFI, n.d.; PFI, 2020). The top five pet food manufacturers in 2020 were Mars Petcare Inc., Nestle Purina PetCare, J.M. Smucker, Hill's Pet Nutrition, and General Mills (WATT Global Media, n.d.). Given the information available on annual global revenue of pet food manufacturers from Pet Food Industry Magazine, there is a global four firm concentration ratio of 40.1% (Frimpong, 2021; WATT Global Media, n.d.). This means that pet food manufacturing is highly concentrated among four of the global pet food manufacturers.

Looking at US specific data from IBISWorld, Nestle, Mars, JM Smucker, and Colgate-Palmolive (Hill's Pet Nutrition), remain in the top of pet food manufacturers with 31.1%, 19.2%, 10.8%, and 7.1% market share by revenue respectively as seen in **Figure 14** (Diment, a2021). This means that there is a high market concentration of pet food manufacturers in the US.

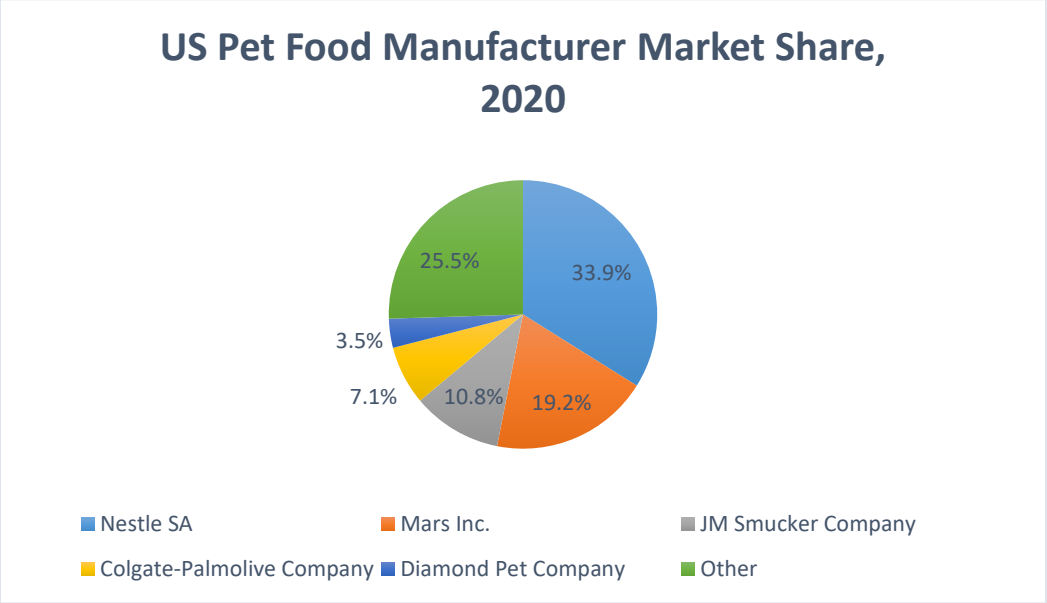


Figure 14. Pet Food Manufacturer Concentration, 2020
Source: Diment, a2021

6.2.10 Vertical Integration

Vertical integration can be seen in many stages of the animal protein-based ingredient supply chain. Although slaughter and processing can be considered two different activities because they result in different products, they are often vertically integrated and done in the same facilities (Schulman, 2021). There can also be vertical integration between meat processing and renderers. This is commonly seen in large meat processors with integrated rendering facilities (Jekanowski, 2011).

There is significant vertical integration between slaughter and processing activities in beef production. Many slaughterers are involved in making processed beef products. There are

also many slaughterers that produce the further processed products found in ready to eat meals. This segment is becoming increasingly vertically integrated as slaughterers/packers are acquiring further processing companies (Lowe & Gereffi, 2009).

Poultry production is highly vertically integrated between production and processing with 90% of chickens produced by independent farmers that have contracts with integrated production and processing companies (Poultryproducer.com, 2020). The amount of vertical integration between poultry slaughter and processing has increased over time. In the past, poultry slaughterers sold whole carcasses to retailers and restaurants that were then responsible from processing into smaller retail cuts. Now, slaughterers in the US also handle the further processing of poultry products. In the United States, there are only a few slaughtering plants not involved in the further processing steps. Out of 85 broiler slaughter plants surveyed in Georgia, Arkansas, Mississippi, and North Carolina, only one plant was only involved in slaughter (Kiepper, 2017).

Vertical integration exists between renderings and meat processing for large companies. There are integrated renderers associated with large meat processing companies such as Tyson, Cargill, and Smithfield. They also are typically rendering only one species at their plants, based on the meat processing company they are associated with (Jekanowski, 2011).

6.3 Objective Three: Supply Chain Inefficiency Analysis

6.3.1 Supply Chain Inefficiencies

The supply chain issues facing the pet food industry have become clearer since the covid-19 pandemic. The challenges regarding the supply chain have different root causes with some being a direct result of issues caused by the covid-19 pandemic, and others being more systemic issues.

Supply chain challenges involving ingredients, labor, and transportation are key issues impacting the pet food industry. These issues will likely be exacerbated in 2022 by government mandates and tax incentives involving renewable diesel production (Beaton, 2022). Speaking with industry stakeholders at Petfood Forum 2022 provided more details on the supply chain issues in the pet food industry. Some of these issues include a lack of labor to keep up with demand, the opportunity cost of raw materials taking ingredients out of pet food, and longer wait times to get ingredients from imports (Industry Stakeholder, 2022). Some rendering companies are having problems with upstream supply chain issues at the meat processing level. Labor issues in meat processing are causing delays in the amount of material available for rendering (Industry Stakeholder, 2022).

