A SYSTEM APPROACH TO STUDY THE U.S. POULTRY AND PORK INDUSTRIES

A Dissertation

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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December 2016

Major Subject: Agricultural Economics

ABSTRACT

In the presence of significant industrial consolidation and concentration in the pork industry and complications of disease outbreaks facing today's poultry industry, as well as the increase in feed grain prices starting from 2007 strongly affecting the U.S. livestock sectors, a more up-to-date partial equilibrium, sector-specific modelling system is developed to facilitate analyzing the U.S. pork, broiler, egg, and turkey sectors, understand their interactions with other sectors, and make more accurate projections. The model can be used to analyze the effects of shocks to poultry and pork sectors and evaluate policy proposals, especially for the broiler industry where separate production regions have been included in the model to assist studying regional events that affect one region but not another.

The partial equilibrium system was applied to quantify the effects of the 2015 highly pathogenic avian influenza (HPAI) outbreak on the U.S. poultry and egg industries. The effects of the shock on production started to fade out after the second year while the effects of the shock on exports lasted longer. Different levels of shocks have also been assumed for broiler production in the AI-outbreak regions; although this has not happened in reality, the simulation results help industry stakeholders get prepared. Shocks on the broiler industry had larger effects on the other two poultry sectors than on the pork sector since the three poultry industries are closely correlated either from the supply side (broiler and egg) or from the demand side (broiler and turkey) compared to the pork industry.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my advisor, Dr. James Richardson, for his financial support and encouragement for my research. This dissertation would not have been possible without him. Besides, he supported me in all the difficult situations where I needed help. He gave me a lot of guidance not only on academic study but also on my career path. Thank you.

I would like to thank Dr. David Bessler, Dr. Henry Bryant and Dr. Ke-li Xu for their time in serving in my committee. I appreciate Dr. Bessler's direction on demand analysis, from model selection to the discussion on the topic of consumer preferences. Dr. Bryant is a genius. He helped setting up the simulation environment of my model, which is an unexplored field for me.

Several other people at Texas A&M helped me in my research work. Thanks to Dr. David Anderson who spent a lot of time in discussing the supply side of my model with me. Thanks to Dr. Aleksandre Maisashvili, for helping and guiding me to merge my study to the large National Agricultural Simulation Model maintained by the Policy Center by his expertise and carefulness on programming. I deeply appreciate your kindness.

I would also like to thank my parents for their constant support and encouragement through every major decision in my life. Everything I have accomplished thus far I owe to them. Although I seldom say it - Thank you.

Last but not least, I would like to thank my loving husband, Jingwei Xu, who has supported me in much more ways than meets the eye. He did an extraordinary task of pursuing his Ph.D. degree at Texas A&M University, building up his career, while taking care of the family. He has always been supportive, which helps me keep my

head on straight when times were tough. I appreciate your company and I believe that you are the ideal role model for our newborn, whom we named Bryan, after the memorable place - Texas A&M University!

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1. INTRODUCTION

1.1 Statement of Problem

Livestock and poultry industries are very important to U.S. agriculture. Three major sectors, cattle and calves, poultry and eggs, and hogs, accounted for 37 percent of total farm cash receipts from all commodities in 2014 according to Farm Income and Wealth Statistics [1]. They are also major staples for the American diet. In 2014, 58.4 pounds of broilers, 51.8 pounds of beef, 43.6 pounds of pork, and 12.5 pounds of turkey meat were consumed per capita according to World Agricultural Supply and Demand Estimates (USDA)[2]. All three sectors have experienced significant industry consolidation and concentration during the past couple of decades. Four-firm concentration ratio (CR4), which calculates the percentage of total output produced by the four largest firms in an industry, is often used to measure the degree of concentration of the market. CR4 in livestock slaughter rose from 36 percent and 34 percent in 1980 to 85 percent and 64 percent in 2012 for calves and hogs respectively. Noteworthy increase in CR4 has also been witnessed in the poultry sector, from 14 percent and 23 percent in 1963 to 51 percent and 53 percent in 2012 for broiler industry and turkey industry respectively[3, 4]. A recent study by Maisashvili [5] analyzes the beef industries in sufficient details; and a close look at the poultry and hog industries will be conducted in this dissertation, given their importance and drastic changes.

Major structural changes exploiting scale economies have occurred in the U.S. hog industry during the last twenty years. These structural changes, leading to increased productivity in hog industry, mainly reflect in the following three aspects: increase in use of production contracts, increase in market share of specialized operations, and increase in size of operations.

