Graduate Theses and Dissertations   Graduate School and International Education

5-2019

Comprehensive Poultry Supply Chain Model with Vertical and Horizontal Linkages: Implication of Domestic and International Shocks

Hakan Unveren
University of Arkansas, Fayetteville

Comprehensive Poultry Supply Chain Model with Vertical and Horizontal Linkages:
Implication of Domestic and International Shocks

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Agricultural Economics

by

Hakan Unveren
Akdeniz University
Bachelor of Science in Agricultural Engineering, 2013

May 2019
University of Arkansas

This thesis is approved for recommendation to the Graduate Council.

_____
Jeff Luckstead, Ph.D.
Thesis Director

_____
H.L. Goodwin, Jr., Ph.D.
Committee Member

_____
Alvaro Durand Morat, Ph.D.
Committee Member

_____
Andrew M. McKenzie, Ph.D.
Committee Member

Abstract

According to USDA FAS, in 2017, the US was the largest broiler-producing country with 18.696 million metric tons and the second largest exporter of broiler products with 3.075 million metric tons (Brazil is the largest exporter with 3.847 million metric tons). Thus, around 83% of US production is consumed domestically. According to USITC, chickens are the most important protein source in the US, and Americans consume more chicken per capita than any other country. However, while the broiler industry is a key segment of US agriculture, it is underserved by large-scale supply-chain and trade models.

In this study, to fill this gap in the literature, we build a comprehensive supply-chain model of the US broiler industry that accounts for corn and soybean, feed mills, breeders, hatcheries, grow-out farms, broiler processing, further processing, and international trade. This broiler supply-chain model is calibrated to US data averaged over 2012 - 2017 to analyze two scenarios: a) impacts of a shock to the corn and soybean prices due to tariffs imposed by China on US corn and soybeans and b) effects of the productivity increase in grow-out segments on entire the US broiler supply chain.

The results of the first and second alternate scenarios are compared to the baseline scenario to quantify the impact of the reduction corn and soybean prices and productivity shock to grow-out farmers. The numerical analysis from first scenario shows that as the price of corn and soybean in the US market fall by 18% and 24%, respectively, feed supply increase and feed prices decreases, which directly lower the production costs of breeders and grow-out farms. Thus, while the Chinese tariff on corn and soybean undoubtedly make corn and soybean producers worst off, the chicken industry benefits from lower costs. Also, the numerical analysis from second scenario shows that boosting productivity by 10% in the grow-out segment led to only an increase an increase broiler chicken production but also a reduction in input demand. Thus, this analysis highlights the trade off advances in research and development in chicken breads as producer upstream from grow-out farm are worse off as demand for their products falls, but grow-out farms, downstream producers, and consumer benefit.

Acknowledgments

The completion of this study could not have been possible without the expertise of Dr. Jeff Luckstead, our beloved thesis adviser. He has taught and supported me through every step of the graduate program, particularly during the thesis research. I also express my heart-felt gratitude to all faculties and staff of the Department of Agricultural Economics and Agribusiness.

Dedication

This thesis is dedicated to my beloved parents, Osman Unveren and Sengul Unveren, who are always supporting me. It is also dedicated to all the people who have offered their time, support and commitment.

Table of Contents

List of Figures

List of Tables

Chapter 1.   Introduction

This chapter provides background information on the US broiler industry, development in the highly integrated supply chain, impacts of US-China trade war in feed costs, advances in the productivity of grow-out farmers, objectives of the analysis, and organization of the thesis.

1.1   Background Information

In this section, information on trends in the consumption and production of broiler meat are detailed.

1.1.1   Consumption

The chicken is bred and raised specifically for meat production, which is called "broiler". Broiler has become an increasingly important part of the US diet.   After 1960, broiler consumption increased.   US broiler consumption per capita was 28 pounds in 1960, which rose to 89.8 lbs in 2016, and was estimated at 90.1 lbs and 91.3 lbs for 2017 and 2018, respectively (NCC, 2018c).   According to the American Meat Institute, chicken has become the number one source of meat consumed by Americans, surpassing beef and pork by a significant margin. Some of the reasons why chicken meat is consumed more than beef and pork meat are price, awareness about health issues, and a myriad of ready-to-cook products.

Price is one of the most significant factors affecting consumers' meat buying decisions. Studies illustrate that meat is fairly elastic since an increase in the price of one type of meat leads to consumers buying another type of meat as a substitute (Weaver, 2014).   For example, Schroeder et al. (2000) showed that beef consumption increases if the price of chicken rises. However, technological improvements and economies of scale in the broiler industry are the main factors helping to keep chicken prices low relative to that of beef and pork.   This relatively low chicken price has resulted in the popularity of chicken among US consumers.   In 2017, the average price of whole chicken, for instance, was 1.47 $/lb, and the average price of beef steak and chops center cut pork meat was 5.78 $/lb and 3.73 $/lb respectively (USDA, 2018d).

Chicken meat is more healthy than red meat since it has less fat and more protein per unit (USDA, 2018a). This fact is another reason for the increase in chicken consumption relative to beef and pork. Also, white meat, which is defined as chicken breast and wings, is the most preferred type of chicken meat in the United States. There are two main reasons for this type of consumption. Firstly, there is an understanding that dark meat is more dirty and tough when compared to the breast in the US culture (Arumugam, 2011). Tenderness and color, thus, has shaped domestic chicken consumption in the United States. The second reason is healthy eating habits. Because the white meat includes more protein and less fat than remaining chicken parts, the US consumers purchase more white meat. However, although white meat is the number one consumed type of chicken meat, domestic consumption of dark meat is expanding because of increasing immigration and ready-to-cook innovations. Also, the new type of ready-to-cook techniques have provided tastier marketing options in dark meat for consumer and time saving.

Lastly, reducing preparation time is another significant factor why the popularity of chicken consumption has been increasing in the United States. Large broiler integrators have produced many types of ready-to-cook products by employing new methods and improving their products such as pan-ready meals and microwavable items (Weaver, 2014). As a result of this production, consumers prefer these products more than other types of meat. In response to increasing total chicken demand, production has expanded to meet this new consumption. In addition to growth in US consumption, global chicken demand has also been increasing. For instance, according to USDA World Markets Trade (2018), stronger demand by countries such as Japan, Cuba, and Ghana has lead to a two percent increase in imports from 11.07 million tons in 2017 to a record 11.3 million tons in 2018.

1.1.2 Production

After the 1950s, the US poultry industry, in particular both chicken and egg production, went through significant and rapid concentration (Weaver, 2014). Broiler production is changing because of technology, science, and markets which led to reduced production cost and an

increase in total US sales (Reimund et al., 1981). Moreover, agricultural research brought four important developments: new breeds for meat, better nutrition and disease control, more efficient management of confined poultry, and better processed chicken (Perry et al., 1999). In addition, these developments resulted in faster, cheaper, and safer production of chicken meat. Therefore, broiler production has increased in the United States from 13.81 million pounds in 1950 to 40,260 million pounds in 2016 (NCC, 2018d).[1]

The increase in chicken production did not occur only in the United States, but also globally. Global production was estimated to grow at 2% in 2018 to 92.5 million tons, with gains primarily in the United States, Brazil, India, and the European Union (USDA, 2018d). The world's largest chicken production country is the United States, followed by Brazil, the European Union, and China 1.1.
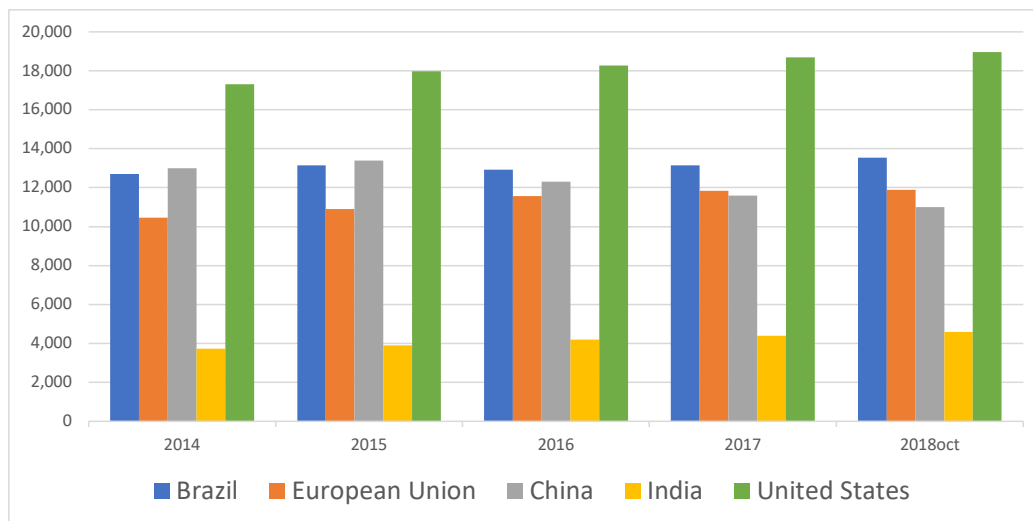
Source: (USDA, 2018d)

Figure 1.1: Broiler Meat Production

US broiler production is higher than chicken demand in the United States. In 2017, for instance, broiler production was 18,696 thousand tonnes, contrasted with domestic broiler consumption which was 15,643 thousand tonnes. Therefore, the high excess supply in US broiler

[1]Note that the majority of US poultry producer locations are intensively concentrated in the southeastern and mid-Atlantic states. The top 5 broiler producing states are Georgia, Arkansas, Alabama, North Carolina, and Mississippi (NCC, 2018a).

3

production has resulted in US producers becoming strong players in the world market. As a result, revenues from broiler exports have played a significant role in the US broiler meat industry. Despite Brazil being the second largest broiler producer, it is the largest broiler exporter, followed by the United States. In 2012, US broiler meat exports totaled $4.2 billion and accounted for 20% of US broiler meat production by weight (USDA, 2018a). The primary destinations for US broiler meat are Mexico (about 21% of total export) and Canada (about 6% of total export), followed by Angola, Cuba, and Taiwan (USDA, 2018e). Moreover, US production is expected to grow by 2% to a record 17.23 million tonnes in 2018, supported primarily by growth in domestic consumption, and exports will rise 3% to nearly 2,90 million tonnes (USDA, 2018d).

The main reason that the United States is considered among the most efficient broiler producers after Brazil in the world and is considered highly competitive globally is the structure of broiler industry. The highly vertical integrated structure of the broiler industry, with a high level of control over their product, leads to more effectiveness and more manageability.

1.2 Vertical Integration in the Poultry Industry

In a supply chain, upstream companies produce goods that downstream companies use as an input and, along with other raw materials, add value to create new products. However, through vertical integration along the supply chain, producers can control at least two stages of the value chain. The US poultry industry epitomizes the benefits of vertical integration. While producers worldwide have benefited from the vertical integration in the broiler supply chain since the early 1960s, the US poultry supply chain is the most integrated (Manning and Baines, 2004), with only breeders and grow-out farmers being independent while the remaining stages are typically controlled by integrators (Weaver, 2014).[2] According to Goodwin (2005), who described the vertical integration of the broiler industry in detail, integrators, which are individual companies that fulfill all production segments or majority of production

---

[2] Namely, the pioneer breeder companies such as Hubbard LLC, Cobb Vantress, Heritage breeders, and Aviagen have supplied between 80% and 98% of the breeder stock for both the national and global broiler industries (Madlom, 2013).

segments, provide feed to independent breeders and grow-out farms. Also, they provide genetic stock, hatching the eggs, delivery of chicks to grow-out farmers, and transport them to their plants for processing. In other words, Vukina (2001) explained that the broiler industry is one of the largest and most efficient in the world as a result of its structure. Also, in particular, the broiler industry in the US has usually been considered a role model for the industrialization of agriculture (Vukina, 2001).

Since the 1950s, as the broiler industry has become vertically integrated, the number of firms operating has decreased. Between 1950 and 2005, the number of firms operating in the broiler industry fell from 250 to less than 50 companies; as of 2005, the 50 companies account for approximately 95% of broiler production (Goodwin, 2005).[3]Also, according to USDA (2014), there are 20 integrators that accounted for 96% of the total broiler production share in 2012. Moreover, the top three of them supplied 50% of total broiler demand.[4]Contract farmers are the key players in broiler production in the US. Contracts between integrators and farmers led to lower financial risk for the farmers, rapid technology adoption, quicker response to changing consumer demand, and improved industry access to capital. However, some farmers have issues with specific aspects of the contracts, e.g., bonus determination method, communication, and a number of other operational issues with their contractor (Vukina, 2001). Despite the high degree of vertical integration, many large integrators still do not raise broiler and rely on independent grow-out farmers, with 97% of broilers raised on contract operations (USDA, 2014).

Based on the preceding description, the structure of the model is discussed. In the broiler industry, there are six different production stages from eggs to broilers to processed broiler products, and these stages may be independent or operate under a vertically-integrated integrator. Figure 1.2 depicts the different segments along the broiler-industry value chain. The

---

[3]Hinrichs and Welsh (2003) report that, by 1975, the top eight broiler processing firms controlled 30% of production.

[4]These top three integrators are Tyson Foods, Pilgrim's Corporation and Perdue Farms, Inc., from largest to smallest, respectively.

dashed boxes indicate independent farmers/producers, the circles indicate stages of production owned by an integrator, the hexagon represents markets for final broiler products, and descriptions next to an arrow are the output of the previous stage. First, the most upstream segment of the supply chain is independent raw material producers who sell corn and soybean to feed mills. Second, integrator feed mills produce feed that is provided to breeder farms and grow-out farms. Third, independent breeder farms produce fertilized eggs for hatcheries.[5] Fourth, with the fertilized eggs, integrator hatcheries produce day old chicken (DOC). Fifth, independent grow-out farmers sign contracts with integrators for DOC and feed to raise broiler chickens.[6] Sixth, integrator processing plants utilize broiler chickens and slaughter them to produce whole chicken, chicken parts for consumption, and prepare live chickens for the value-added segment. Seventh, integrator value-added plants also utilize slaughtered chicken from processing plants and other inputs (e.g., oil, flour, eggs, spices, etc.) to produce processed (value-added) chicken products.[7] Figure 1.3 shows how broilers have been processed for consumption between 1962 and 2014 (NCC, 2018b). The share of whole chickens decreased dramatically from 83% to 11%, while the share of chicken parts has increased from 15% to 40%, and the share of processed (value-added) chicken increased dramatically from 2% to 49%. The model is closed through market clearing conditions for whole chickens, chicken parts, and processed (value-added) chicken where total production equals total domestic consumption and exports. Note, the model also includes market-clearing conditions for every step of the supply

---

[5]Note that upstream from the breeder farms are both integrator-controlled and private genetic companies that work to improve parent flocks. However, because public data on this segment is not available, we are not able to include the primary breeding sector in the supply chain model.