Another problem faced by companies involved in production of animal protein-based ingredients is a lack of market information on prices. Since ingredients are often sold on a contract basis to pet food manufacturers, there is no way of knowing what other companies are charging for their ingredients. A few ingredients have USDA price data available to obtain an estimate of the ingredient value, however, this is only available for a few organ ingredients that have not been further processed. These prices are based on semi-annual contracts and have very little variation over several year periods as seen in **Figure 15.** There are also issues with missing data in these categories. Looking at information for beef and pet products, the only years there is data available is displayed in **Figure 15**. This presents a challenge because pork data stopped being reported in 2016. There is also no data available for poultry products, even though chicken is the most common animal protein used in pet food (DIS using Neilson, 2020).

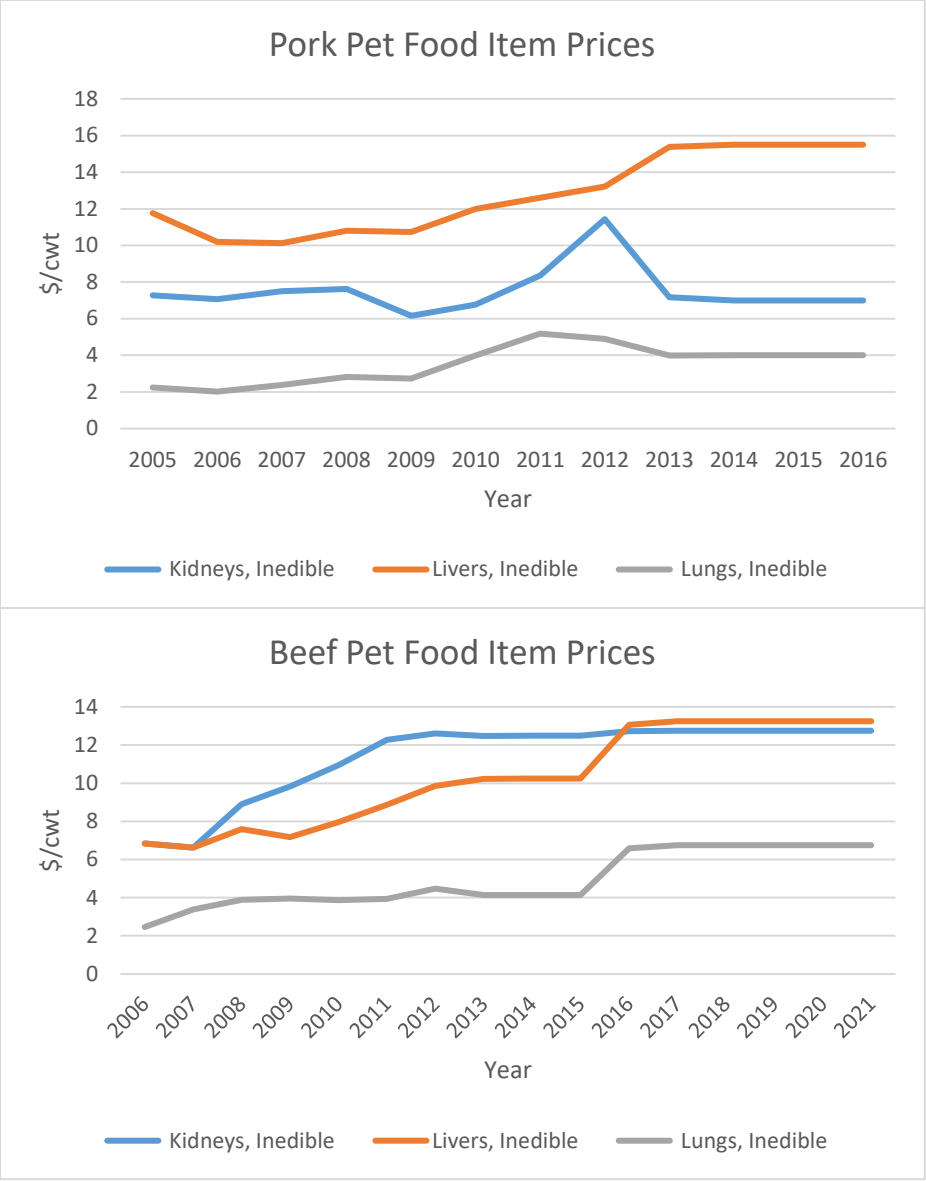


Figure 15. Beef and Pork Pet Food Item Prices

Source: USDA AMS, 2022

6.3.2 Overcoming Supply Chain Inefficiencies

One potential opportunity to increase the supply of animal protein available to pet food is to use more waste from supermarket food in pet food. This includes food that supermarkets can't sell or donate that would likely end up in a landfill. There is currently over 3 million tons of food being wasted at supermarkets in the US each year, including trimmings and expired meat. Capturing more from this stage of the supply chain can help alleviate some of the issues

currently faced by the pet food industry (California Safe Soil, LLC, 2022). Currently, there is no market available to absorb these products, likely due to the liability associated with the byproduct/expired foods (Harvard Food Law and Policy Clinic, 2017). However, the need to increase the availability of animal protein for pet food could present the opportunity for a market to be created to capture this product.

Another method to increase the availability of animal-based protein for use in pet food is to overcome bottlenecks in the supply chain. Looking at animal protein that goes to rendering from slaughter and processing shows that between 16.85% and 31% of rendered product is going to pet food (Tyler, 2021; Informa Economics, 2011). This means there is a large portion of animal protein going to other industries. A recent development in pet food is that proposed guidelines for "human grade" pet food have been approved by the AAFCO Pet Food Committee (Fairfield, 2022). This will create new opportunities for USDA plants to receive higher value for byproducts and ingredients going to pet food by creating the products in their own facilities, rather than selling ingredients into the pet market at a lower value.

In order to be classified as "human-grade" the pet product must be stored, handled, processed, and transported in accordance with the same laws applied to food for human consumption (AAFCO, 2021). Pet food ingredients coming from USDA facilities lose their value when they enter the pet market. However, if these ingredients stayed in the USDA facility and were converted into a packaged, ready to sell pet food, they would retain higher value. This means there is the opportunity to bring some of the intermediary processing activities into the processing and slaughter sector. This will lead to efficiency gains from less transportation and increased value in the ingredients since they could be labeled as human-grade. This can be

accomplished through vertical integration between the highlighted activities in **Figure 16**.