For the U.S. hog industry, production contracts usually stipulate that the contractors have the control over some production decisions and provide feeder pigs and management services for the growers; and the growers are paid for their labor rendered as well as land and facilities provided. The reliance on formal production contracts increased notably during the past 20 years: only 3 percent of all hog and pig producers and approximately 5 percent of hogs sold by growers were under production contracts in 1992 [6]; the proportions increased to 15 percent and 54 percent respectively in 2012 [USDA Census of Agriculture 2012]. Among all producers in hog industry, 98 percent of wean-to-feeder producers, 75 percent of feeder-to-finish producers, and 50 percent of farrow-to-wean producers were operating under contracts by 2009 [7].

Table 1.1: Percentage of Hog Farms of Different Types, 1992 and 2012

Year	Farrow to Finish	Farrow to Feeder	Finish only	Farrow to Wean	Nursery	Other	All Producers
1992	54	8	19	0	0	19	100
2012	27	8	37	9	2	17	100

Hog operations become more specialized in certain production stages. In 1992, 54 percent of U.S. hog farms were farrow-to-finish operations while the market share is only 19 percent and 8 percent for the farms specializing in hog finishing and farrow-to-feeder pig raising respectively according to U.S. Hog Production Costs and Returns (USDA ERS 1992). After 20 years of development, the share of farrow-to-finish operations decreased to 27 percent in 2012; and the more specialized hog producing operators increased their market share, 37 percent for hog finishing operations and 19 percent for all types of feeder pig providers, according to Census of Agriculture (USDA 2012) Table 1.1.

The number of U.S. hog farms declined by more than 70 percent over the past thirty years from 243,398 in 1987 to 63,246 in 2012 ; while hog inventory maintained a steady increasing trend as shown in Figure 1.1. From 1987 to 2012, the share of the U.S. hog and pig inventory on farms with 2,000 head or more increased from around 20 percent to 90 percent as shown in Figure 1.2. Small farms with low production efficiency exited the market; large hog enterprises benefiting from economy of scale survive and thrive.