[6]The contracts between the integrators and grow-out farms are very detailed and typically specify conditions beyond DOC and feed. For example, the integrators provide veterinary and management services (Vukina and Leegomonchai, 2006). However, for the model, we focus on only DOC and feed because they are key to the broiler supply chain.

[7]Note it is more common for further processing plants to utilize chicken parts from processing plants for value-added production. However, as discussed in Chapter 4 Section 1 Data and Sources, data does not exist for splitting chicken parts between market sales and value-added processing. Therefore, the diagram depicts the assumptions based on data availability. In the results, Chapter 3 Section 1 Model, we discuss the limitations of this assumption.

chain to endogenously determine prices. The prices for corn, soy meal, and broiler chickens are endogenous market prices, while the prices for feed, fertilized eggs, and DOCs are endogenous transfer prices within the integrator.
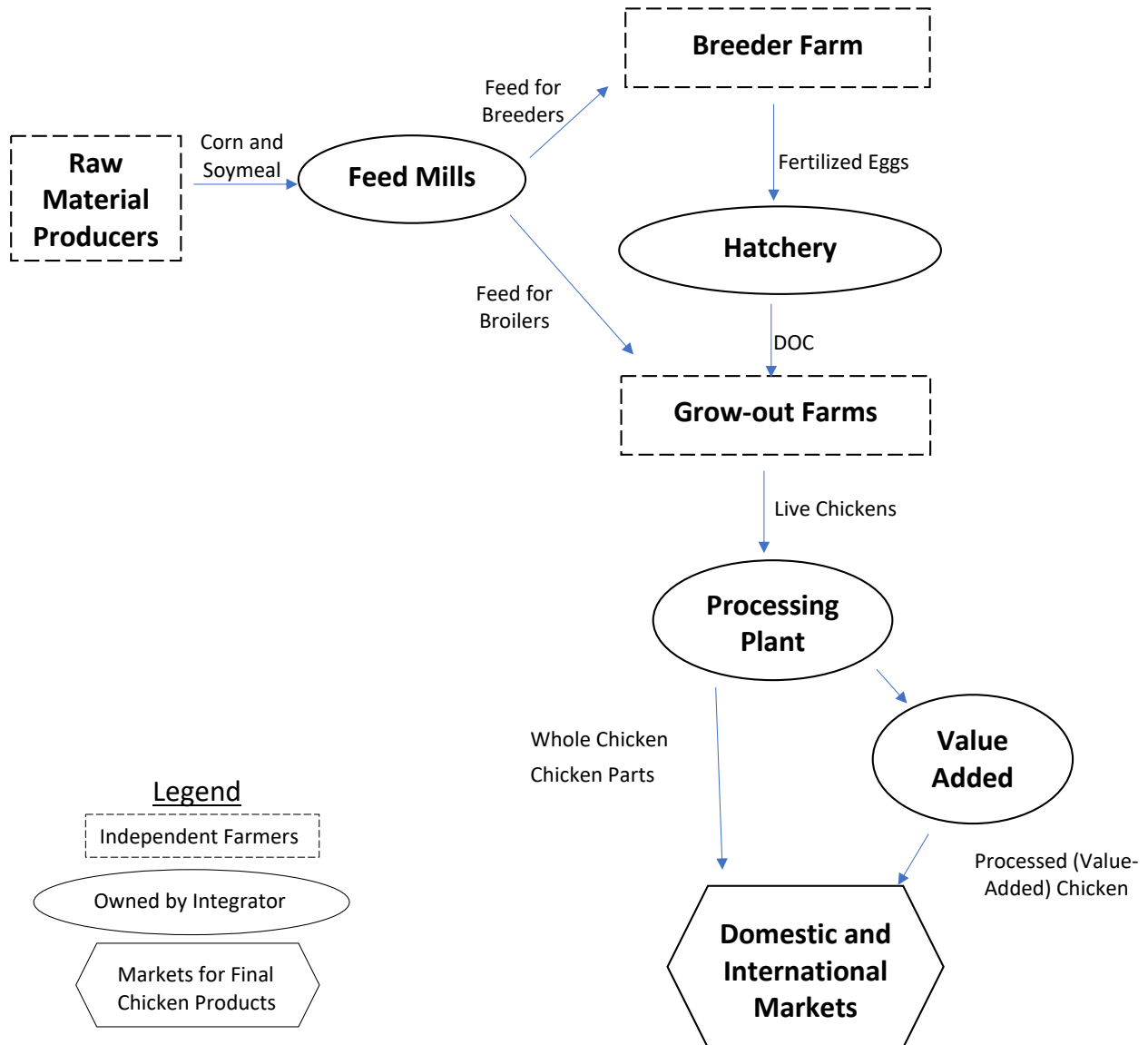
Figure 1.2: Broiler Industry Supply Chain
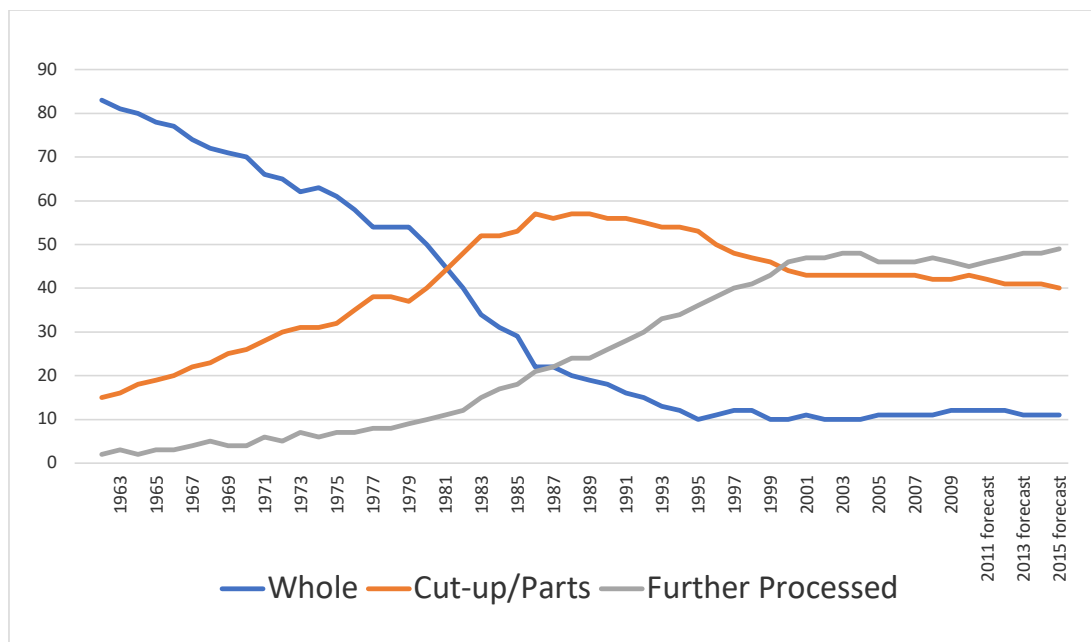
Figure 1.3: How Broilers are Marketed

1.3 Feed cost effects on the broiler industry

The poultry industry is one of the fastest growing livestock sectors, and its feed demand has increased over time. According to IFEEDER (2017), the total quantity of feed production in 2016 was 214.36 million metric tons that was supplied to the nine main livestock industries, including poultry. The quantity of feed used in the broiler sector was about 51.07 million tonnes for 8.7 billion tonnes of broiler chickens. Also, approximately 14.87 million tonnes fed 290.5 million egg layers, 72.6 million tonnes fed pullets, and 58.2 million tonnes fed breeder layers in 2016 (IFEEDER, 2017). Therefore, broiler chickens accounted for 30% (23.3% for grow-out farm and 6.7% for breeder, egg layers and pullets) of total feed production in the United States (IFEEDER, 2017).

The cost of producing broiler chickens mainly consists of feed expenses. According to Schnepf (2011), poultry production ranks third in terms of the feed operating cost share at 70% (average for 2009 and 2010). However, due to variability in raw products for feed, the feed cost operating share can range between 50% and 80% for the poultry industry (Schnepf,

2011). Focusing only on the broiler production, feed cost typically ranges between 65% and 75% (Weaver, 2014). Therefore, availability of cheap feed is crucial to the profitability and production for US broiler producers. The fluctuation cost of production has resulted in broiler feed ingredients prices shock in the crops market.

Corn and soybean are primary ingredients in the US feed production; thus, the feed price depends heavily on the price of these two ingredients. Therefore, these two major crops have a critical economic effect on broiler production through feed cost. In particular, broiler feed typically consists of about 44% corn and 26% soybean meal, which indicates around 70% of broiler feed price formation comprise these two major components (IFEEDER, 2017). Furthermore, Donohue and Cunningham (2009)estimate that the costs of producing one pound of live chicken meat increase by $0.001 if the corn prices rise by $0.10 per bushel or if soybean meal costs increases by $10.00 per bushel. Therefore, any price shock in corn and soybean impacts broiler feed cost, production expenses, and market price.

Under the Trump administration, the United States and China are engaged in a trade war. In response to the new US tariffs on many Chinese imports, China has imposed retaliatory tariffs on US soybean and corn imports. The United States is the largest producer of soybeans, and China is the largest buyer of US soybeans. Furthermore, in 2017, soybeans were the largest US agriculture product exported to China at $12.3 billion (Thukral and Patton, 2018). As a result of this conflict, the quantity of soybeans exported from the United States to China decreased about 27% in March 2017 compared with March 2016 (Cang and Sedgman, 2018). This situation caused an increased soybean quantity in the domestic market and resulted in a decrease in price. Moreover, after tariff confliction between the US and China, soybean meal prices dropped approximately 24% from $10.34 to $7.84 and corn prices declined 18% from $3.78 to $3.09 between March and July 2018 (Swanson et al., 2018). Once the soybean and corn prices decline, the cost of broiler feed production decreases since soybean and corn take a large portion in the broiler feed diet combination. Therefore, it is important to investigate the effect of corn and soybean price changes on the entire broiler supply chain.

1.4 Productivity Improvements in the Grow-Out Segment

Productivity in the broiler industry has increased due to technological improvements, which improves efficiency throughout the supply chain. With advances in genetics, feed efficiency, and selective breeding, broiler chickens are healthier and reach desired slaughter weight faster, implying increased productivity in broiler industry (Broiler productivity, 2018). Therefore, while several performance measures impact productivity throughout the supply chain, we focus on three performance measures that impact grow-out farmers: First, shortening chicken production length cycle leads to an increase in productivity because less labor and input needs are needed to produce same the number of chicken. For example, the average market age of a broiler in 1925 was 112 days (Broiler Performance, 2018), compared to 49 days (USDA, 2014). Second, decreasing mortality rates are another important factor in increasing productivity. Improvements in veterinary services and chicken house conditions have reduced the mortality rate approximately fourfold from 18% in 1925 to 4.7% in 2017 (Broiler Performance, 2018). Third, the feed conversion ratio has decreased considerably. In 1925, 4.7 pounds of broiler feed were needed to produce one pound of chicken meat, compared to 1.83 in 2017 (USDA, 2014). These three performance measurements show considerable developments in broiler producer efficiency from 1925 to 2017. Therefore, it is important to investigate the effect of gains in productivity in the grow-out segment.

1.5 Objectives

The goal of the thesis is to examine the US broiler industry from an economic perspective by considering the entire broiler supply chain.

The specific objectives of this thesis are

1. Develop a model of the US broiler supply chain that captures the vertical and horizontal linkages,

2. Collect data for all segments of the US broiler supply chain,

3. Calibrate the US broiler model to ensure the model accurately represents the data,

4. Run two counterfactual analyses to analyze the impact of US

    (a) Shock to the corn and soybean prices on the broiler industry due to tariffs imposed by China on US corn and soybeans

    (b) Increases in the productivity of the grow-out segments on the US broiler industry.

1.6 Organization

The rest of the thesis is organized as follows. The second chapter focuses on agent specific analysis on broiler industry, the effect of sanitary policy on the industry, consumer preferences, and the review of the existing relevant literatures, particularly with regard to the methods and findings. The third chapter presents the method of simulation model for each segment of production vertically and horizontally. In addition, market clearing conditions are described in this section. The fourth chapter presents certain data calculation, its sources, and the results of simulation analysis. Calibration of certain variables are demonstrated in this section. Furthermore, the fourth chapter illustrates the results of the price shocks of corn and soybean and productivity increase in grow-out farmers that affects the input and output prices for all parts of the supply chain.

Chapter 2.   Literature Review

2.1   Economic Analysis Papers

This chapter reviews the literature pertaining to the broiler industry in four sections: a) agent-specific analysis which includes food safety, structural and technological change, and feed cost, b) sanitary and tariff effects on the broiler trade, c) shift in consumer preferences, and d) existing supply chain models. This chapter concludes by highlighting the contribution of this thesis to the literature.

2.1.1   Agent-Specific Analysis

A large portion of the literature analyzing the broiler industry focuses on the impact of a specific event on a specific segment of the industry. Food recalls in the poultry industry have adversely impacted both producers and consumers of poultry products. Thomsen and McKenzie (2001) investigated the effects of food recalls and ensuing financial support from the government on meat and poultry firms that are publicly traded.[1] In doing so, they analyzed the impact of internalizing losses of food recall on stock value and investment decisions. The authors analyzed stock values between 1982 and 1998 using an Event Study framework. The results showed that when news was published of a food safety risk for food companies' products, the stock value decreased; in other words, recalls announcements have negative effects on the stock market. Furthermore, these losses are not temporary and can last for about one month after the announcement. Dahlgran and Fairchild (2002) examined the severity of financial losses because of a decrease in demand for chicken meat due to adverse food safety news. They implemented an advertising-induced demand shifts model to derive an advertising response function. They estimated the response function using weekly data on Salmonella contamination news. The results revealed that negative news about food safety in chicken products has almost no effect on chicken demand, which implies consumers have a short memory about negative food-safety news.