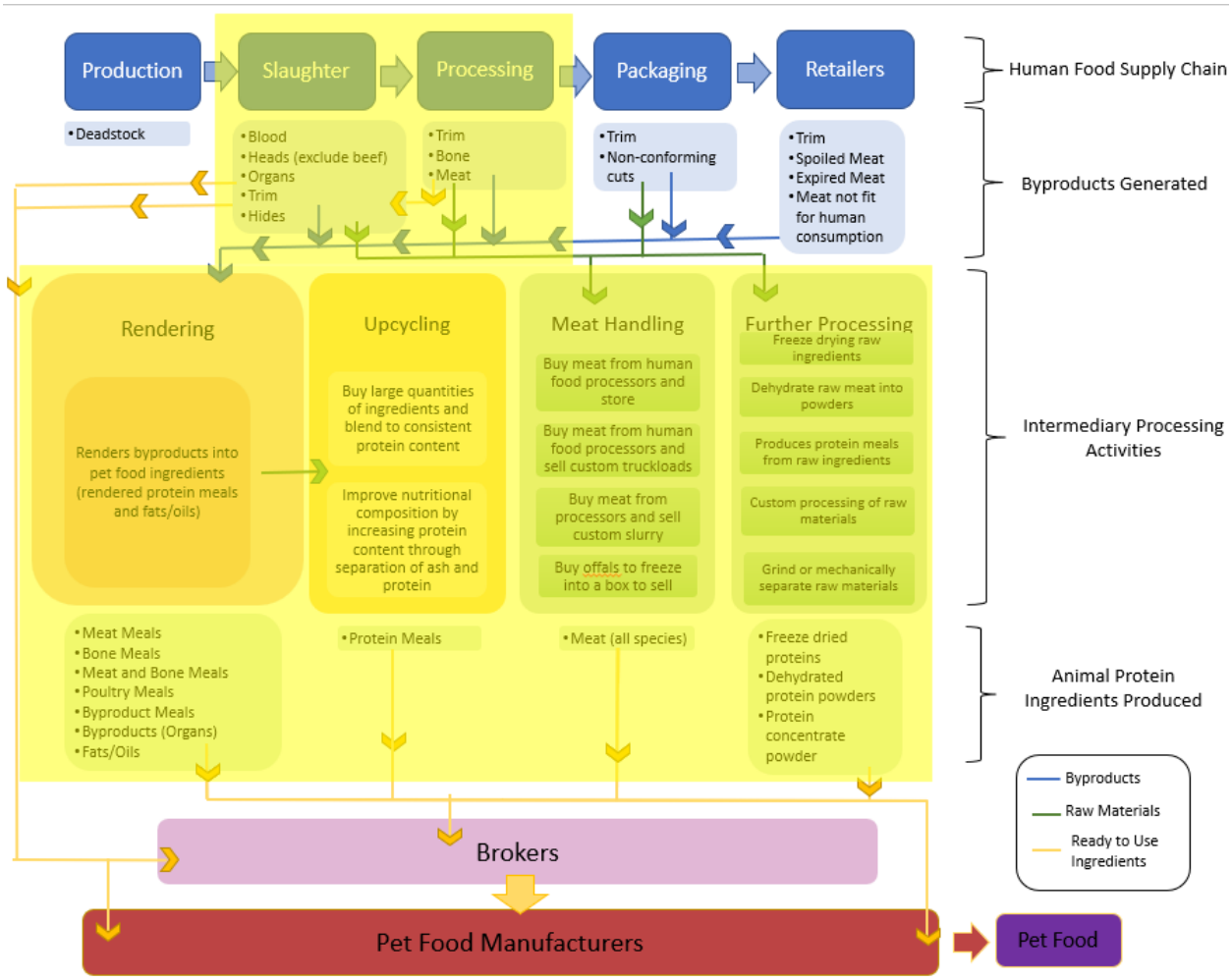


Figure 16. Increasing Efficiency in the Supply Chain of Animal-Based Protein Ingredients

A potential way to overcome the challenge of not having market prices available for animal-based protein ingredients is to develop a method to estimate the value animal byproducts that aren't currently available. This was attempted using turkey live weight price and available parts prices. The idea behind this method, was that every part of the bird has value, even if it is nott being used for human consumption. So, the live bird price can be compared to the sum of the available component prices. The difference between these values could be used to estimate the value of the organs with no available price.

The first step in this process is to breakdown a live turkey into its components by average weight. These components can be separated into products used for human consumption and not used for human consumption as shown in **Table 1**. This data comes from a study evaluating the weights of 16-week-old hens and 20-week-old toms.

Table 1. Breakdown of Turkey Components by Percent Body Weight

Turkey Component	**% of Body Weight, Toms**	**% of Body Weight, Hens**
Neck	3.15%	3.17%
Breast	31.43%	28.55%
Trim (from back)	8.77%	9.08%
Legs (drumstick + thigh)	24.71%	25.07%
Wings	9.23%	9.25%
Gizzard	0.66%	0.63%
Liver	0.95%	1.21%
Hearts	0.34%	0.36%
Total Edible	**79.24%**	**77.32%**
Blood	3.88%	3.15%
Feathers	2.23%	6.72%
Head	1.72%	1.50%
Feet	2.80%	2.83%
GI Tract	3.36%	4.26%
Lungs and Trachea	0.13%	0.63%
Kidneys	0.38%	0.37%
Abdominal Fat	1.47%	2.35%
Bones (from back)	3.74%	3.71%
Total Non-Edible	**19.72%**	**25.51%**

Source: Murawska et al, 2015; Murawska, 2013

It can be seen that the edible and non-edible components do not add up to 100% exactly. This is likely due to rounding and combining the lean meat and organ data from two different studies. This data can be used to calculate the weight of each of these components by multiplying

the component percentage and live turkey weight. Next, the sum of these values can be compared to the live bird value. This is displayed in **Table 2** as an example when a turkey weights 42.7 lbs.