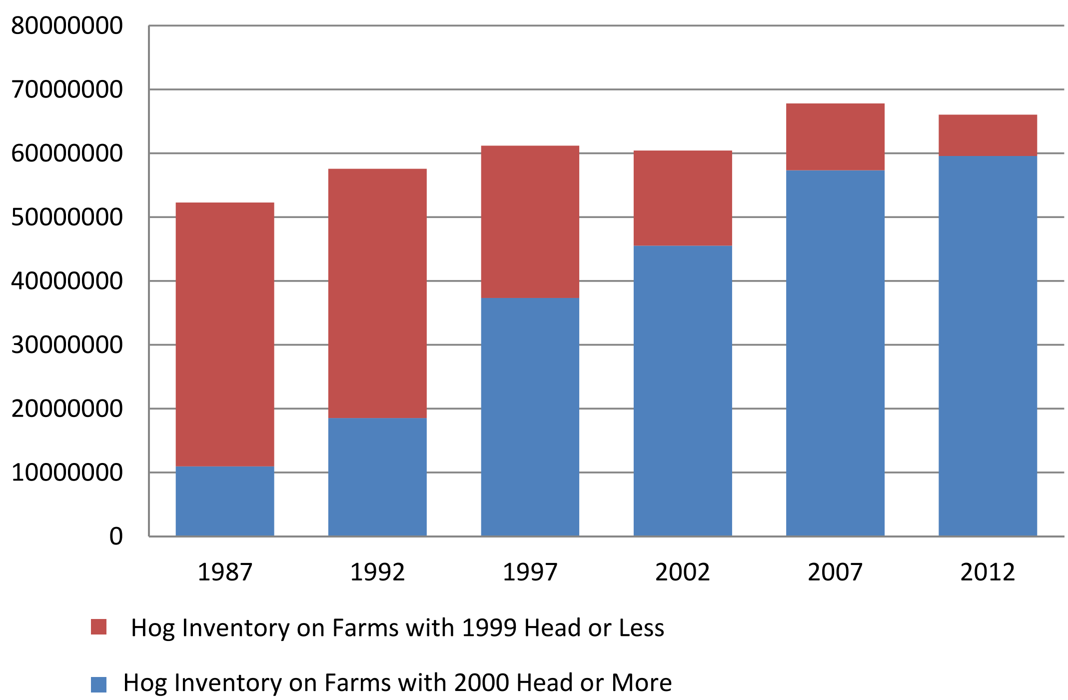


Figure 1.1: Number of Hog Farms and Hog Inventory 1987-2012

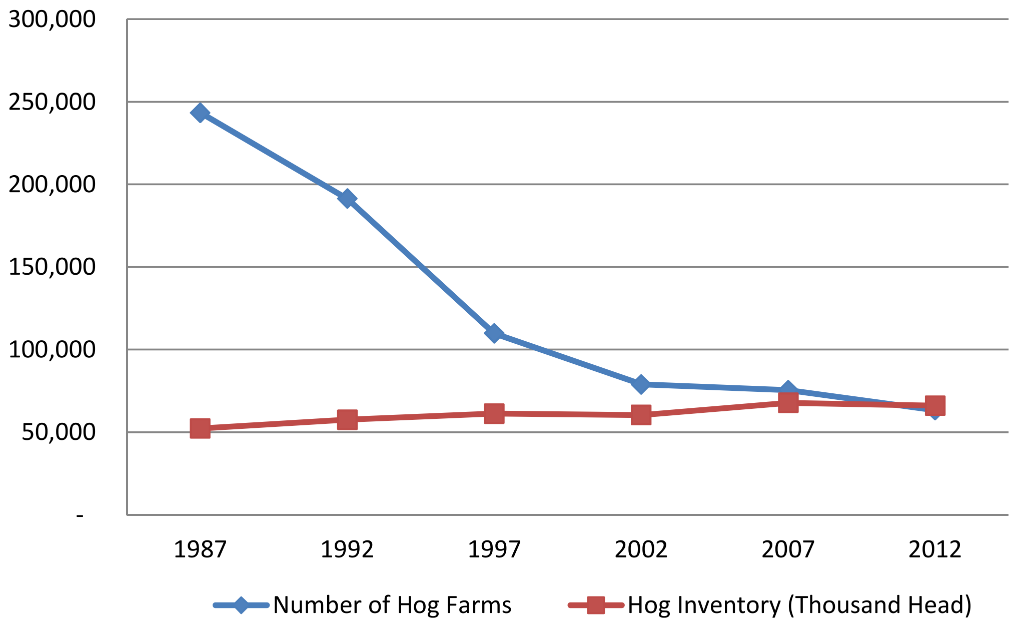
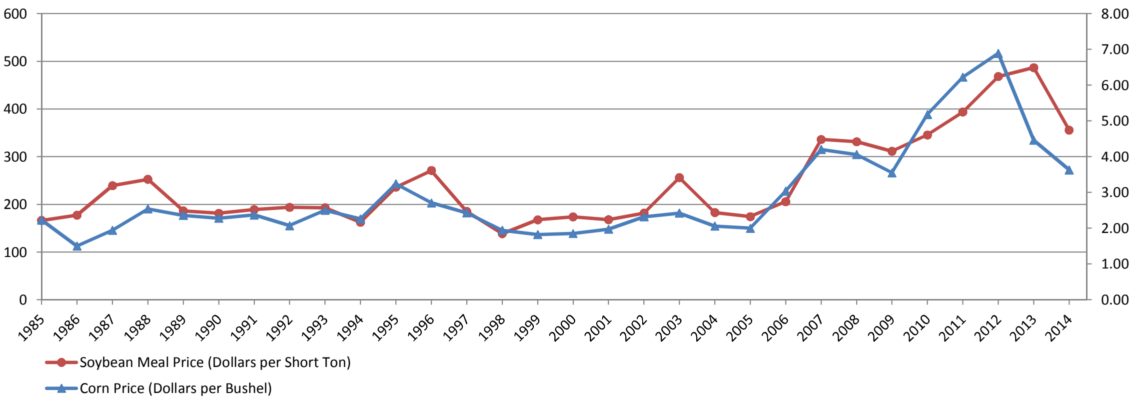


Figure 1.2: Hog Inventory in Small and Large Farms 1987-2012

The shifts toward using of production contracts, larger farms, and more specialized production operations have mainly been driven by financial benefits, including less product price risks and lower capital requirement for farmers; and advantages of economies of scale for hog owners. The structural changes in the U.S. hog industry are also intensified in recent years due to surging feed cost. Starting from 2007, corn and soybean meal prices have risen unprecedentedly and reached a record high after the worst U.S. drought in more than half a century in 2012 as shown in Figure 1.3. Decreases in the number of hog farms with less than 2000 head in Figure 1.2 during this period suggests that many small, likely less efficient operations ceased production.