---

[1]They focus on firms that are publically traded on the New York Stock Exchange (NYSE), American Stock Exchange (AMEX), and NASDAQ.

There are several studies that focus on the technological changes and structure of the broiler industry. For example, Ollinger et al. (2005) investigated technological change and its impacts on the US poultry industry. In doing so, they highlighted how vertical integration has impacted the cost structure in the poultry industry. They utilized a trans-log cost function to model slaughter plant cost by using time series data. The data were obtained for individual plants from the US Census Bureau for the years 1967 - 1992. Their results showed an increase in plant size in the US poultry industry. Furthermore, relative to the cattle and hog slaughter industries, not only is the size increase and economies of scales in poultry plants more pronounced, but there is a higher degree of vertical integration. This situation led to a reduction in the cost of production in the poultry industry. However, if poultry firms build larger plants , they could decrease processing cost even more. Although the new type value-added of consumer demand product caused a higher production cost, technological change in the process led to a lowered cost of plants for huge plant sizes and greater commodity specialization. Ollinger (2011) investigated the increase in plant size and economies of scale in the poultry slaughter industry[2] throughout a period of heightened government oversight through the Hazard Analysis and Critical Control Points (HACCP) system. They demonstrated the effects of HACCP and the structural change on long-run costs for this industry in the 1990s. For their analysis, the authors employed a trans-log cost function and plant-level data was obtained from the Longitudinal Research Database maintained at the Center for Economic Studies of the U.S. Bureau of the Census. They found that, for processed meat, the cost share of primary inputs (e.g., live chickens, cattle, and hogs) decreased, while labor and capital cost shares went up in all industries. However, the total cost of production rose in the long run for all meat processing industries as a result of HACCP; note that this result is in contrast to Ollinger et al. (2005), who found that total cost decreased after the implementation of HACCP. Bukari (2014) primarily focused on the effects of structural changes on performance and industry size for integrators and grow-out farms in Tennessee. This thesis utilized secondary

---

[2]This paper also analyzes cattle and pork industries.

data from the Tennessee Department of Agriculture and collected primary data through a survey. The results showed that successful agreements between independent grow-out farmers and large integrators are a main cause of structural change in the broiler industry in Tennessee. This structural change has led to heightened vertical coordination and a reduction in transaction costs.

There are few studies that analyze supply shock on broiler prices and poultry price relationships across different products and US regions. Holt and McKenzie (2003) analyzed the impact of supply shocks on US broiler producers' price expectation by incorporating the additional information provided by future prices into a standard price regression. That is, the authors incorporated future prices in the expectation formulation in a "Hamilton-type" model. The result suggested that a surge in corn prices has a small but permanent effect on expected broiler price and broiler production. However, a shock to future prices in the beef and pork industries caused a long-run and highly significant adjustment in the broiler industry. Goodwin et al. (2003) examined price relationships among chicken parts in the wholesale broiler market using vector auto-regressive regression time series modeling approach. Their analysis implements monthly data for prices of chickens without giblets, boneless and skinless breasts, wings, and leg quarters for the years between 1987 and 2000. The results revealed a strong price relationship between chickens without giblets and boneless and skinless breast meat, whereas a weaker price relationship exists among other broiler meat categories. For example, the price transmission effect of a shock to breast meat is substantially higher than a similar shock to dark meat markets on chickens without giblets. Awokuse and Bernard (2007) examined the structure of the US broiler market by considering if the law of one price holds across urban areas in the Northeast, South, Midwest, and West. They implemented multivariate co-integration methods and dynamic time-series techniques using data obtained from the US Bureau of Labor Statics. The results indicate that, though evidence exists for long-run spatial integration in the regional broiler market, the law of one price does not hold. Further-

more, price signals transfer from net-producing areas (South and Midwest) to net consuming areas (Northeast and West).

While feed cost is an important input in broiler production, feed costs have received relatively little attention in the literature. Suh and Moss (2016) investigated the substitution between Distiller's Dried Grain with Solubles (DDGS) and corn-based feed as production and prices change using a dynamic linear logic model. Results showed that, because corn and soybean demand is inelastic, a rise in the price of corn and soybean meal result in high input costs for feed-input related sectors. Also, production increases in livestock and poultry resulted in decreasing the relative shares of corn and soybean meal to DDGS. Therefore, producers consider DDGS to be a significant substitute for corn-based feed, which can lead to decreased feed cost in poultry production.

2.1.2 Sanitary policy effect on Broiler trade papers

Given the highly contagious nature of Highly Pathogenic Avian Influence (HPAI), several studies have analyzed the impact of Sanitary and Phytosanitary (SPS) barriers imposed by governments of chicken importing countries. Wieck et al. (2012) investigated trade and welfare impacts of importer countries' (e.g., Russia and Japan) policy changes regarding avian influenza on important broiler exporters (e.g., Brazil, China, France, Germany, Netherlands, and the United States). The trade impacts are estimated via a gravity model using a Hackman-type econometric model approach and data collected from the UN Comtrade Database. Then, welfare impacts are considered by employing a spatial-equilibrium simulation analysis based on the Takayama–Judge approach. For their simulation, they consider two scenarios: first is the drastic scenario,[3] and the second is the realistic scenario.[4] The econometric results show that a ban on uncooked poultry meat almost eliminates trade flows. The simulation analysis

---

[3]Avian influenza-free countries ban both cooked and uncooked poultry import from highly pathogenic avian influenza and low pathogenic avian influenza countries, whereas low pathogenic avian influenza ban both cooked and uncooked poultry imports from highly pathogenic avian influenza countries.

[4]Both avian influenza-free countries and low pathogenic avian influenza countries ban uncooked poultry import from highly pathogenic avian influenza countries.

revealed three key results: production shifted from uncooked to cooked meat, a trade diversion effect based on a country's infection status, and global welfare decreased when an import ban policy was applied in both scenarios.

Peterson and Orden (2005) analyzed the impacts of the removal of SPS barriers, tariffs, and tariff-rate quotas on poultry trade by implementing a partial-equilibrium trade model that differentiates between high-value (i.e., white) and low-value (i.e., dark) meat. They simulate four different scenarios[5] in the world market. The benchmark bilateral trade flows are obtained from the USDA's International Bilateral Agricultural Trade Database. Removing only tariff and tariff-rate quotes have limited but positive effects on world trade, whereas removal of all barriers has the largest positive impact on the quantity of world poultry trade. On the other hand, the Russian import ban on US poultry products has a negative impact of trade flows but small overall impact on US poultry producers. Djunaidi and Djunaidi (2007) measured the effects of 15 region-based hypothetical HPAI outbreak scenarios on world poultry trade volumes and prices by employing a spatial equilibrium model based on (Takayama and Judge, 1964). The results showed that when the United States and Brazil are hit by a HPAI outbreak, there is a large negative impact on poultry trade; however, these two countries remain the two largest chicken suppliers.

2.1.3   Shift in Consumer Preferences

A shift in consumer preference in the 1970s led to structural changes in meat (poultry, beef, and pork) demand as consumers substituted poultry meat for beef (Unnevehr et al., 2010). Thurman (1987) investigated the stability of poultry demand empirically by employing OLS, instrumental variables model, and two-stage least squares utilizing annual data for 1955 to 1981 from the US poultry market. The results showed a shift in demand for chicken meat in the 1970s, while pork and poultry shifted from substitutes to independence. Their results also show that, for poultry demand, price is predetermined and quantity is the appropriate de-

---

[5]The four scenarios are removal of a) tariffs and tariff-rate quotas only, b) SPS barriers only c) tariffs, taiff-rate quatos, and SPS barriers, and d) Russian ban on dark meat imports from the United States.

pendent variable in estimating poultry demand. However, Eales and Unnevehr (1993) investigated whether all kinds of meat prices and quantities are endogenous. Also, they aimed to explain changes in consumer preferences for meat demand. The authors utilized an Inverse of the Almost Ideal Demand System model and obtained data from the USDA annually from 1962 to 1989. Results proved that for all categories of meat, prices, and quantities are endogenous. In addition, demand shifts from beef to poultry meat stem from supply-side driven price shocks. Chavas (1983) built a model that demonstrated structural shift in meat demand between 1975 and 1979 by utilizing a linear model based on the Kalman Filter and Akaike estimation of the variance of random coefficients model. Results revealed significant changes in demand for beef and poultry meat; however, they found no changes in pork demand. Furthermore, by analyzing income elasticities, they found that consumer preferences shifted toward poultry meat more so than beef. Eales and Unnevehr (1988) investigated two questions: a) whether consumers prefer meat by looking at the type of animal or product type, and b) whether structural changes in meat demand stem from disaggregation of meat into products. They utilized an Almost Ideal Demand System model to analyze these questions. The primary data source was the USDA for the years 1965 - 1985. Their results showed that consumers choose different types of meat by looking at quality of the meat, not by looking at the type of animal. Also, the model showed that consumers preferred chicken meat instead of beef after 1976. According to Piggott and Marsh (2004), no consensus has emerged as to whether changes in prices and income or other factors (i.e., health concerns or technological advances) are responsible for the changes in meat demand.

2.1.4 Existing Supply Chain Models

The literature analyzing the poultry industry largely includes studies of specific events or agents. Furthermore, the literature that employs large-scale impact assessment models does not capture the full supply chain.

Existing large-scale models of the U.S. agricultural sectors do not capture the full poultry supply chain or allow for detained policy analysis along the supply chain. For example,

while the GTAP model (a highly popular computable general equilibrium model) does include vertical linkages in the supply chain, it aggregates poultry and other animal sectors together, making poultry-specific analysis difficult. The Food and Agricultural Policy Research Institute (FAPRI) maintains an econometric poultry model as part of its multi-commodity modeling system (FAPRI, 2004, 2018). As part of the poultry supply sector, the model specifies the number of pullets placed, broiler production, feed costs, and retail prices. However, the complete supply chain and structure of integrators is not fully captured, as hatcheries and breeders are modeled as one stage of production and processed broiler products (which account for approximately 49% of the market share (NCC, 2018b)) are not modeled. Furthermore, linear supply functions are econometrically estimated, as opposed to modeling profit functions with revenue and cost explicitly defined. The partial-equilibrium Aglink-Cosimo model (OECD, 2014) disaggregates poultry production and disappearance, but mainly focuses on world agriculture markets. Therefore, many of the vertical supply relations are not modeled.

2.2 Contribution to Literature

As this literature review reveals, the majority of studies examining the poultry industry focuses on the impact of an event on a specific segment of the poultry supply chain or closely related segments. Furthermore, while large scale supply chain simulation models do include poultry, poultry is either aggregated with other meat products or does not incorporate the entire supply chain. In addition, the poultry sector is not the primary focus of the existing large scale supply chain models, and, consequently, the poultry industry is underserved by these models. The contribution of this thesis is to comprehensively model the broiler supply chain. In doing so, the model can analyze the impact of Chinese tariffs on corn and soybean and productivity increase in grow-out segments and its effect on all segments of the poultry supply chain.

Chapter 3.   Theoretical Model and Analysis

3.1   Model

This chapter develops the vertical and horizontal supply chain model of the US broiler in-dustry.   The supply chain consists of corn/soybean, feed mills, breeders, hatcheries, grow-out farms, broiler processing, value-added, and exports.   Although the broiler industry is highly integrated (with the integrator controlling feed mills, breeders, hatcheries, broiler processing, and value-added), except for corn and soybean which are modeled with supply functions, each stage along the supply chain is controlled by a profit maximizing agent.[1]   The supply chain arises from upstream agents in the supply chain supplying or selling inputs to downstream agents.

To focus on the vertical integration of the model, we only include inputs that are part of the supply chain, while other inputs such as labor, capital, and land are excluded from the profit function.   Therefore, labor, capital, and land are fixed factors of production and the value of these input are capture in the returns-to-scale parameter, defined below.

All output and input prices along the supply chain are determined endogenously through market-clearing conditions.   Next, each segment (corn/soybean, feed mills, breeders, hatcheries, grow-out farms, broiler processing, and value-added) is defined in turn.   Then, the market-clearing conditions are established.

3.1.1   Corn/Soybean Segment

The corn and soybean segment of the supply chain is independent from the integrator. Corn and soybean required for broiler feed mills have been taken into consideration instead of total quantity of corn and soybean because the model only focuses on the broiler industry. Therefore, we define residual supply of corn $\left(S^C\right)$ and soybean $\left(S^{SM}\right)$ to broiler feed mills are represented as reduced-form supply functions:

$$S^C = \psi^C \left(p^C\right)^{\varepsilon^C},\tag{3.1}$$

---

[1]Note that due to a lack of public data on genetic companies, we are not able to include the genetics segment in the supply chain model.

$$S^{SM} = \psi^{SM} \left(p^{SM} \right)^{\varepsilon^{SM}}, \tag{3.2}$$

where p^C and p^{SM} are the prices of corn and soybean, respectively, ψs are supply scale parameters, and εs are elasticities.