Table 2. Turkey Component Values for 20-week-old Tom

Component	Pounds/Bird	Wholesale Value ($/lb)	$/Bird
Neck	1.35	$0.6827	$0.9186
Breast	13.42	$1.1976	$16.0745
Trim (from back)	3.74	$0.5012	$1.8765
Legs (drumstick + thigh)	10.55	$1.1979	$12.6402
Wings	3.94	$0.8187	$3.2281
Total			**$34.7379**

Source: USDA AMS, 2022; USDA NASS, 2022

The average price for a live turkey is $0.821/lb, makings its value $35.057. When compared to the value of the available components, there is a difference of $0.3191 to split between the remaining components. Unfortunately, this would be a large underestimate of what the remaining components would be worth. This can be inferred because turkey gizzards (hearts) and livers likely have values similar to chickens which are valued at $0.1336/lb and $0.7872/lb (USDA AMS, 2022). One reason for this is that the turkey components in **Table 2** have been processed, so their value would increase to reflect that. This demonstrates the difficulty of calculating prices when there are no public market prices available.

Another way to attempt to estimate prices is to compare them to a similar human food ingredient. For example, the meat used in pet foods is typically the same type of meat used in hot dogs. For this reason, the price for this meat in pet food is based off the price that large hot dog manufacturers are paying for mechanically separated meat. The price paid by pet food manufacturers will be lower because the mechanically separated meat sold to pet food companies is not inspected by the USDA. (Aldrich, 2021).

Section 2 - Trade Analysis

Chapter 7 - Introduction

It is important for US pet food manufacturers to understand the international pet food market as it can impact the domestic pet food market. The amount of pet food imported and exported by value from the US has been steadily increasing since 1995 (**Figure 17)**. The US is a net exporter of pet food, meaning they export more pet food than they import (Gaulier & Zignango, 2010). This plays into the importance of understanding the supply chain of animal-based protein in pet food. As US pet food exports increase, there is more pet food being produced domestically. This can increase the need for animal-based protein ingredients for pet food production in the US.

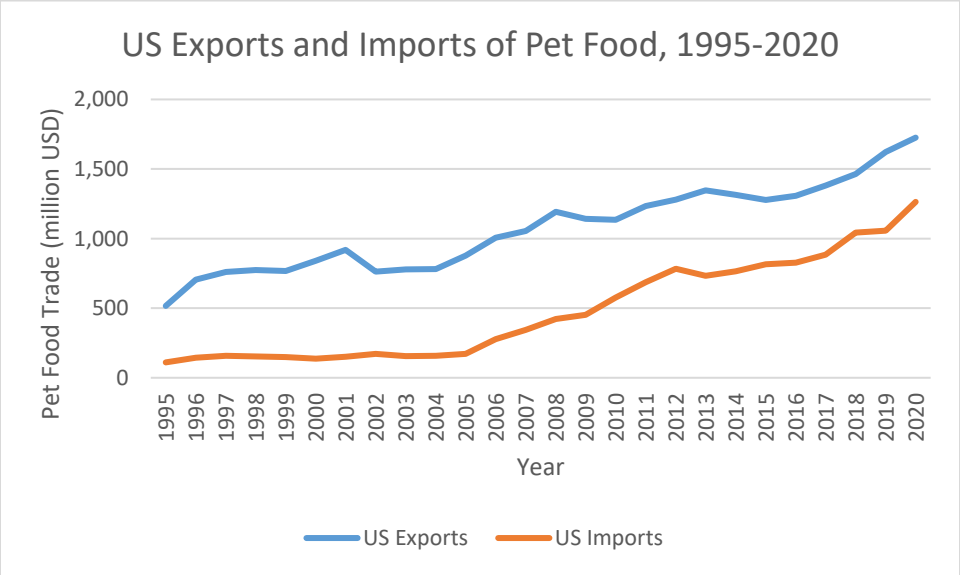


Figure 17. Change in US Pet Food Imports and Exports, 1995-2020
Source: Gaulier & Zignago, 2010

Pet food imports make up a small, but growing portion of the US pet food market, from ~1.7% in 1997 to ~3.4% in 2019 as displayed in **Figure 18** (Gaulier & Zignago, 2010; Gibbons,

2021). Exports, on the other hand, have become a smaller percentage of US pet food production as displayed in **Figure 18**. The fact that the amount of pet food being sold in the US from other countries is increasing, while most of the pet food produced in the US is sold domestically could signal that the pet food market in the US is growing at a faster rate than the global pet food market.