Major structural change occurred for the U.S. poultry industry in the more distant 1950s and 1960s. But the increase in feed grain prices also affects the poultry sector notably as feed is the largest single cost item . Due to the noteworthy and most

Figure 1.3: Feed Grain Prices 1985-2014



prolonged increase in feed grain prices, the U.S. poultry industry is also undergoing a significant change.

Another ongoing shock for the U.S. poultry industry is the outbreak of the highly pathogenic avian influenza (HPAI) H5 incidents along the Pacific, Central and Mississippi flyways since mid-December 2014. To date, the most affected flocks have been the turkey and table egg layers located in Midwestern States according to Livestock, Dairy, and Poultry Outlook (USDA June 16, 2015).

In the effort of controlling the spread of HPAI, large amount of infected flocks are removed and international trade is restricted. Thus, negative impacts in production for table eggs and turkeys as well as a hard hit for the export of U.S. poultry and poultry products can be foreseen. Paarlberg, Seitzinger, and Lee addressed the importance of regionalization in measuring the real export and welfare losses of an HPAI outbreak [8].

In the presence of the massive structural changes in the pork industry and complicated situations facing todays poultry industry, a more up-to-date modelling system is required to help us study the related agriculture sectors, understand their interactions, and making more accurate forecasts and policy evaluations.

1.2 Objective

The objective of this study is to analyze the effects of the increases in input cost, the outbreak of HPAI, as well as other possible shocks to the economy, on the U.S. poultry industry and the pork industry as they continue to experience consolidation. The analysis will be based on a model that includes a complete representation of the demand for meat from the consumer sector and the supply for meat from the livestock producers sector, and the assumption that market clears according to price adjustment.

2. LITERATURE REVIEW

Analysis of the U.S. livestock and poultry industries has a long history. The development of large quantitative models proliferated during the period of 1970s to 1990s to cope with the increasing complexities and interdependencies policy makers faced in the fast growing agriculture sectors. This cursory review of literature includes the econometric models that are still in use and/or contribute in one way or another to the construction of the present study.

2.1 FAPSIM

USDA's Food and Agricultural Policy Simulator (FAPSIM) is the USDA in-house annual simulation model. The model was originally developed during the early 1980s by Salathe et al. [9] and has been continually updated as structures changed in the U.S. food and agricultural sectors. FAPSIM is sector-specific and commodities included in the FAPSIM system are corn, sorghum, barley, oats, wheat, rice, upland cotton, soybeans, cattle, hogs, broilers, turkeys, eggs, and dairy. Each livestock commodity sub-model contains equations describing production, market and retail prices, civilian consumption, and ending stocks. Each crop commodity sub-model consists of a set of equations estimating production, price, civilian consumption, exports, feed demand, seed demand, and ending stocks. Different livestock and crop sectors are all linked together via important variables, such as feed demand and land use for grains and grain prices for livestock sectors. The model is solved by a price vector that clears all sub-sectors simultaneously. Single equation ordinary least squares method is applied to estimate most of the equations since "the large size of the model precludes the use of econometric methods designed for systems of equations" [10].

For hog sector, considerable detail is provided on pork production due to its complexity. Total production is fitted as a linear function of hogs slaughtered and the profitability of livestock feeding. Barrow and gilt slaughter is affected by the beginning marketing hog inventory on farm and pig crop. The beginning breeding herd level, together with investment and disinvestment of breeding herd stock, influences pig crop, which in turn affects marketing hog inventory. Additions to the breeding herd and slaughter of sows are affected by the profitability of livestock feeding, representing by the price ratio of livestock prices to feed price. Major equations include:

PORAP-77 = f(.TIME, (BAGKS + 1.5 SOWKS), BAGPM7C(t-1)/CORPF(t-2))

BAGKS = f(HOGSM(t-1), PIGSC)

SOWKS = f(HOGSNBR(t-1), BAGPM7C/CORPF(t-1))

HOGSM ≡ PIGSC × (1-PIGDD) BAGKS PIGSEBR + HOGSM(t-1)×(1-PIGDD)

PIGSC = f (HOGSNBR(t-1), PIGSEBR(t-1), (SOWKS PIGSEBR))

HOGSNBR ≡ PIGSEBR SOWKS + HOGSNBR(t-1)

PIGSEBR = f (HOGSNBR(t-1), SOWKS, BAGPM7C/CORPF(t-1))

BAGPM7C = f (.WRHMP, .PWO51*, PORIR.67)

where variables are defined in Table 2.1, and dummies in the original FAPSIM model are omitted in the above description for simplicity.