3.1.2 Feed Mills

The feed mill segment is controlled by the integrator because feed formulas are tightly controlled by integrators. Thus, feed is not purchased from large feed companies. Feed mills buy corn and soybean from the independent farmers or grain elevators to produce broiler feed. The profit maximization function $\left(\Pi^F \right)$ for feed mills is

$$\Pi^F = \rho^F Q^F - C^F \left(p^C, p^{SM}, Q^F \right), \tag{3.3}$$

where ρ^F is the transfer price of feed and Q^F is quantity of feed. $C^F(\cdot)$ is the cost function for feed

$$C^F(\cdot) = \left(\frac{Q^F}{A^F} \right)^{\frac{1}{v^F}} \left[\left(\alpha_C^F \right)^{\frac{1}{1+\eta^F}} \left(p^C \right)^{\frac{\eta^F}{1+\eta^F}} + \left(\alpha_{SM}^F \right)^{\frac{1}{1+\eta^F}} \left(p^{SM} \right)^{\frac{\eta^F}{1+\eta^F}} \right]^{\frac{1+\eta^F}{\eta^F}}, \tag{3.4}$$

where p^C is cost price of corn, p^{SM} is cost price of soybean, A^F is productivity, v^F is returns to scale, α_C^F and α_{SM}^F are share parameters, and η^F is the CES parameter. Define $\chi^F \equiv \left(\alpha_C^F \right)^{\frac{1}{1+\eta^F}} \left(p^C \right)^{\frac{\eta^F}{1+\eta^F}} + \left(\alpha_{SM}^F \right)^{\frac{1}{1+\eta^F}} \left(p^{SM} \right)^{\frac{\eta^F}{1+\eta^F}}$. Then, taking the partial derivative of profits with respect to Q^F and setting it equal to zero gives the first-order condition:

$$\frac{\partial \Pi^F}{\partial Q^F} = \rho^F - \left[\left(\frac{Q^F}{A^F} \right)^{\frac{1}{v^F}-1} \frac{\left[\chi^F \right]^{\frac{1+\eta^F}{\eta^F}}}{v^F A^F} \right] = 0. \tag{3.5}$$

Solving for Q^F yields supply as a function of the output price and input prices:

$$Q^F = \left(\frac{1}{\rho^F v^F} \left(A^F \right)^{\frac{-1}{v^F}} \left[\chi^F \right]^{\frac{1+\eta^F}{\eta^F}} \right)^{\frac{v^F}{v^F-1}}. \tag{3.6}$$

Using Shepard's lemme, take partial derivatives of the cost function with respect to each input price (p^C and p^{SM}) to obtain input demand functions for corn (D_C^F) and soybean (D_{SM}^F), respec-

tively:

$$D_C^F = \frac{\partial C^F(\cdot)}{\partial p^C} = \left(\frac{Q^F}{A^F}\right)^{\frac{1}{v^F}} \left((\chi^F)^{\frac{1}{\eta^F}} (\alpha_1^F)^{\frac{1}{1+\eta^F}} (p^C)^{\frac{-1}{1+\eta^F}}\right), \tag{3.7}$$

$$D_{SM}^F = \frac{\partial C^F(\cdot)}{\partial p^{SM}} = \left(\frac{Q^F}{A^F}\right)^{\frac{1}{v^F}} \left((\chi^F)^{\frac{1}{\eta^F}} (\alpha_2^F)^{\frac{1}{1+\eta^F}} (p^{SM})^{\frac{-1}{1+\eta^F}}\right). \tag{3.8}$$

The feed mill industry is downstream in the supply chain from the corn and soybean segment because corn and soybean are sold as inputs to the feed mill segments. Mathematically, in the corn and soybean segments, the corn and soybean prices are *output* prices, while in the feed mill segment these are *input* prices to feed production.

3.1.3 Breeders

The breeders segment of supply chain is independent from the integrators. Breeder companies produce new lines of breeder stock to meet specific market requirements. After producing a new type of breeder stocks, they sell eggs to pullet farmers (contracted), who raise the chicken until it can start producing eggs for the hatchery (about 1 year). *Pullets* are not explicitly modeled here; one can think of pullet as part of the breeders' costs, in which feed is the main requirement for pullets to produce eggs. The other costs such as labor or technical research expenditure are fixed factors of production reflected in the returns-to-scale parameter. The profit maximization function $\left(\Pi^B\right)$ for breeders is

$$\Pi^B = p^B Q^B - C^B\left(\rho^F, Q^B\right), \tag{3.9}$$

where p^B is the price of fertilized eggs and Q^B is the quantity of fertilized eggs. $C^B(\cdot)$ is the cost function for producing fertilized eggs:

$$C^B(\cdot) = \left(\frac{Q^B}{A^B}\right)^{\frac{1}{v^B}} \rho^F, \tag{3.10}$$

where ρ^F is transfer cost price for feed, A^B is productivity, and v^B is returns to scale. Taking the partial derivative of profit with respect to Q^B and setting it equal to zero gives the first-

order condition:

$$\frac{\partial \Pi^B}{\partial Q^B} = p^B - \left[\left(\frac{Q^B}{A^B} \right)^{\frac{1}{v^B}-1} \frac{\rho^F}{v^B A^B} \right] = 0. \tag{3.11}$$

Solving for Q^B yields supply as a function of the output price and input prices:

$$Q^B = \left(\frac{1}{p^B v^B} \left(A^B \right)^{\frac{-1}{v^B}} \rho^F \right)^{\frac{v^B}{v^B-1}}. \tag{3.12}$$

Using Shepard's lemme, take the partial derivatives of the cost function with respect to ρ^F to obtain input demand functions for feed (D_F^B):

$$D_F^B = \frac{\partial C^B(\cdot)}{\partial \rho^F} = \left(\frac{Q^B}{A^B} \right)^{\frac{1}{v^B}}. \tag{3.13}$$

The breeders industry is downstream in the supply chain from the feed mills segment because the broiler feed is sold as an input to the breeders. Mathematically, in the feed mills segment, the feed prices are output prices, while in the breeders segment the feed price is input price to fertilized eggs production.

3.1.4 Hatcheries

The hatcheries are controlled by the integrator. In the hatching segment, fertilized eggs were purchased from the breeder to produce day-old chicken, which is the only expense for hatching stage. The other costs such as land and labor are fixed factors of production that are reflected in the returns-to-scale parameter. The profit maximization function for hatchery Π^H is

$$\Pi^H = \rho^H Q^H - C^H \left(p^B, Q^H \right), \tag{3.14}$$

where ρ^H is the transfer price of day old chicken (DOC) and Q^H is the number of DOCs. $C^H(\cdot)$ is the cost function for producing DOC:

$$C^H(\cdot) = \left(\frac{Q^H}{A^H} \right)^{\frac{1}{v^H}} p^B, \tag{3.15}$$

22

where A^H is productivity and v^H is returns to scale. Taking the partial derivative of profits with respect to Q^H and setting it equal to zero gives the first-order condition:

$$\frac{\partial \Pi^H}{\partial Q^H} = \rho^H - \left[\left(\frac{Q^H}{A^H} \right)^{\frac{1}{v^H}-1} \frac{p^B}{v^H A^H} \right] = 0. \tag{3.16}$$

Solving for Q^H yields supply as a function of the output price and input prices:

$$Q^H = \left(\frac{1}{\rho^H v^H} \left(A^H \right)^{\frac{-1}{v^H}} p^B \right)^{\frac{v^H}{v^H-1}}. \tag{3.17}$$

Using Shepard's lemme, taking the partial derivatives of the cost function with each input price (p^B) to obtain yields input demand functions for fertilized eggs (D_B^H):

$$D_B^H = \frac{\partial C^H(\cdot)}{\partial p^B} = \left(\frac{Q^H}{A^H} \right)^{\frac{1}{v^H}}. \tag{3.18}$$

The hatchery industry is downstream in the supply chain from the breeders segment because the fertilized eggs are sold as an input to the hatcheries by breeders. Mathematically, in the breeders segment, fertilized eggs are output prices, while in the hatchery segment, fertilized is input price to produce day-old chicken.

3.1.5   Grow-Out Farmers

The grow-out farms are independent from the integrator. More than 90% of chicken production in the United States is raised by independent farmers. The farmers enter into a contract with the integrators. Although there are different types of agreements between integrators and farmers based on different integrators, the main structure of agreement is similar, in which integrators provide chicks, feed, technical service, managerial expertise, and a guaranteed market. The farmers are responsible for the land, labor, utilities, and other operating expenses, which we model as fixed factors of production reflected in the returns-to-scale parameter. The farmers are supplied feed and DOC from integrators based on their contracts and are the primary costs for grow-out farmer. Then, they sell their broiler chickens when they reach

23

desired weight. The profit maximization function for grow-out farmer Π^G is

$$\Pi^G = p^G Q^G - C^G \left(\rho^H, \rho^F, Q^G \right), \tag{3.19}$$

where p^G is the price of full grown live chickens and Q^G is the number of full grown live chickens. $C^G(\cdot)$ is the cost function for full grown live chicken:

$$C^G(\cdot) = \left(\frac{Q^G}{A^G} \right)^{\frac{1}{\nu^G}} \left[\left(\alpha_1^G \right)^{\frac{1}{1+\eta^G}} \left(\rho^H \right)^{\frac{\eta^G}{1+\eta^G}} + \left(\alpha_2^G \right)^{\frac{1}{1+\eta^G}} \left(\rho^F \right)^{\frac{\eta^G}{1+\eta^G}} \right]^{\frac{1+\eta^G}{\eta^G}}, \tag{3.20}$$

where A^G is productivity, ν^G is returns to scale, α_1^G and α_2^G are share parameters, and η^G is the CES parameter. Define $\chi^G \equiv \left(\alpha_1^G \right)^{\frac{1}{1+\eta^G}} \left(\rho^H \right)^{\frac{\eta^G}{1+\eta^G}} + \left(\alpha_2^G \right)^{\frac{1}{1+\eta^G}} \left(\rho^F \right)^{\frac{\eta^G}{1+\eta^G}}$. Then, taking the partial derivative of profit with respect to Q^G and setting it equal to zero gives the first-order condition:

$$\frac{\partial \Pi^G}{\partial Q^G} = p^G - \left[\left(\frac{Q^G}{A^G} \right)^{\frac{1}{\nu^G}-1} \frac{\left[\chi^G \right]^{\frac{1+\eta^G}{\eta^G}}}{\nu^G A^G} \right] = 0. \tag{3.21}$$

Solving for Q^G yields supply as a function of the output price and input prices:

$$Q^G = \left(\frac{1}{p^G \nu^G} \left(A^G \right)^{\frac{-1}{\nu^G}} \left[\chi^G \right]^{\frac{1+\eta^G}{\eta^G}} \right)^{\frac{\nu^G}{\nu^G-1}}. \tag{3.22}$$

Using Shepard's lemme, take the partial derivatives of the cost function with respect to each input price (ρ^H and ρ^F) to obtain input demand functions for hatching eggs (D_H^G) and feed (D_F^G), respectively:

$$D_H^G = \frac{\partial C^G(\cdot)}{\partial \rho^H} = \left(\frac{Q^G}{A^G} \right)^{\frac{1}{\nu^G}} \left(\left(\chi^G \right)^{\frac{1}{\eta^G}} \left(\alpha_1^G \right)^{\frac{1}{1+\eta^G}} \left(\rho^H \right)^{\frac{-1}{1+\eta^G}} \right), \tag{3.23}$$

$$D_F^G = \frac{\partial C^G(\cdot)}{\partial \rho^F} = \left(\frac{Q^G}{A^G} \right)^{\frac{1}{\nu^G}} \left(\left(\chi^G \right)^{\frac{1}{\eta^G}} \left(\alpha_2^G \right)^{\frac{1}{1+\eta^G}} \left(\rho^F \right)^{\frac{-1}{1+\eta^G}} \right). \tag{3.24}$$

The grow-out farmers are downstream in the supply chain from the feed mills and the hatchery segments because feed and day-old chicken are sold as inputs to the grow-out farmer. Mathematically, the prices of feed and day-old chicken are output prices for feed mill and

hatcheries, respectively, while these prices are input variables for grow-out farmer to produce broiler chickens.

3.1.6 Processing Plants

The processing plants are controlled by the integrator. A processing plant is the main segment in which broiler chickens are prepared for selling in the market as a whole chicken and chicken parts by slaughtering and packaging. Also, in this section, live broiler chickens are prepared for value-added processing segments. Because chicken parts and preparing chicken value-added products require more processing than whole birds, we model whole chickens separately from chicken parts and processing for value-added products.

3.1.6.1 *Whole Chickens*

For whole chicken, the main input is broiler chicken purchased (transfered) from grow-out farmers based on the contract agreements. The profit maximization function for a whole chicken Π^W is

$$\Pi^W = p^W Q^W - C^W \left(p^G, Q^W \right) \tag{3.25}$$

where p^W is price per pound of whole chickens and Q^W is number of pounds of whole chickens produced. $C^W (\cdot)$ is the cost function of whole chickens:

$$C^W (\cdot) = \left(\frac{Q^W}{A^W} \right)^{\frac{1}{v^W}} p^G, \tag{3.26}$$

where A^W is productivity and v^W is returns to scale. Taking the partial derivative of profits with respect to Q^W and setting it equal to zero gives the first-order condition:

$$\frac{\partial \Pi^W}{\partial Q^W} = p^W - \left[\left(\frac{Q^W}{A^W} \right)^{\frac{1}{v^W} - 1} \frac{p^G}{v^W A^W} \right] = 0. \tag{3.27}$$

Solving for Q^W yields supply as a function of the output price and input prices:

$$Q^W = \left(\frac{1}{p^W v^W} \left(A^W \right)^{\frac{-1}{v^W}} p^G \right)^{\frac{v^W}{v^W - 1}}. \tag{3.28}$$

25

Using Shepard's lemme, taking the partial derivatives of the cost function with respect to p^G to obtain the input demand function for whole chickens (D_G^W):

$$D_G^W = \frac{\partial C^W(\cdot)}{\partial p^G} = \left(\frac{Q^W}{A^W}\right)^{\frac{1}{v^W}}. \tag{3.29}$$

3.1.6.2   Chicken Parts

Next, we define the profit function for chicken parts. Based on data from USDA (2018h), one chicken yields 1.81 pounds of chicken breasts (Q^{Br}) , 0.45 pounds of chicken wings (Q^{Wi}), and 2.12 pounds of dark meat (Q^D). Therefore, one pound of chicken (breast) meat yields γ (0.25) pounds of wings and η (1.17) pounds of dark meat:

$$Q^{Br} = \gamma Q^{Wi} \quad \text{and} \quad Q^{Br} = \eta Q^D. \tag{3.30}$$

The total pounds of chicken parts is

$$Q^P = Q^{Br} + Q^{Wi} + Q^D. \tag{3.31}$$

Combined, the above three equations yield the total pounds of chicken parts in terms of chicken breasts:

$$Q^P = Q^{Br} + \frac{1}{\gamma}Q^{Br} + \frac{1}{\eta}Q^{Br} = Q^{Br}\left(1 + \frac{1}{\gamma} + \frac{1}{\eta}\right). \tag{3.32}$$