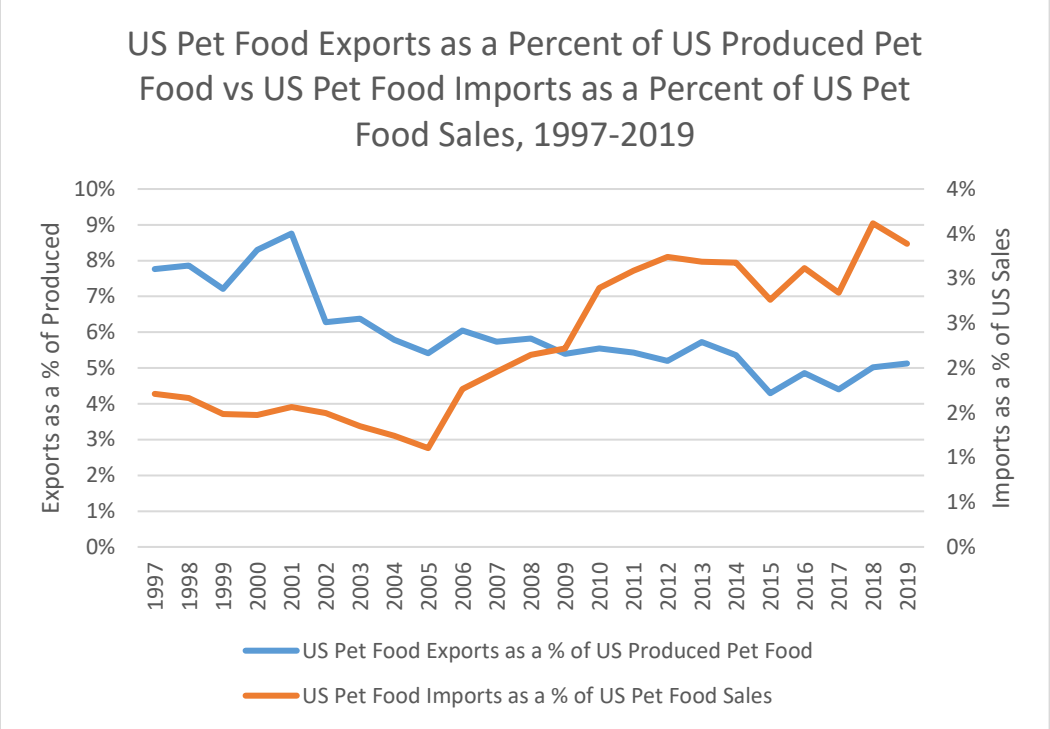


Figure 18. US Pet Food Imports as a Percent of Domestic Pet Food Sales vs US Pet Food Exports as a Percent of Pet Food Produced in the US, 1997-2019

Source: Gaulier & Zignago, 2010; Gibbons, 2021

Chapter 8 - Literature Review

To date, the pet food industry has not been given focused attention by agricultural economics/agribusiness in academic research. In journal articles, pet food is mentioned incidentally, such as being negatively affected by BSE and Creutzfeldt-Jacob disease (Henson & Mazzocchi, 2002), or how offals from human food production are being used in pet food (Reithmayer et. al, 2020; Bernstein & Skully, 2003; Mathews & McConnell, 2012). There are a few articles available from industry literature that have brought up some of the factors affecting pet food trade. For example, Petfood Industry mentions the increase of US pet food exports to Mexico and Canada since NAFTA came into effect (Wall, c2018). Petfood Industry also highlights the increase in pet food exports globally. Exports from the US have increased significantly in Mexico, but according to the AFIA, the reasons beyond a change in tariff fees are not yet understood (Phillips-Donaldson, 2022).

The lack of research on pet food global trade is a limiting factor for understanding important issues such as the role of foreign demand, the importance of foreign suppliers, as well as the policies that can be implemented to improve the industry's profitability. This research begins filling this gap by looking at a broad set of determinants of bilateral international trade that capture the role of trade costs and geography, as well as the role of international trade agreements on pet food trade. Regional trade agreements (RTAs) are an important policy for pet food manufacturers to understand as it can provide insight on a controllable factor affecting trade.

Chapter 9 - Methods

It has been shown that the gravity model can be used to analyze and gain an understanding of the factors affecting the trade of goods (Rahman, 2010; Dascal et al, 2002; Fuller & Kennedy, 2019). The gravity model was first introduced by Tinbergen (1962) as a way to measure bilateral trade between two countries by relating trade to Newton's gravity equation from physics. He proposed that trade between two countries is positively related to their sizes and negatively related to their distance from each other. To date there has not been a gravity model study conducted to evaluate factors affecting pet food trade. The gravity model in this thesis will be used to analyze a single commodity, pet food, to gain insights on if RTAs have a significant impact on pet food trade. Importer and exporter fixed effects will be used to control for effects specific to each importing or exporting country. Year fixed effects will be used to control for effects specific to each year. The following gravity model specifications in log linear form, were used to analyze the factors of pet food trade:

$$lnX_{ijt} = \alpha_1 CONT_{ij} + \alpha_2 lnD_{ij} + \alpha_3 COML_{ij} + \alpha_4 RTA_{ijt} + \alpha_5 IFE + \alpha_6 XFE + e_{ijt} \quad (1)$$

$$lnX_{ijt} = \alpha_1 CONT_{ij} + \alpha_2 lnD_{ij} + \alpha_3 COML_{ij} + \alpha_4 RTA_{ijt} + \alpha_5 IFE + \alpha_6 XFE + \alpha_7 t + e_{ijt} \quad (2)$$

$$lnX_{ijt} = \alpha_1 CONT_{ij} + \alpha_2 lnD_{ij} + \alpha_3 COML_{ij} + \alpha_4 RTA_{ijt} + \alpha_5 IFEt + \alpha_6 XFEt + e_{ijt} \quad (3)$$

where X_{ijt} is the value of pet food exported from the country i to country j in year t, $CONT_{ij}$ is a contiguity dummy variable that equals one when country i and j share a border, D_{ij} is the distance between countries i and j, $COML_{ij}$ is a common language dummy variable that equals one when countries i and j speak the same official language, RTA_{ijt} is a dummy variable for the presence of a regional trade agreement between the country i and country j at time t, IFE are importer fixed effects, XFE are exporter fixed effects, t is year fixed effects, and IFEt and XFEt are interacted importer-year and exporter-year fixed effects.

The identification strategy underlying the gravity model is that, once that time-invariant exporter and importer fixed effects are controlled for, the effects of distance, contiguity, language, and RTA membership are exogenous to bilateral trade flows. Analyzing pet food trade using a gravity model will provide numerical information on the effect of these factors on trade of pet food, helping to identify which factors have the largest impact on pet food exports.

Chapter 10 - Data

Bilateral trade values of pet food for retail sale (HS 230910) from 1995-2020 were obtained from BACI (Gaulier & Zignago, 2010). Data on contiguity, distance, common language, and RTA information from 1995-2020 are from CEPII (2021). After eliminating missing variables for contiguity, distance, common language, or presence of a RTA, the sample contained 56,722 observations. The definition of variables and descriptive statistics are shown in **Table 3**.