Poultry production is described by much simpler model specifications. For chicken, both young chicken and other chicken production is modeled:

CHISPYO = f (CHISPYO(t-1), (CHIPWBR9C(t-1)/FDC(-1) + CHIPWBR9C/FDC), .TIME)

CHIAPOT = f (CHISVLA, (EGGPF(t-1)/FDE(t-1) + EGGPF/FDE), (CHIPWXB(t-1)/FDE(t-1) + CHIPWXB/FDE))

where young chicken production is a function of time, production in the previous period, and the profitability of broiler feeding, representing by the price ratio of broiler wholesale prices to feed cost index. Other chicken production comes from slaughter of chicken egg layers, and thus number of layers on farm, egg farm price, other chicken wholesale price, and feed cost index for eggs are included in the equation. Variables are defined in Table 2.1, and dummies in the original FAPSIM model are omitted in the above description for simplicity.

Turkey production is modeled as a function of time, production in previous period, and the profitability of turkey feeding, representing by the price ratio of turkey farm price to feed cost index:

TURAP = f (.TIME, (TURPF(t-1)/FDT(t-1) + TURPF/FDT), TURAP(t-1),)

where variables are defined in Table 2.1, and dummies in the original FAPSIM model are omitted in the above description for simplicity.

Egg production is determined by number of layers on farm and egg laying rate with unit adjustment. The number of layers on farm is modeled as a function of the lagged dependent variable and the profitability of egg layers feeding, representing by the price ratio of non-broiler chicken wholesale price to feed cost index and the price ratio of egg farm price to feed cost index. Egg-type layers laying rate is modeled as a function of the lagged dependent variable and time trend:

EGGAP = CHISVLA × EGGAA / 12

CHISVLA = f (CHISVLA(t-1), (CHIPWXB(t-1)/FDE(t-1) + CHIPWXB/FDE), (EGGPF(t-1)/FDE(t-1) + EGGPF/FDE))

Table 2.1: FAPSIM Model Variable Names and Descriptions

Variable Names	Description	Variable Names	Description
.NPC	Population, total	EGGAP	Eggs, production
.PC	Consumer price index, all items	EGGBB	Eggs, used for hatching
.PCPOU	Consumer price index, poultry	EGGCC	Eggs, civilian disappearance
.PWO51*	Fuel and utilities, consumer price index	EGGIR.67	Eggs, retail price index
.TIME	Year, 1955=55	EGGPF	Eggs, average price received by farmers
.WRHMP	Wage rate, meat packing industry	FDC	Feed cost index, chickens
.YPD$	Personal disposable income	FDE	Feed cost index, eggs
BAGKS	Barrows and gilt, slaughter	FDT	Feed cost index, turkeys
BAGPM7C	Barrows and gilts, market price, 7 markets	HOGSM	Hogs, market, number on farms, Dec.1
BEEIR	Beef, retail price index	HOGSNBR	Hogs, breeding, number on farms, Dec.1
CHIAPOT	Chickens, other, production	PIGDD	Hogs, percent death loss
CHICCOT	Chicken, other, civilian disappearance	PIGSC	Hogs, pig crop
CHICCYO	Chicken, young, civilian disappearance	PIGSEBR	Pigs, additions to breeding herd
CHIIRFR	Chickens, grying, retail price index	PORAP-77	Pork, production, carcass weight
CHIPWBR9C	Broilers, 9-City wholesale price	PORCC-77	Pork, civilian disappearance
CHIPWXB	Chickens, non broiler, wholesale price	PORIR.67	Pork, retail price index
CHISPYO	Chickens, young, production	SOWKS	Sows, slaughter
CHISVLA	Chickens, layers, number on farms	TURAP	Turkey, production
CHISVLA	Chickens, number of layers on farms	TURCC	Turkey, civilian disappearance
CORPF	Corn, average farm price, Oct.-Sept.	TURPF	Turkeys, average price received by farmers
EGGAA	Eggs, number produced per layer	TURPR	Turkey, retail price

EGGAA = f (EGGAA(t-1), .TIME)

where variables are defined in Table 2.1, and dummies in the original FAPSIM model are omitted in the above description for simplicity.