Total revenue of chicken parts is obtained by multiplying quantity by price:

$$p^P Q^P = p^{Br} Q^{Br} + p^{Wi} Q^{Wi} + p^D Q^D \tag{3.33}$$

where p^P is a price index for parts, p^{Br} is price per pound of chicken breast, p^{Wi} is price of per pound of chicken wings, and p^D is price per pound of chicken dark meat. We can define the price index for parts by substituting (3.30) into (3.33), which yields

$$
\begin{aligned}
p^P Q^P &= p^{Br} Q^{Br} + p^{Wi}\frac{1}{\gamma}Q^{Br} + p^D\frac{1}{\eta}Q^{Br} \\
p^P Q^P &= \left(p^{Br} + p^{Wi}\frac{1}{\gamma} + p^D\frac{1}{\eta}\right)Q^{Br}
\end{aligned}
$$

Substituting (3.32) into the above equation yields

$$p^P Q^{Br} \left(1 + \frac{1}{\gamma} + \frac{1}{\eta}\right) = \left(p^{Br} + p^{Wi}\frac{1}{\gamma} + p^D\frac{1}{\eta}\right) Q^{Br}$$

$$p^P \left(1 + \frac{1}{\gamma} + \frac{1}{\eta}\right) = p^{Br} + p^{Wi}\frac{1}{\gamma} + p^D\frac{1}{\eta}.$$

Solving for p^P yields the price index for chicken parts:

$$p^P = \frac{\left(p^{Br} + p^{Wi}\frac{1}{\gamma} + p^D\frac{1}{\eta}\right)}{\left(1 + \frac{1}{\gamma} + \frac{1}{\eta}\right)}.$$

The profit maximization function for chicken parts $\left(\Pi^P\right)$ is

$$\Pi^P = p^P Q^P - C^P\left(p^G, p^{PI}, Q^P\right) \tag{3.34}$$

where Q^P is quantity of chicken parts produce. $C^P(\cdot)$ is the cost function of chicken parts:

$$C^P(\cdot) = \left(\frac{Q^P}{A^P}\right)^{\frac{1}{v^P}} \left[\left(p^G\right)\right], \tag{3.35}$$

where A^P is productivity and v^P is returns to scale. Taking the partial derivative of profits with respect to Q^P and setting it equal to zero gives the first-order condition:

$$\frac{\partial \Pi^P}{\partial Q^P} = p^P - \left[\frac{1}{v^P}\left(\frac{Q^P}{A^P}\right)^{\frac{1}{v^P}-1}\frac{1}{A^P}\left[\left(p^G\right)\right]\right] = 0. \tag{3.36}$$

Solving for Q^P yields supply as a function of the output price and input prices:

$$Q^P = \left(\frac{1}{p^P v^P}(A^P)^{\frac{-1}{v^P}}\left[p^G\right]\right)^{\frac{v^P}{v^P-1}}. \tag{3.37}$$

Using Shepard's lemme, take the partial derivatives of the cost function with respect to p^G to obtain the input demand function for grown whole chicken (D_G^P):

$$D_G^P = \frac{\partial C^P(\cdot)}{\partial p^G} = \left(\frac{Q^P}{A^P}\right)^{\frac{1}{v^P}}. \tag{3.38}$$

3.1.6.3 Chicken Processing for the Value-added Segment

For chickens processed for value-added products, the main input is broiler chicken bought from the grow-out farmers. The profit maximization function Π^{PV} is

$$\Pi^{PV} = \rho^{PV} Q^{PV} - C^{PV}\left(p^G, Q^{PV}\right), \tag{3.39}$$

where ρ^{PV} is the transfer price per pound of whole chickens and Q^{PV} is number of pounds of value-added processing. $C^{PV}(\cdot)$ is the cost function of whole chickens:

$$C^{PV}(\cdot) = \left(\frac{Q^{PV}}{A^{PV}}\right)^{\frac{1}{v^{PV}}} p^G, \tag{3.40}$$

where A^{PV} is productivity and v^{PV} is returns to scale. Taking the partial derivative of profits with respect to Q^{PV} and setting it equal to zero gives the first-order condition:

$$\frac{\partial \Pi^{PV}}{\partial Q^{PV}} = \rho^{PV} - \left[\left(\frac{Q^{PV}}{A^{PV}}\right)^{\frac{1}{v^{PV}}-1} \frac{p^G}{v^{PV} A^{PV}}\right] = 0. \tag{3.41}$$

Solving for Q^{PV} yields supply as a function of the output price and input prices:

$$Q^{PV} = \left(\frac{1}{\rho^{PV} v^{PV}} \left(A^{PV}\right)^{\frac{-1}{v^{PV}}} p^G\right)^{\frac{v^{PV}}{v^{PV}-1}}. \tag{3.42}$$

Using Shepard's lemme, take the partial derivatives of the cost function with respect to p^G to obtain the input demand function for demand for grow-out chicken (D_G^{PV}):

$$D_G^{PV} = \frac{\partial C^{PV}(\cdot)}{\partial p^G} = \left(\frac{Q^{PV}}{A^{PV}}\right)^{\frac{1}{v^{PV}}}. \tag{3.43}$$

The processing segment of all whole chickens, chicken parts, and processing for value-added products is downstream in the supply chain from the grow-out farmers because broiler chickens are sold as inputs to processor. Mathematically, the price of broiler chicken is an output price for grow-out farmers, while the price of broiler chicken is an input price for whole chickens, chicken parts, and processing for value-added. In addition, there is internal horizontal linkage in the processing segments of the broiler supply chain between whole chickens, chicken parts and processing for value-added. This linkage arises because all whole chickens,

chicken parts, and processing for value-added segments demand broiler chickens, implying that they compete with each other for broiler chicken.

3.1.7 Value-Added Plants

The value-added plants are controlled by the integrator. The purpose of value-added plants is to add value on the broiler chicken by applying some well-known recipes to make ready-to-cook products in the retailer and wholesale market. In this production segment, an operator buys slaughtered chicken ready to value-add as an input. Then, outputs such as chicken nuggets sell to the wholesaler and retailer. Profit maximization function for value-added plants Π^{VA} is

$$\Pi^{VA} = p^{VA} Q^{VA} - C^{VA} \left(\rho^{PV}, Q^{VA} \right), \tag{3.44}$$

where p^{VA} is price of VA chicken and Q^{VA} is the quantity VA chicken. $C^{VA}(\cdot)$ is the cost function for value-added chicken:

$$C^{VA}(\cdot) = \left(\frac{Q^{VA}}{A^{VA}} \right)^{\frac{1}{v^{VA}}} \rho^{PV}, \tag{3.45}$$

where A^{VA} is productivity and v^{VA} is returns to scale. Taking the partial derivative of profits with respect to Q^{VA} and setting it equal to zero gives the first-order condition:

$$\frac{\partial \Pi^{VA}}{\partial Q^{VA}} = p^{VA} - \left[\frac{1}{v^{VA}} \left(\frac{Q^{VA}}{A^{VA}} \right)^{\frac{1}{v^{VA}}-1} \frac{\rho^{PV}}{A^{VA}} \right] = 0. \tag{3.46}$$

Solving for Q^{VA} yields supply as a function of the output price and input prices:

$$Q^{VA} = \left(\frac{\left(A^{VA} \right)^{\frac{-1}{v^{VA}}}}{p^{VA} v^{VA}} \rho^{PV} \right)^{\frac{v^{VA}}{v^{VA}-1}}. \tag{3.47}$$

Using Shepard's lemme, take the partial derivatives of the cost function with respect to ρ^{PV} to obtain the input demand function for processed chickens (D_{PV}^{VA}):

$$D_{PV}^{VA} = \frac{\partial C^{VA}(\cdot)}{\partial \rho^{PV}} = \left(\frac{Q^{VA}}{A^{VA}} \right)^{\frac{1}{v^{VA}}}, \tag{3.48}$$

The value-added segment is downstream in the supply chain from the grow-out farmers because broiler chickens are sold as inputs to grow-out farmers. Mathematically, the prices of broiler chickens are output price for grow-out farmers, while the prices of broiler chickens are input price for value-added plants. Also, there is a horizontal linkage between sales of whole chickens/parts and value-added chicken because these two segments both demand slaughtered chickens from processing plants. Therefore, whole chicken, chicken parts, and value-added segments all compete with each other for slaughtered chickens.

3.1.8   Market-Clearing Conditions

This section provides market-clearing conditions, which determine prices endogenously, for each segment of the broiler supply chain. For the corn and soybean segment, the market-clearing conditions are

$$S^C(p_C) = D_C^F(p_C), \tag{3.49}$$

$$S^{SM}(p_{SM}) = D_{SM}^F(p_{SM}). \tag{3.50}$$

The first equation implies total corn supply is equal to the total demand of corn by feed mills. The second equation equates total soybean supply equal to the total demand of soybean by the feed mills. The price of feed is determined by the market-clearing condition:

$$Q^F = D_F^G + D_F^B, \tag{3.51}$$

where total quantity of feed is equal to demanded quantity of feed by grow-out farmers and demanded quantity of feed by breeders. The price of fertilized eggs in the breeders is determined by the market-clearing condition:

$$Q^B = D_B^H, \tag{3.52}$$

where total number of fertilized eggs equals the total demand by hatcheries. The price of DOCs are determined by the market-clearing condition:

$$Q^H = D_H^G, \tag{3.53}$$

where the number of DOCs equal the total demand of the DOC by grow-out farmers. The price of fully grown (grow-out) chickens is determined by the market-clearing condition:

$$Q^G = D_G^{PV} + D_G^P + D_G^W, \tag{3.54}$$

where the total production of broiler chickens is equal to the demanded quantity of broiler chickens by the ready-to-cook segment, processing chicken parts, and whole chicken segments.

The price of whole chicken is determined by the market-clearing condition:

$$Q^W = D_W^{USC}\left(p^W\right) + D_W^{MexC}\left(p^W\right) + D_W^{CanC}\left(p^W\right) + D_W^{ROWC}\left(p^W\right), \tag{3.55}$$

where $D_W^{USC}\left(p^W\right) = \delta_W^{USC}\left(p^W\right)^{\varepsilon_W^{USC}}$ is the reduced-form demand function of US consumers, $D_W^{MexC}\left(p^W\right) = \delta_W^{MexC}\left(p^W\right)^{\varepsilon_W^{MexC}}$ is the reduced-form demand function of Mexican consumers, $D_W^{CanC}\left(p^W\right) = \delta_W^{CanC}\left(p^W\right)^{\varepsilon_W^{CanC}}$ is the reduced-form demand function of Canadian consumers, and $D_W^{ROWC}\left(p^W\right) = \delta_W^{ROWC}\left(p^W\right)^{\varepsilon_W^{ROWC}}$ is the reduced-form demand function of ROW consumers for whole chickens produced in the United States, δ^is are scale parameters, and ε^is are elasticities. This equation indicates that the quantity of whole chicken produced in the United States equals the demand of whole chicken by US, Mexican, Canadian, and ROW consumers.

The prices of chicken parts (chicken breasts, wings, and dark meat) are determined individually by their market-clearing conditions. For chicken breast, the market-clearing condition is

$$Q^{Br} = D_{Br}^{USC}\left(p^{Br}\right) + D_{Br}^{MexC}\left(p^{Br}\right) + D_{Br}^{CanC}\left(p^{Br}\right) + D_{Br}^{ROWC}\left(p^{Br}\right), \tag{3.56}$$

where $D_{Br}^{USC}\left(p^{Br}\right) = \delta_{Br}^{USC}\left(p^{Br}\right)^{\varepsilon_{Br}^{USC}}$ is the reduced-form demand function of US consumers, $D_{Br}^{MexC}\left(p^{Br}\right) = \delta_{Br}^{MexC}\left(p^{Br}\right)^{\varepsilon_{Br}^{MexC}}$ is the reduced-form demand function of Mexican consumers, $D_{Br}^{CanC}\left(p^{Br}\right) = \delta_{Br}^{CanC}\left(p^{Br}\right)^{\varepsilon_{Br}^{CanC}}$ is the reduced-form demand function of Canadian consumers, and $D_{Br}^{ROWC}\left(p^{Br}\right) = \delta_{Br}^{ROWC}\left(p^{Br}\right)^{\varepsilon_{Br}^{ROWC}}$ is the reduced-form demand function of ROW consumers for chicken parts produced in the United States. This market-clearing condition indicates that quantity of chicken breast produced in the US equals the quantity of chicken breast demanded by US, Mexican, Canadian, and ROW consumers. Similarly, for chicken wings, the

market-clearing condition is

$$Q^{Wi} = D_{Wi}^{USC}\left(p^{Wi}\right) + D_{Wi}^{MexC}\left(p^{Wi}\right) + D_{Wi}^{CanC}\left(p^{Wi}\right) + D_{Wi}^{ROWC}\left(p^{Wi}\right), \qquad (3.57)$$

where $D_{Wi}^{USC}\left(p^{Wi}\right) = \delta_{Wi}^{USC}\left(p^{Wi}\right)^{\varepsilon_{Wi}^{USC}}$ is the reduced-form demand function of US consumers, $D_{Wi}^{MexC}\left(p^{Wi}\right) = \delta_{Wi}^{MexC}\left(p^{Wi}\right)^{\varepsilon_{Wi}^{MexC}}$ is the reduced-form demand function of Mexican consumers, $D_{Wi}^{CanC}\left(p^{Wi}\right) = \delta_{Wi}^{CanC}\left(p^{Wi}\right)^{\varepsilon_{Wi}^{CanC}}$ is the reduced-form demand function of Canadian consumers, and $D_{Wi}^{ROWC}\left(p^{Wi}\right) = \delta_{Wi}^{ROWC}\left(p^{Wi}\right)^{\varepsilon_{Wi}^{ROWC}}$ is the reduced-form demand function of ROW consumers for chicken wings produced in the United States. For dark meat, the market-clearing condition is

$$Q^{D} = D_{D}^{USC}\left(p^{D}\right) + D_{D}^{MexC}\left(p^{D}\right) + D_{D}^{CanC}\left(p^{D}\right) + D_{D}^{ROWC}\left(p^{D}\right), \qquad (3.58)$$

where $D_{D}^{USC}\left(p^{D}\right) = \delta_{D}^{USC}\left(p^{D}\right)^{\varepsilon_{D}^{USC}}$ is the demand function of US consumers, $D_{D}^{MexC}\left(p^{D}\right) = \delta_{D}^{MexC}\left(p^{D}\right)^{\varepsilon_{D}^{MexC}}$ is the demand function of Mexican consumers, $D_{D}^{CanC}\left(p^{D}\right) = \delta_{D}^{CanC}\left(p^{D}\right)^{\varepsilon_{D}^{CanC}}$ is the demand function of Canadian consumers, $D_{D}^{ROWC}\left(p^{D}\right) = \delta_{D}^{ROWC}\left(p^{D}\right)^{\varepsilon_{D}^{ROWC}}$ is the demand function of ROW consumers for dark meat produced in the United States. The price of processing for value-added products is determined by the market-clearing condition:

$$Q^{PV} = D_{VA}^{PV}, \qquad (3.59)$$

where total supply of slaughtered chicken equals demand for slaughtered chicken for value-added products.