Table 3. Variable Definitions and Descriptive Statistics

Variables	**Definitions**	**Mean (SD)**	**Observations**
Value	Value of pet food traded (thousand USD)	3301.61 (18304.41)	56,722
Contiguity	1 = countries share a common border	0.09 (0.28)	56,722
Distance	Distance between countries most populated cities (km)	5148.37 (4415.71)	56,722
Common Language	1 = countries share a common official or primary language	0.20 (0.40)	56,722
RTA	1 = countries have a regional trade agreement	0.47 (0.50)	56,722

Abbreviation: SD, standard deviation.
Source: Data from Gaulier & Zignago, 2010; CEPII, 2021. Analysis by author

The trade data available can be used to evaluate how major pet food trade partners with the US have changed over time. The change in the number of countries importing pet food from the US and the value of trade can be seen in **Figure 19** below where gold corresponds to a smaller amount of US pet food imports and green corresponds to a larger amount of US pet food imports. Comparing the 1995 and 2020 map, there appears to be an increase in the number of countries importing US pet food and an increase in green colored countries. This means that more countries are importing pet food from the US and more countries are importing larger values of US pet food.

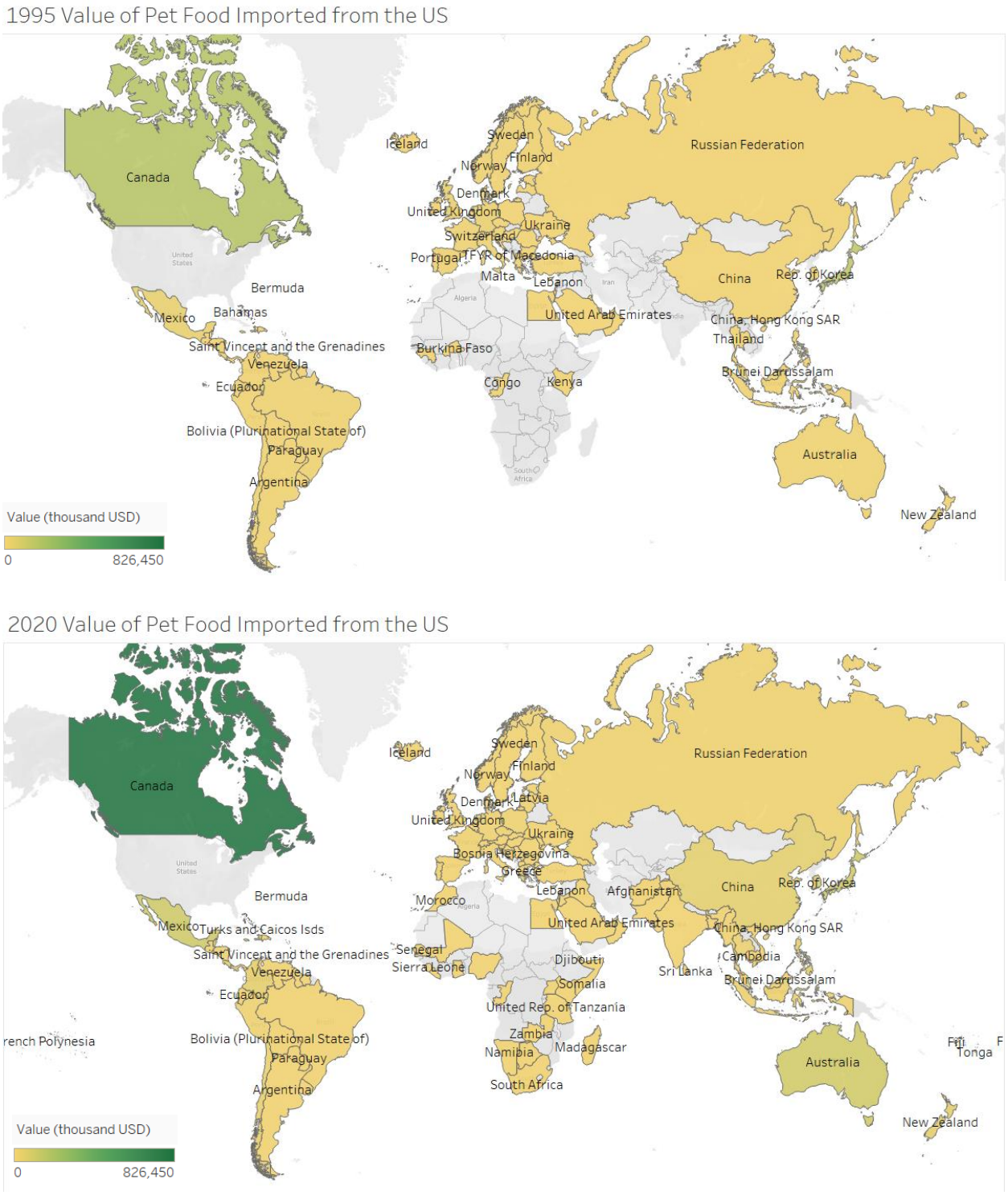
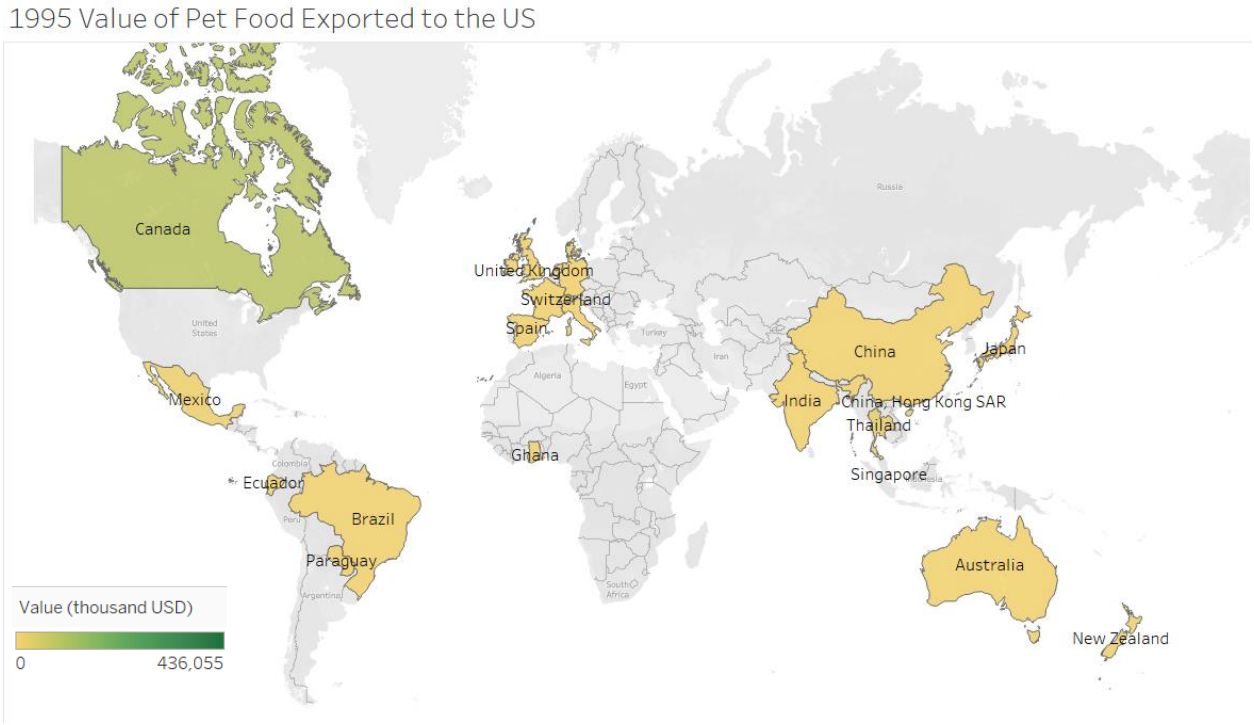