The price of value-added chicken is determined by the market-clearing condition:

$$Q^{VA} = D_{VA}^{USC}\left(p^{VA}\right) + D_{VA}^{MexC}\left(p^{VA}\right) + D_{VA}^{CanC}\left(p^{VA}\right) + D_{VA}^{ROWC}\left(p^{VA}\right), \qquad (3.60)$$

where $D_{VA}^{USC}\left(p^{VA}\right) = \delta_{VA}^{USC}\left(p^{VA}\right)^{\varepsilon_{VA}^{USC}}$ is the reduced-form demand function of US consumers, $D_{VA}^{MexC}\left(p^{VA}\right) = \delta_{VAD}^{MexC}\left(p^{VA}\right)^{\varepsilon_{VA}^{MexC}}$ is the reduced-form demand function of Mexican consumers, $D_{VA}^{CanC}\left(p^{VA}\right) = \delta_{VA}^{CanC}\left(p^{VA}\right)^{\varepsilon_{VA}^{CanC}}$ is the reduced-form demand function of Canadian consumers, and $D_{VA}^{ROWC}\left(p^{VA}\right) = \delta_{VA}^{ROWC}\left(p^{VA}\right)^{\varepsilon_{VA}^{ROWC}}$ is the reduced-form demand function of ROW consumers for value-added chicken produced in the United States. The equation of this market-clearing condition indicates that the quantity of value-added chicken produced in the US equals

the quantity demanded of value-added chicken by US, Mexican, Canadian, and ROW consumers.

Chapter 4.   Numerical Analysis

This chapter provides three different sections.   The first section provides information about data and sources.   The second section elaborates the calibration procedure for the parameters. The third section discusses the simulation and results.

4.1   Data and Sources

This paper uses secondary and annually data from the government reports and databases from various institutions which include production, consumption, prices, and trade data.   Total production of corn and soybean use in the feed and residual was obtained from the Feed Grains Database, United States Department of Agriculture (USDA) for the 2012-2017 marketing years (USDA, 2018c).   However, since the model needs only the demand of corn and soybean meal in the broiler sector, the percentage of corn and soybean meal used in the broiler industry by utilizing Animal Food Consumption report has been calculated (AFIA, 2017).   This report has just been published about animal feed data for 2016.   Therefore, we assumed that the use of corn and soybean to produce broiler feed has had the same percentage in the last five years.   Corn price was taken from the Quick Stats, USDA for the 2012-2017 marketing years (USDA, 2018h).   Soy-meal price was taken from the Feed Grains Database, USDA for the 2012-2017 annually marketing years (USDA, 2018c).

After finding broiler feed inputs data, broiler feed price was calculated by using a formula 4.1 that was obtained from the National Agricultural Statistic Service (NASS), USDA for each marketing year between 2012 and 2017 (USDA, 2018g).   Feed in the broiler industry is needed by the breeders and the grow-out segments during the chicken production.   Therefore, the total feed production assumed that the total of these two production segments feed were needed.   In 2016, the feed demanded by Grow-out farms is about 96% and breeders is 4%.   This estimation is calculated by taking the Animal Food Consumption Report data into consideration (IFEEDER, 2017).   However, since the report has just been published for 2016 marketing year, the assumption can be made that the feed demand by grow out and breeder farms is between 2012 and 2017.

$$\rho^F = (0.58 * \frac{p^C}{56}) + (0.42 * \frac{p^{SM}}{60}) \qquad (4.1)$$

The data for the next sections for breeder and hatcheries in terms of the number of produced fertilized hatching eggs and hatching eggs use were obtained from NASS, USDA (USDA, 2018d). The price of fertilized eggs and hatched fertilized eggs were taken from a report for 2016 (Clauer, 2017). It was assumed that each fertilized and hatched eggs are the same price during the same time period 2012-2017 since there is only price data for 2016 (Clauer, 2017). The number of hatched fertilized eggs was obtain from Quick Stats,USDA in between 2012-2017 (USDA, 2018h).

After day-old-chicken production, the quantity of producing broiler chicken and its price was obtained from Quick Stats, USDA from 2012-2017 (USDA, 2018h). Broiler chickens are sold into processing plants where they are processed for three different types of meat which are whole chicken, chicken cut up parts (whole chicken, chicken breast, wings, and dark meat), and chicken processing for the value-added segment. The data of percentage of live chicken needed by these three type of processed chickens was obtained from National Chicken Council (NCC, 2018b). Based on these breaking out percentages, the quantities of broiler chicken in these three industries were calculated.

The prices of chicken breast, dark meat, and whole chicken were obtained from US Bureau of Labor Statistics (U.S. Bureau of Labor Statistics, 2018). However, since we could not find chicken wing price for the entire country, we have used wings prices of the southern states which was obtained from USDA Agricultural Marketing Service (AMS) (USDA, 2018f), and the assumption was made that this price is valid all across the United States. The domestic, Mexico, Canada and ROW consumption of whole chicken, chicken breast, wings and dark meat was calculated by using the database of the USDA Foreign Agricultural Service (US-DAFAS) (USDA, 2018i).

In the calculation, total trade value for chicken wings and dark meat was obtained from the standard query, and tariff on this export is zero because of the NAFTA agreement. Therefore,

the domestic US prices of dark meat and wings are the same as Mexican and Canadian dark meat and wing prices. Then, the quantity of Mexico, Canada and ROW chicken demand was calculated by dividing total trade value with unit export prices of the wings and dark meat. The next calculation is for domestic chicken wing and dark meat consumption. The difference between the total quantity of wings and dark meat production and quantity of wings and dark meat exported gave to us domestic chicken wings and dark meat consumption for the United States.

In terms of whole broiler and chicken breast, according to a report from the Economic Research Service, the whole chicken and chicken breast export was approximately 3% and 0.02% of all chicken production, respectively, between 2012 and 2017 (USDA, 2018a). Since the whole chicken and breast meat export value is low, we do not consider exports of these products in the analysis below. Therefore, domestic consumption exactly equals production for whole chicken and chicken breast.

Finally, value-added products total production in US was calculated by utilizing percentage data that was obtained from National Chicken Council. Then, value-added products trade data was taken from United Nation Comtrade database(UNComtrade, 2018). To calculate consumption of domestic value-added products amount, difference between quantity of value-added products export to Mexico, Canada and ROW and total value-added products production in the US allows us to find out domestic value-added products consumption. Also, the export quantity of ROW for dark meat and chicken wings was calculated by using weighted average tariff rate. Tariff rate was obtained by WTO. The price of value added products were assumed to be $1.

4.2 Calibration

This model contains 42 parameters. Because there are eight segments in the supply chain model (corn/soybean production,feed mills, breeders, hatcheries, grow out farms, broiler processing, value added, and exports), the parameters in the model are calibrated for each segment separately. Tables 4.1 and 4.2 report parameter values.

Table 4.1: Calibrated and Assumed Parameters

Parameters	Description	Value
ψ^C	Supply Scala parameter for corn production.	4.68×10^{-11}
ψ^{SM}	Supply Scala parameter for soybean production.	2.33×10^{-10}
ε^C	Elasticity for corn	4
ε^{SM}	Elasticity for soybean production.	3
A^F	Productivity for Feed Mills	0.65
v^F	Return to scale for Feed Mills	0.55
α_1^F	Share parameter for Feed Mills	0.77
α_2^F	Share parameter for Feed Mills	0.22
α_3^F	Share parameter for Feed Mills	0
η^F	Constant elasticity of substitution parameters	2
A^B	Productivity for Breeders	4.57
v^B	Return to scale for Breeders	0.25
α_1^B	Share parameter for Breeders	1
α_2^B	Share parameter for Breeders	0
η^B	Constant elasticity of substitution parameters	2
A^H	Productivity for Hatcheries	0.78
v^H	Return to scale for Hatcheries	0.99
α_1^H	Share parameter for Hatcheries	1
α_2^H	Share parameter for Hatcheries	0
η^H	Constant elasticity of substitution parameters	4
A^G	Productivity for Grow-out Farmers	106.51
v^G	Return to scale for Grow-out Farmers	0.91
α_1^G	Share parameter for Grow-out Farmers	0.998
α_2^G	Share parameter for Grow-out Farmers	0.001
α_3^G	Share parameter for Grow-out Farmers	0
η^G	Constant elasticity of substitution parameters	4
A^W	Productivity for Whole Chicken	3.01
v^W	Return to scale for Whole Chicken	0.52
α_1^W	Share parameter for Whole Chicken	1
α_2^W	Share parameter for Whole Chicken	0
η^W	Constant elasticity of substitution parameters	2

Table 4.2: Calibrated and Assumed Parameters Continued

Parameters	Description	Value
A^P	Productivity for Chicken Parts	2.27
v^P	Return to scale for Chicken Parts	0.33
α_1^P	Share parameter for Chicken Parts	1
α_2^P	Share parameter for Chicken Parts	0
η^P	Constant elasticity of substitution parameters	2
A^{PV}	Productivity for Processing Value-added	1.46
v^{PV}	Return to scale for Processing Value-added	0.77
α_1^{PV}	Share parameter for Processing Value-added	1
α_2^{PV}	Share parameter for Processing Value-added	0
η^{PV}	Constant elasticity of substitution parameters	2
A^{VA}	Productivity for Value added	0
v^{VA}	Return to scale for Value added	9.28
α_1^{VA}	Share parameter for Value added	1
α_2^{VA}	Share parameter for Value added	0
η^{VA}	Constant elasticity of substitution parameters	2

4.2.1 Corn/Soybean Segment

Here, we assume the elasticities of supply for corn and soybean to be relatively elastic at $\varepsilon^C = 4$ and $\varepsilon^{SM} = 3$ because these supply functions only account for supply of these primary goods going to the broiler industry. Given these elasticities and data on the corn and soybean prices, we calibrate the corn and soybean supply parameters as

$$\psi^C = \frac{S^C}{(p^C)^{\varepsilon^C}},$$

$$\psi^{SM} = \frac{S^{SM}}{(p^{SM})^{\varepsilon^{SM}}}.$$

4.2.2 Feed mills

Here, we calibrate the cost function parameters for feed mills. With the functional for the cost function give in 3.4, we assume the CES parameter η^F to positive at 2, then the elasticity of substitution is calculated as $\sigma^F = \frac{1}{1+\eta^F} = 0.33$ which implies a low degree of substitutability between corn and soybean. Given the assumption on σ^F and data on the corn price, demand for corn, soybean price, and demand for soybean, we calibrate the corn and soybean

CES share parameters as

$$\alpha_C^F = \frac{p^C D_C^F \frac{1}{\sigma^F}}{p^C D_C^F \frac{1}{\sigma^F} + p^{SM} D_C^{SM} \frac{1}{\sigma^F}},$$

$$\alpha_{SM}^F = \frac{p^{SM} D_{SM}^F \frac{1}{\sigma^F}}{p^C D_C^F \frac{1}{\sigma^F} + p^{SM} D_{SM}^F \frac{1}{\sigma^F}}.$$

Next, we calibrate the returns to scale parameter as input expenditures on corn and soybean ($\tilde{C}^F = p^C D_C^F + p^{SM} D_{SM}^F$) divided by total revenue

$$v^F = \frac{\tilde{C}^F}{\rho^F Q^F}.$$

Finally, given the CES share parameters, returns to scale parameters, and data on total production and input prices, we calibrate the productivity parameter. To do this, note that the total cost function equals input expenditures, which implies that $\tilde{C}^F = C^F(\cdot)$. Then, using this relationship and equation 3.4, the productivity parameter is calibrated as the residual:

$$A^F = Q^F \left(\frac{\tilde{C}^F}{\left[\left(\alpha_C^F\right)^{\frac{1}{1+\eta^F}} \left(p^C\right)^{\frac{\eta^F}{1+\eta^F}} + \left(\alpha_{SM}^F\right)^{\frac{1}{1+\eta^F}} \left(p^{SM}\right)^{\frac{\eta^F}{1+\eta^F}} \right]^{\frac{1+\eta^F}{\eta^F}}} \right)^{-v^F}.$$

4.2.3 Breeders

Here, we calibrate the returns to scale parameter as input expenditure on feed ($\tilde{C}^B = \rho^F D_F^B$) divided by total revenue

$$v^B = \frac{\tilde{C}^B}{p^B Q^B}.$$

Next, using the data on total number of fertilized eggs and price of feed, we calibrate the productivity parameter. As with the feed segment, total cost function equals input expenditure, which implies that $\tilde{C}^B = C^B(\cdot)$. Then, using this relationship and equation 3.10, the productivity parameter is calibrated as the residual:

$$A^B = Q^B \left(\frac{\tilde{C}^B}{\rho^F} \right)^{-v^B}.$$

4.2.4 Hatcheries

Similarly, we calibrate the returns to scale parameter as input expenditure on fertilized eggs ($\tilde{C}^H = p^B D_B^H$) divided by total revenue

$$v^H = \frac{\tilde{C}^H}{\rho^H Q^H}.$$

Next, based on the data on total number of day-old-chickens and price of fertilized eggs, we calibrate the productivity parameter. To do this, note that the total cost function equals input expenditure, which implies that $\tilde{C}^H = C^H(\cdot)$. Then, using this relationship and equation (3.15), the productivity parameter is calibrated as the residual:

$$A^H = Q^H \left(\frac{\tilde{C}^H}{p^B} \right)^{-v^H}.$$

4.2.5 Grow-out Farmers

Here, we calibrate the cost function parameters for grow out farmers. We assume the CES parameter η^G to be 4, then the elasticity of substitution is calculated as $\sigma^G = \frac{1}{1-\eta^G} = 0.2$ which approximates the Leontief cost function. Given the assumption on σ^G and data on demand for day-old-chicken and feed, we calibrate the day-old-chicken and feed CES share parameters as

$$\alpha_H^G = \frac{\rho^H D_H^{G \frac{1}{\sigma^G}}}{\rho^H D_H^{G \frac{1}{\sigma^G}} + \rho^F D_F^{G \frac{1}{\sigma^G}}},$$

$$\alpha_F^G = \frac{\rho^F D_F^{G \frac{1}{\sigma^G}}}{\rho^H D_H^{G \frac{1}{\sigma^G}} + \rho^F D_F^{G \frac{1}{\sigma^G}}}.$$