Figure 19. Large US Pet Food Importers in 1995 vs 2020

Source: Gaulier & Zignag, 2010

The US is also a significant importer of pet food. The change in number of countries exporting pet food into the US and the value of trade can be seen in **Figure 20** below where gold corresponds to a smaller amount of pet food exports to the US and green corresponds to a larger amount of pet food exports to the US. Comparing the 1995 and 2020 map, shows an increase in the number of countries exporting pet food to the US and an increase in green countries, meaning that more countries are exporting pet food to the US and the value exported in increasing.



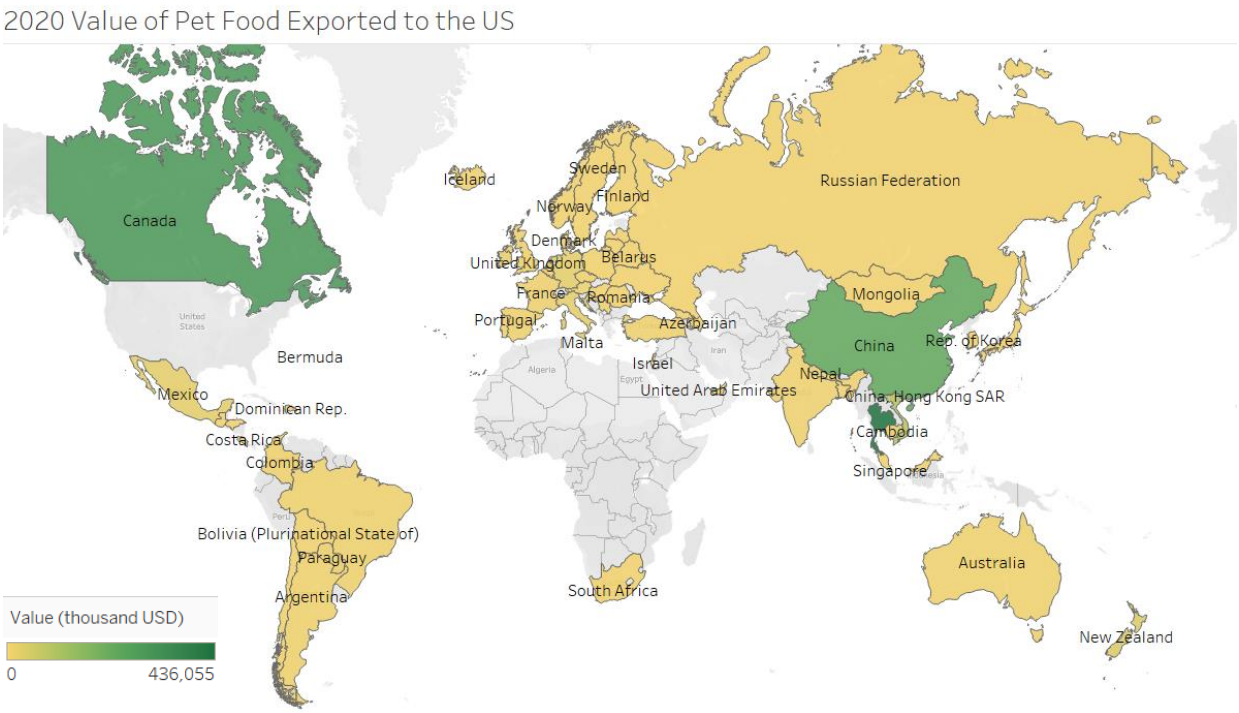


Figure 20. **Large Pet Food Exporters to the US in 1995 vs 2020**

Source: Gaulier & Zignago, 2010

It is clear from the increase in US pet food trade in **Figures 19 and 20** that pet food is becoming a more globalized industry. As the pet food industry becomes more globalized, it will create new opportunities for research. This helps show why pet food trade is becoming a more important area for research.

Chapter 11 - Results and Discussion

Three different models were tested by evaluating varying fixed effects in each regression, (Equation 1: importer and exporter fixed effects, Equation 2: importer, exporter, and year fixed effects, and Equation 3: importer-year and exporter-year interacted fixed effects). This was done to explore the robustness and stability of the parameter estimates. The models were taken a step further by controlling for heteroskedasticity in standard errors and country pairs. This was done to correct for bias in the standard errors a cluster correction using country pairs is included to alleviate this concern. The summary of these results is displayed in **Table 4**.