Next, we calibrate the returns to scale parameter as input expenditures on corn and soybean ($\tilde{C}^G = \rho^H D_H^G + \rho^F D_F^G$) divided by total revenue

$$v^G = \frac{\tilde{C}^G}{p^G Q^G}.$$

Finally, given the CES share parameters, returns to scale parameters, and data on total the amount of broiler production and prices of day-old-chicken and feed, we calibrate the productivity parameter. To do this, note that the total cost function equals input expenditures, which

40

implies that $\tilde{C}^F = C^F(\cdot)$. Then, using this relationship and equation 3.20, the productivity parameter is calibrated as the residual:

$$A^G = Q^G \left(\frac{\tilde{C}^G}{\left[\left(\alpha_H^G \right)^{\frac{1}{1+\eta^G}} \left(\rho^H \right)^{\frac{\eta^G}{1+\eta^G}} + \left(\alpha_F^G \right)^{\frac{1}{1+\eta^G}} \left(\rho^F \right)^{\frac{\eta^G}{1+\eta^G}} \right]^{\frac{1+\eta^G}{\eta^G}}} \right)^{-\nu^G}.$$

4.2.6 Processing Plants

Here, we calibrate the returns to scale parameter as input expenditure on broiler chicken $(\tilde{C}^W = p^G D_G^W)$ divided by total revenue

$$\nu^W = \frac{\tilde{C}^W}{p^W Q^W}$$

Next, data on the total quantity of whole chicken and price of broiler chicken, we calibrate the productivity parameter. To do this, note that the total cost function equals input expenditure, which implies that $\tilde{C}^W = C^W(\cdot)$. Then, using this relationship and equation (3.26), the productivity parameter is calibrated as the residual:

$$A^W = Q^W \left(\frac{\tilde{C}^W}{p^G} \right)^{-\nu^W}$$

Here, we calibrate the returns to scale parameter as input expenditure on broiler chicken $(\tilde{C}^P = p^G D_G^P)$ divided by total revenue

$$\nu^P = \frac{\tilde{C}^P}{p^P Q^P}$$

Next, data on total the quantity of chicken parts such as chicken breast, wings as well as dark meat and the price of broiler chicken, we calibrate the productivity parameter. To do this, note that the total cost function equals input expenditure, which implies that $\tilde{C}^P = C^P(\cdot)$. Then, using this relationship and equation 3.35, the productivity parameter is calibrated as the residual:

$$A^P = Q^P \left(\frac{\tilde{C}^P}{p^G} \right)^{-\nu^P}$$

4.2.7 Value Added

Here, we calibrate the returns to scale parameter as input expenditure on broiler chicken $(\tilde{C}^{RC} = p^G D_G^{RC})$ divided by total revenue

$$v^{RC} = \frac{\tilde{C}^{RC}}{p^{RC} Q^{RC}}$$

Next, data on the total quantity of value added chicken and the price of broiler, we calibrate the productivity parameter. To do this, note that the total cost function equals input expenditure, which implies that $\tilde{C}^{RC} = C^{RC}(\cdot)$. Then, using this relationship and equation 3.40, the productivity parameter is calibrated as the residual

$$A^{RC} = Q^{RC} \left(\frac{\tilde{C}^{RC}}{p^G} \right)^{-v^{RC}}.$$

4.2.8 Reduced-Form Demand Functions

For US, Mexican, Canadian, and ROW reduced-form demand functions, we assume the demand elasticities ε_j^i, $i = MexC, CanC, ROWC$ and $j = W, Br, Wi, D, VA$ to be between 0.8 and 0.9 for W, Br, and VA and between 0.2 and 0.4 for D and Wi. This assumption represents that demand elasticities of the US Broiler meat are relatively inelastic for US, Mexician, Canadian, and ROW consumers. Given consumption and price data and demand elasticities, the scale parameter is calibrated as

$$\delta_j^{USC} = \frac{D_j^{USC}}{(p^j)^{\varepsilon_j^{USC}}}.$$

4.3 Simulation Analysis

The supply chain model for the US broiler industry is simulated numerically to endogenously determine the prices of each input and output of the supply chain. Specifically, with supply functions (equations 3.1, 3.2, 3.6, 3.12, 3.17, 3.22, 3.28, 3.37, 3.42, 3.47) and input demand function (equations 3.7, 3.8, 3.13, 3.18, 3.23, 3.24, 3.29, 3.38, 3.43, 3.48) all functions of endogenous prices (p^C, p^{SM}, ρ^F, p^B, ρ^H, p^G, p^W, p^{Br}, p^{Wi}, p^D, ρ^{PV}, and p^{VA}), we numerically solve the equilibrium conditions (equations 3.49 - 3.60) for these endogenous prices

Table 4.4: The Impact on Quantities

Variables	Baseline unit	Corn and Soybean Price Shock (% Change)	Grow-out Productivity Shock (% Change)
Corn Q^C(mil. tonne)	0.042	20.47%	-1.99%
soybean Q^{SM}(mil. tonne)	0.02	23.57%	-1.94%
Broiler Feed Q^F(mil. tonne)	0.09	11.68%	-1.08%
Fertilized Eggs Q^B(bil.)	1.14	6.40%	-0.61%
Hatched Eggs Q^H(bil. head)	0.81	7.03%	-0.67%
Broiler Chicken Q^G (bil. lbs)	56.37	9.53%	9.00%
Whole Chicken Q^W(bil. lbs)	14.90	5.70%	5.39%
Chicken Breast Q^{Br}(bil. lbs)	1.68	2.88%	2.72%
Chicken Wings Q^{Wi}(bil. lbs)	1.96	2.88%	2.72%
Dark Meat Q^D(bil. lbs)	0.45	2.88%	2.72%
Proc. for Value-Added Q^{PV}(bil. lbs)	18.25	6.67%	6.30%
Value-added Proc. Q^{VA}(bil. lbs)	116.98	21.77%	20.59%

by considering a baseline and two counterfactual scenarios. The baseline maintains current values for all policy variables and replicates the benchmark data. The first alternate scenario considers the impact of a price shock on corn and soybean, and the second alternate scenario analyzes the impact of an increase in grow-out farmer's productivity. The results of the first and second alternate scenarios are compared to the baseline scenario to quantify the impact of the reduction in corn and soybean prices and productivity shock to grow-out farmers. Table 4.4 reports the baseline values for quantities and impacts of the two alternate scenarios in percentage change relative to the baseline. Table 4.5 presents the baseline values for prices and impacts of the two alternate scenarios in percentage change relative to the baseline. Table 4.6 reports the baseline values for domestic consumption and exports and the impacts of the two alternate scenarios in percentage change relative to the baseline.

4.3.1   Corn and Soybean Price Shock

In the first part of 2018, China imposed retaliatory tariffs on corn and soybean, among other agricultural and non-agricultural products. These tariffs indirectly impact the broiler supply chain by effecting the supply and market price of corn and soybean. With corn and soybean accounting for about 60% and 25%, respectively, of feed inputs, and feed accounting

Table 4.5: The Impacts on Prices

Variables	Baseline ($/unit)	Corn and Soybean Price Shock (% Change)	Grow-out Productivity Shock (% Change)
Corn p^C ($/tonne)	166.142	−18.07%	−0.50%
soybean p^{SM} ($/tonne)	420.437	−24.05%	−0.65%
Feed Price ρ^F ($/tonne)	266.2158	−13.76%	−1.46%
Fertilized Eggs p^B ($/Dozen)	3.360	3.05%	−3.23%
Hatched Eggs ρ^H ($/Dozen Head)	4.32	3.09%	−3.24%
Broiler Chicken p^G ($/lbs)	0.551	−11.26%	−10.70%
Whole Chicken p^W ($/lbs)	1.47	−6.69%	−6.35%
Chicken Breast p^{Br} ($/lbs)	3.33	−3.48%	−3.30%
Chicken Wings p^{Wi} ($/lbs)	1.71	−8.98%	−8.52%
Dark Meat p^D ($/lbs)	1.5565	−8.15%	−7.74%
Proc. for Value-Added ρ^{PV} ($/lbs)	1	−9.6%	−9.11%
Value-added Proc. p^{VA} ($/lbs)	1	−20.814%	−19.82%

Table 4.6: Domestic Consumption and Export

Demand	Baseline (lbs)	Corn and Soybean Price Shock	Productivity Improvement
Whole Chickens			
Domestic Consumption	1.49	5.31%	5.03%
Chicken Breast			
Domestic Consumption	1.68	2.63%	2.49%
Chicken Wings			
Domestic Consumption	0.39	2.54%	2.41%
Exports to Mexico	0.0062	2.79%	2.65%
Exports to Canada	0.0091	3.05%	2.89%
Exports to ROW	0.044	3.31%	3.14%
Dark Meat			
Domestic Consumption	1.01	2.18%	2.07%
Exports to Mexico	0.092	2.51%	2.38%
Exports to Canada	0.0006	2.84%	2.69%
Exports to ROW	0.858	3.17%	3.01%
Value Added			
Domestic Consumption	25.02	7.02%	6.64%
Exports to Mexico	0.076	7.29%	6.90%
Exports to Canada	0.029	7.56%	7.16%
Exports to ROW	0.247	7.84%	7.42%

for between 45% and 70% of total cost of broiler production, these are key inputs in this industry. Therefore, this scenario measures the effect of a decline in domestic corn and soybean prices by 18% and 24%, respectively, following the tariffs imposed by China on US corn and soybean.

With the Chinese tariffs on corn and soybean expanding the US supply of corn and soybean, the price of these key inputs of feed declines. As a result, the cost to produce broiler feed falls, and the supply of feed to the broiler industry expands by 12.21%. This expansion of production puts downward pressure on the price of broiler feed. As the feed price falls, demand for feed by breeders and grow-out farms expand. Because the direct effect of the expansion of feed supply dominates the indirect effect of an increase in demand for feed, the price of feed falls by 13.63%.

The lower price of feed benefits both breeders and grow-out farmers by lowering their cost of production, which expands production of these two segments and puts downward pressure on the prices of both fertilized eggs and broiler chickens. The expansion of broiler chicken production increases the demand for DOC, causing production and price of DOC to rise by 7.34% and 4.57%, respectively. Further upstream, the expansion of DOC production increase demand for fertilized eggs, and puts upward pressure on the price of fertilized eggs. The results show that the higher demand for fertilized eggs caused by the increase in broiler and DOC production outweighs the increase in supply of fertilized eggs resulting from reduction in feed costs. Consequently, the supply and price of fertilized eggs both increase by 6.69% and 4.53%, respectively.

For grow-out farmers, the reduction in feed cost dominate the increase in cost of DOC and production expands, putting downward pressure on the price of broiler chickens. The lower price of broiler chickens benefits downstream segments because the lower price of these chickens reduces the cost of production. The lower input prices expand demand for broiler chickens by the processing plant segment, which further expands production, but puts upward pressure on the price of broiler chickens. Consequently, broiler production increases by 9.95%,

and the direct effect of lower feed cost in expanding output dominates the indirect effect of the increases in demand causing the broiler price price to fall by 10.56%.

With input prices falling, production expands for whole chickens, chicken parts (breast meat, wings, and dark meat), and processed chicken for valued-added production, which puts downward pressure on the prices. With lower prices, domestic consumption for whole chicken and chicken breasts increase by 6.46% and 3.19%, respectively. Also, domestic consumption and exports to Canada, Mexico, and ROW increase for wings and dark meats increase between 2.6% and 4.1%. Despite lower prices, lower cost of production and higher demand cause production to expand for whole chickens, breast meat, wings, dark meat, and processed chicken for valued-added production by 5.31%, 2.63%, 2.63%, 2.63%, and 7.72%, respectively. The direct supply effect outweighs the indirect demand effect leading to a decrease in equilibrium prices by 6.26%, 3.19%, 8.02%, 10.22%, and 8.62%, respectively.

With a lower price of processed chicken, the costs of value-added chicken processing also falls, leading to an increase in production. The lower costs and increase in domestic demand cause equilibrium sales to rise by 7.14% and price to fall by 8.13%.

4.3.2 Technology Increase

The US broiler industry has depicted significant technological improvements over the last 50 years. These improvements allowed more broiler chickens to be produced with less inputs. As a result, the cost of production has been decreasing and profitability has increased. Therefore, by focusing on productivity in the grow-out farmers, this scenario analyzes the increase of the productivity of grow-out farmers by 10%. This productivity gain embodies the effect of an improvement of performance measurements—such as reducing the number of day until an average chicken reaches market weight, reducing the mortality rate, and decreasing the feed-conversion ratio on the entire supply chain—for grow-out farmers.

Technology improvements have both a direct input demand and supply effect as overall efficiency of grow-out farmers improves. The results show that production increases (9.41%) which is less than the increase in productivity (10%). This occurs because the gain in produc-

46

tivity shifts the supply curve to the inelastic part of the processing plants' input demand curves for broiler chickens. Consequently, grow-out farmers dampen the increase in production by using fewer inputs until supply reaches the unit elastic portion of these input demand curves. This allows grow-out farmers to maximize revenue by balancing the production increase with the fall in the price of broiler chickens while decreasing production cost.

For upstream segments, demand for DOC and, thus fertilized eggs, falls as grow-out farms reduce input use to lower cost. As a result, production and the price of DOC decrease by 0.40% and 1.92%, respectively, and production and the price of fertilized eggs fall by 0.36% and 1.91%. Similarly, the demand for feed by breeders and grow-out farmers falls by 0.64%, which causes the price of broiler feed to decline by 0.86%. Therefore, corn and soybean demand declines by 1.17% and 1.14%, respectively, and their prices decreased by 0.38% and 0.29%.