Table 4. Gravity Model Results

	Dependent variable:		
	Log Trade		
	Equation 1	Equation 2	Equation 3
	(1)	(2)	(3)
Contiguity	0.646***	0.680***	0.682***
	(0.124)	(0.126)	(0.139)
Log Distance	-1.205***	-1.334***	-1.389***
	(0.043)	(0.045)	(0.050)
Common Language	0.651***	0.692***	0.752***
	(0.099)	(0.102)	(0.111)
Regional Trade Agreement	0.785***	0.480***	0.523***
	(0.070)	(0.074)	(0.091)
Observations	56,722	56,722	56,722
Adjusted R^2	0.516	0.536	0.556
Note:			*p<0.1; **p<0.05; ***p<0.01

Source: Data from Gaulier & Zignago, 2010; CEPII, 2021. Analysis by author

Table 5: Interpretation of Gravity Model Results

Coefficient	**Equation 1**	**Equation 2**	**Equation 3**
Contiguity	90.79%	97.39%	97.78%

Distance	-1.205	-1.334	-1.389
Common Language	91.75%	99.77%	112.12%
RTA	119.24%	61.61%	68.71%

Looking at the signs of each coefficient estimate can be used to help verify the accuracy of the estimates at a basic level. Contiguity, common language, and RTA coefficient estimates are all positive. This means that the presence of these parameters will increase the value of pet food traded. While distance has a negative coefficient estimate and will decrease the value of pet food traded. This makes sense because contiguity, common language, and an RTA are all things that lower the barriers of trade which would be expected to positively affect trade. Distance increases the costs of trade and is expected to decrease trade.

The interpretation of the gravity model results are displayed in **Table 5**. The interpretation of contiguity for each equation is that if two countries share a border, they trade 90.79%, 97.39%, or 97.78% than countries without a shared border for Equations 1, 2, and 3 respectively. The distance coefficients show that if the distance between two countries increases 1 km, the value of pet food traded between them decreases by 1.205, 1.334, or 1.389 thousand USD for Equations 1, 2, and 3 respectively. The effect of common language can be interpreted as when two countries share an official common language, the value of pet food trade increases 91.75%, 99.77%, or 112.12% for Equations 1, 2, and 3 respectively. Turning to the results for the presence of a RTA, Equation 1 shows that if two countries are involved in an RTA, bilateral trade is 119.24% higher than if they do not have an RTA. Equation 2 shows a decrease in the effect of an RTA by almost half, so bilateral trade between countries with an RTA is 61.61% higher than countries with no RTA. This suggests there are factors that vary over time that impact the effect of an RTA on pet food trade. This means that Equation 1 likely yields an

overestimate on the effect of an RTA. Finally, for Equation 3 if two countries were involved in an RTA, bilateral trade would be 68.71% higher than if they did not have an RTA.

One important takeaway from these results, is that varying the fixed effects and controlling for heteroskedasticity in standard errors and country pairs does not change the significance level of the results. This indicates that the estimates are robust to correlated errors within country pairs and verifies the robustness of this model, showing that RTAs have a significant effect on bilateral pet food trade.

The findings suggest that RTAs are important to look at regarding ways to affect international trade of pet food. RTAs are something that can be lobbied for and changed, while other factors of trade such as distance, common language and contiguity do not change. Some policy implications from these results are that RTAs have a significant effect on pet food trade, thus the industry could lobby for the establishment of an RTA with countries that they would like to increase pet food trade. Recently, the pet food industry has become more vocal about lobbying for issues, as seen in 2021 with the supply chain issues and ingredient competition, being faced (Brooks, 2021).

Chapter 12 - Conclusion

Pet food production in the US is growing at a faster rate than animal slaughter. Since the pet food industry primarily sources their animal protein ingredients from animal slaughter for human consumption, it is not growing at a sufficient rate to maintain availability. Understanding the supply chain can help companies find and overcome issues to increase animal protein availability. There are many paths that animal protein-based ingredients can take to move from the human food supply chain to pet food. However, there are some limitations and constraints in this supply chain, such as bottlenecks, lack of public market prices, increased ingredient costs, labor shortages, and new government mandates. Some of these issues can be overcome by reworking the supply chain to increase efficiency, developing a method for estimating the value of ingredients, turning to underutilized animal protein sources, developing strategies to retain employees, and lobbying against harmful mandates.

Pet food is becoming a more globalized industry as seen by increased trade. Understanding the factors that affect pet food trade could be beneficial to pet food manufacturers trying to expand into new international markets. This research shows that RTAs have a significant positive affect of pet food trade. This is important because it means that establishing a RTA is one way to increase the value of pet food traded.

12.1 Limitations

The main limitation in this research was a lack of publicly available data on the pet food industry. Since many companies in the industry are privately held, they are not required to release their information. Data is starting to become more available due to increased studies, such as the IFEEDER study to evaluate the volumes of ingredients used in pet food. However, there are still issues with these studies due to the large number of assumptions made. There is

also not historical data available on ingredient volumes since this study only evaluated one year of data.

12.2 Future Research

Future extensions of the supply chain analysis section include analyzing the supply chain of other ingredient categories used in pet food such as plant-based ingredients. Additional research could also be done to look into the supply chain limitations by surveying companies in the industry. This paper showed the need to develop a method for estimating the value of animal-based protein ingredients in pet food. This is an important area for future research because shedding light on the value of animal-based protein ingredients for pet food could increase the amount of animal protein going to pet food rather than other industries.

Future extensions of the trade analysis section of this thesis include evaluating other factors that could be affecting pet food trade. Interesting factors to look at include a dummy variable for US based pet food manufacturers that have factories in other countries and if the EU having restrictions on GMO foods imported has an effect on pet trade. Another interesting topic to research would be looking at the trade of animal byproducts since those are the ingredients that make up pet food, rather than the trade of finished pet food.

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