Downstream segments benefit because the lower price of broiler chickens reduces the cost of production. The lower input price expands the demand for broiler chickens by the processing plant segment, which further expands broiler chicken production and puts upward pressure on the price of broiler chickens. As broiler chicken production increases and demand for broiler chickens rises, supply of broiler chicken rises by 9.41%. The direct effect of the productivity increase on supply dominates the indirect effect of an increase in demand, leading to a fall in price of broiler chicken by 10.04%.

For the processing plant segment, as a result of lower input price, the production of chicken products (whole chicken, chicken breast, dark meat, chicken wings, and processed chicken for value added) rises, which puts downward pressure on prices. With lower prices, demand increases, which dampens the fall in price. Consequently, production of whole chickens, chicken breast, dark meat, chicken wings, and processed chicken for value-added production increase by 5.03%, 2.49%, 2.49%, 2.49%, and 7.30%, respectively, and prices decrease by 5.95%, 3.03%, 7.62%, 9.72%, and 8.19%, respectively. The lower prices of whole chicken, chicken breast, wings, and dark meat benefit the US consumers as domestic consumption increases by

47

6.09%, 3.01%, 2.91%, and 2.49% respectively. The results showed that the quantity of exported chicken wings expanded to Mexico, Canada, and ROW by 3.20%, 3.50%, and 3.80%, respectively. Similarly, for dark meat, the export expanded to Mexico, Canada, and ROW 2.87%, 3.25%, and 3.64%, respectively.

As the price of processed chicken falls, the supply of value added products increases by 6.76%, which puts downward pressure on the output price of value-added processing. The lower price expands demand, which dampens the price increase. The direct supply effect dominates the indirect demand effect, led to declined the price of value added chicken products by 7.73%. The lower prices of value-added chicken products also benefit the US consumers as consumption increases by 6.64%. Also, exports of value-added chicken production to Mexico, Canada, and ROW increase by 6.90%, 7.16%, and 7.42%, respectively.

Chapter 5.   Summary and Research Extension

This thesis built a comprehensive supply-chain model of the US broiler industry that accounts for corn and soybean, feed mills, breeders, hatcheries, grow-out farms, broiler processing, value added processing, and international trade.   This broiler supply-chain model is calibrated to the US data averaged over 2012 - 2017.   Two scenarios are analyzed: The first scenario simulates the effects of a shock to the corn and soy-meal prices due to corn and soybeans tariffs imposed by China on the US broiler supply chain.   The second scenario considers the effects of an increase in productivity in the grow-out segment on the US broiler supply chain.

The results from the first scenario indicates that as the price of corn and soybean in the US market fall, feed supply increases and feed price decreases, which directly lowers the production costs of breeders and grow out farms.   The lower feed costs cause production of breeders and grow out farmers to rise, which increases demand for DOC and thus fertilized eggs by grow out farmers.   The results show the increase in demand outweigh the increase in supply, causing the price of fertilized eggs and DOC to rise.   The increase in broiler chickens lowers the price of broiler chickens, which lowers cost for all down-stream segments.   As a result, production expands and prices decline.   With lower prices, both domestic and international consumers of whole chicken, chicken parts (wings, chicken breast, and dark meat), and value-added chicken products benefit.   Thus, while the Chinese tariff on corn and soybean undoubtedly makes corn and soybean producers worse off, the chicken industry benefits from lower costs.

The results from the second scenario indicate that boosting productivity in the grow-out segment leads to not only an increase in broiler chicken production but also a reduction in input demand.   Consequently, the fall in input demand lowers production and prices for segments upstream from grow-out farmers, i.e., breeders, hatcheries, and feed mills.   But, with more broilers available, the cost of production for downstream segments (processing and value-added processing) falls, leading to an expansion of production and lower prices.   Thus, this

analysis highlights the trade off of advances in research and development in chicken breeds as producer upstream from grow out farms are worse off as demand for their products falls, but grow-out farms, downstream producers, and consumers benefit. However, from the integrators' perspective, it may be optimal to sacrifice profits in the breeders, hatcheries, and feed mills segments to gain efficiency and profits in processing segments.

There are three major limitations of the supply chain model. First, due to data limitations, the model does not cover variable inputs that are not explicitly produced in the supply chain (such as labor, capital, structures, electric, etc.) in the cost function for each segment. As a result, these variables are consider fixed factors of production and dictate the degree of return to scale in each sector. However, given the low degree of substitutability between these fixed factors of production and the inputs modeled in the supply chain, we believe the simulation analysis provides accurate ex ante predictions. Second, Brazil, the largest producing country, is not explicitly represented in the supply side of the model. Although Brazil takes important role for supplying broiler in the world market, the model was not covered a separate supply function for Brazil because Brazilian exports of broiler products are relatively low to Mexico at 8% Parrish and Sallyards (2018) and Canada at 10% (USDA, 2018b). As a result, we consider net Mexican and Canadian import demand function for US broiler products. The elasticities for the net-import demand function, show consumers' sensitivity to US prices only. Third, the model is a static model, but the broiler supply chain, from fertilized eggs to value-added products ready for consumption, is a dynamic process that can take several months for a shock to the industry to filter through the entire supply chain. Therefore, the static model, coupled with fixed capital, implies the simulation provides short-run predictions.

This research could be extended in four ways: First, by working with industry groups, we could utilized proprietary data for additional inputs (capital, labor, structure, energy, etc.) to production for each segment along the supply chain and for the genetics segment of the supply chain. Second, using proprietary data from industry groups, we could estimate elasticity of substitution between inputs in the cost functions in the broiler supply chain. Third, We

could collect data and estimate demand elasticities for US, Mexican, and Canadian consumers. Fourth, the model could be extended to allow US consumers to substitute between different types of meat (e.g., beef, pork, and fish).

Bibliography

AFIA (2017). ANIMAL FOOD CONSUMPTION. American Feed Industry Association.

Arumugam, N. (2011). The Dark side of the Bird. Technical report, The Slate Group, a Graham Holdings Company.

Awokuse, T. O. and J. C. Bernard (2007). Spatial price dynamics in us regional broiler markets. *Journal of Agricultural and Applied Economics 39*(3), 447–456.

Broiler Performance (2018). U.s broiler performance. National Chicken Council.

Broiler productivity (2018). The real truth about chicken. U.S. Poultry and Egg Association.

Bukari, F. (2014). *Profile of broiler producers in Tennessee and vertical integration in broiler production*. Ph. D. thesis, Tennessee State University.

Cang, A. and P. Sedgman (2018). China strikes at trump's rural heratland with tariff on soybeans. *Bloomberg*.

Chavas, J.-P. (1983). Structural change in the demand for meat. *American Journal of Agricultural Economics 65*(1), 148–153.

Clauer, P. (2017). Modern meat chicken industry. *Penn State Extension*.

Dahlgran, R. A. and D. G. Fairchild (2002). The demand impacts of chicken contamination publicity–a case study. *Agribusiness: An International Journal 18*(4), 459–474.

Djunaidi, H. and A. C. Djunaidi (2007). The economic impacts of avian influenza on world poultry trade and the us poultry industry: a spatial equilibrium analysis. *Journal of Agricultural and Applied Economics 39*(2), 313–323.

Donohue, M. and D. L. Cunningham (2009, 07). Effects of grain and oilseed prices on the costs of US poultry production. *The Journal of Applied Poultry Research 18*(2), 325–337.

Eales, J. S. and L. J. Unnevehr (1988). Demand for beef and chicken products: separability and structural change. *American Journal of Agricultural Economics 70*(3), 521–532.

Eales, J. S. and L. J. Unnevehr (1993). Simultaneity and structural change in us meat demand. *American Journal of Agricultural Economics 75*(2), 259–268.

FAPRI (2004). Documentation of the fapri modeling system. Technical Report FAPRI-UMC Report 12-04, College of Agriculture, Food, and Natural resources, University of Missouri.

FAPRI (2018). Fapri models. Technical Report issue 2, Food and Agricultural Policy Research Institute.

Goodwin, H., A. M. McKenzie, and H. Djunaidi (2003). Which broiler part is the best part? *Journal of Agricultural and Applied Economics 35*(3), 483–495.

Goodwin, H. L. (2005). Location of production and consolidation in the processing industry: the case of poultry. *Journal of Agricultural and Applied Economics 37*(2), 339–346.

Hinrichs, C. C. and R. Welsh (2003). The effects of the industrialization of us livestock agriculture on promoting sustainable production practices. *Agriculture and Human Values 20*(2), 125–141.

Holt, M. T. and A. M. McKenzie (2003). Quasi-rational and ex ante price expectations in commodity supply models: an empirical analysis of the us broiler market. *Journal of Applied Econometrics 18*(4), 407–426.

IFEEDER (2017). 2016 U.S Animal Food Consumption Report. Decision Innovation Solutions.

Madlom, K. (2013). Better broilers in tennessee. Farm Flavor.

Manning, L. and R. Baines (2004). Globalisation: a study of the poultry-meat supply chain. *British Food Journal 106*(10/11), 819–836.

NCC (2018a). Broiler Chicken Industry Key Facts 2018. National Chicken Council.

NCC (2018b). How Broilers are Marketed. National Chicken Council.

NCC (2018c). Per Capita Consumption of Poultry and Livestock,1965 to Estimated 2018, in Pounds. National Chicken Council.

NCC (2018d). U.s. broiler production. National Chicken Council.

OECD (2014). Aglink-cosimo model documentation: A partial equilibrium model of world agricultural markets. Technical report, Organisation for Economic Co-operation.

Ollinger, M. (2011). Structural change in the meat and poultry industry and food safety regulations. *Agribusiness 27*(2), 244–257.

Ollinger, M., J. M. MacDonald, and M. Madison (2005). Technological change and economies of scale in u.s. poultry processing. *American Journal of Agricultural Economics 87*(1), 116–129.

Parrish, M. R. and M. Sallyards (2018). Mexico Poultry and Products Annual. US Department of Agriculture,Foreign Agricultural Service.

Perry, J., D. Banker, and R. Green (1999). Broiler farms' organization, management, and performance. US Department of Agriculture, Economic Research Service.

Peterson, E. B. and D. Orden (2005). Effects of tariffs and sanitary barriers on high-and low-value poultry trade. *Journal of Agricultural and Resource Economics*, 109–127.

Piggott, N. E. and T. L. Marsh (2004). Does food safety information impact us meat demand? *American Journal of Agricultural Economics 86*(1), 154–174.

Reimund, D. A., J. R. Martin, and C. V. Moore (1981). Structural change in agriculture: The experience for broilers, fed cattle, and processing vegetables. tb-1648. *US Dept. Agr., Econ. Res. Serv.*

Schnepf, R. (2011). Us livestock and poultry feed use and availability: Background and emerging issues. Technical Report R41956, Congressional Research Service.

Schroeder, T. C., T. L. Marsh, and J. Mintert (2000). Beef demand determinants: A research summary. Technical Report MF-2457, Kansas State University Agricultural Experiment Station and Cooperative Extension Service.

Suh, D. H. and C. B. Moss (2016). Dynamic interfeed substitution: implications for incorporating ethanol byproducts into feedlot rations. *Applied Economics 48*(20), 1893–1901.

Swanson, K., J. Coppess, and G. Schnitkey (2018). Trade timeline and corn and soybean prices. *farmdocdaily 8*(141). Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign.

Takayama, T. and G. G. Judge (1964). An intertemporal price equilibrium model. *Journal of Farm Economics 46*(2), 477–484.

Thomsen, M. R. and A. M. McKenzie (2001). Market incentives for safe foods: An examination of shareholder losses from meat and poultry recalls. *American Journal of Agricultural Economics 83*(3), 526–538.

Thukral, N. and D. Patton (2018). After sorghum spat us-china trade fears halt soybean imports.

Thurman, W. N. (1987). The poultry market: Demand stability and industry structure. *American Journal of Agricultural Economics 69*(1), 30–37.

UNComtrade (2018). United nations, department of economic and social affairs. United Nations.

Unnevehr, L., J. Eales, H. Jensen, J. Lusk, J. McCluskey, and J. Kinsey (2010). Food and consumer economics. *American Journal of Agricultural Economics 92*(2), 506–521.

U.S. Bureau of Labor Statistics (2018). Databases, tables and calculators by subject ? U.S. Bureau of Labor Statistics.

USDA (2014). Technology, organization, and financial performance in u.s. broiler production. US Department of Agriculture, Economic Research Service.

USDA (2018a). Assessing the growth of u.s broiler and poultry meat exports. US Department of Agriculture, Economic Research Service.

USDA (2018b). Canada Poultry and Products Annual. US Department of Agriculture,Foreign Agricultural Service.

USDA (2018c). Feed Grains Custom Query. US Department of Agriculture, Economic Research Service.

USDA (2018d). Livestock and meat domestic data. US Department of Agriculture, Economic Research Service.

USDA (2018e). Livestock and meat international trade data. US Department of Agriculture, Economic Research Service.

USDA (2018f). Poultry Market news. USDA Agricultural Marketing Service.

USDA (2018g). Price program methodology, 4. parity prices, parity ratio, and feed price ratios. US Department of Agriculture, National Agricultural Statistics Service.

USDA (2018h). Quick stats. US Department of Agriculture, National Agricultural Statistics Service.

USDA (2018i). U.S. Department of Agriculture Foreign Agricultural Service, Standard Query. United States Department of Agriculture.

USDA World Markets Trade (2018). Livestock and poultry: World markets and trade. USDA Foreign Agricultural Service.

Vukina, T. (2001). Vertical integration and contracting in the us poultry sector. *Journal of Food Distribution Research 32*(2), 29–38.

Vukina, T. and P. Leegomonchai (2006). Political economy of regulation of broiler contracts. *American Journal of Agricultural Economics 88*(5), 1258–1265.

Weaver, M. (2014). Poultry industry and trade summary. Technical Report Publication ITS-10, Washington, DC: U.S. International Trade Commission.

Wieck, C., S. W. Schlüter, and W. Britz (2012). Assessment of the impact of avian influenza–related regulatory policies on poultry meat trade and welfare. *The World Economy 35*(8), 1037–1052.