An inverse demand function is used to model the domestic per capita disappearance of pork, chicken, turkey, and egg. For the demand side of the egg sector, both per capita egg consumption and eggs used for hatching are modeled:

PORIR.67 = f (.YPD$/.NPC, [(PORCC-77) × (.PC)/.NPC], BEEIR, .PCPOU, .PC)

CHIIRFR = f (.YPD$/.NPC, [(CHICCYO + CHICCOT) × (.PC)/.NPC], BEEIR, PORIR.67, TURPR, .PC)

TURPR = f (.YPD$/.NPC, [(TURCC) × (.PC)/.NPC], BEEIR, PORIR.67, CHIIRFR, .PC)

EGGIR.67 = f ([(EGGCC) ×(.PC)/.NPC], (.TIME) × (.PC))

EGGBB = f (.TIME, CHISVLA, CHISPYO)

where retail price is specified as a function of income, per capita consumption, prices of closely related commodities, and consumer price index. Variables are defined in Table 2-1, and dummies in the original FAPSIM model are omitted in the above description for simplicity.

2.2 AGMOD

AGMOD is an annual econometric model of U.S. agriculture sectors with a primarily recursive structure. AGMOD was first developed at Michigan State University in 1986 by Ferris [11] and has been re-estimated every year with data going back as far as 1965 [12, 13]. By 2013, the system contained 1190 equations and covers the major U.S. crop and livestock industries, including corn, wheat, other feed grain, soybeans, cattle, hogs, broilers, turkeys, eggs, and dairy as well as an extensive international component [13]. The model employs the Gauss-Seidel solution procedure, which provides approximate solutions to systems of equations, and solves deterministically for a 15-year projection period. There is no explicit production procedure, such as expansion or contraction in breeding herd, described in AGMOD model as in FAPSIM. Gross margin calculated from the market price less feed costs is the direct factor affecting livestock production in the system. For hog sector, gross margin determines the number of sows farrowed, which in turn explains pork production. For poultry sectors, gross margin determines production for chicken, turkey, and eggs directly, similar to the model specification in FAPSIM. AGMOD has been employed in some recent studies [13] to evaluate the effect of federal energy legislation on the agricultural sectors.

2.3 FAPRI Model

The Food and Agricultural Policy Research Institute (FAPRI) is a joint institute launched by the University of Missouri and Iowa State University in July 1984 [14]. The FAPRI model was initially established as an international system for a few key crop commodities. It is comprised of detailed description for domestic market as well as major foreign markets to replace the single-equation U.S. export function. Over the years, the FAPRI model has been expanded greatly with different versions. The livestock models were completely updated and specified by Brown in 1994. Besides, domestic crop models describing barley, oats, cotton, and rice markets, as well as three satellite models describing world trade, government cost, and farm income, are also included in this large scale system. The system is solved by a vector of market clearing prices at which supply equals demand in all five sub-models. Recent applications of FAPRI model include [15, 16].

2.4 Brown (1994)

Brown (1994) modeled the domestic market of major U.S. livestock sectors, including beef, pork, broiler, turkey and dairy [17]. The author also reviewed the theoretical development of breeding herd inventory management in livestock supply response. The supply side of the pork model captured both expansion (gilts added to the breeding herd) and contraction (sow slaughter) in production since these two factors affected the breeding herd level, together with which, they determined the number of sows farrowed and thus pig crop. Current and lagged gross margin were used to explain the level of investment and disinvestment of the hog breeding herd. Pork production was a function of the total number of hogs slaughtered and the profitability of barrows and gilts feeding, representing by the price ratio of barrow and gilt price to corn price. Major equations included:

$$\mathrm{PKGLTADD} = \mathrm{f}\ (\mathrm{PKSOWKS},\ \mathrm{PKGMR},\ \mathrm{PKGMR(t\text{-}1)})$$

$$\mathrm{PKSOWKS} = \mathrm{f}\ (\mathrm{PKHOGNRB(t\text{-}1)},\ \ln(\mathrm{TREND}) \times \mathrm{PKHOGNBR(t\text{-}1)},\ \mathrm{PKGMR})$$

$$\mathrm{PKHOGNBR} \equiv 0.99 \times \mathrm{PKHOGNBR(t\text{-}1)} + \mathrm{PKGLTADD}\quad \mathrm{PKSOWKS}$$

$$\mathrm{PKSOWFAR} = \mathrm{f}\ (\mathrm{PKHOGNBR(t\text{-}1)},\ \mathrm{TREND} \times \mathrm{PKHOGNBR(t\text{-}1)},\ \mathrm{PKGLTADD},\ \mathrm{PKSOWKS})$$

$$\mathrm{PKPIGCRP} \equiv \mathrm{PKSOWFAR} \times \mathrm{PKPIGLIT}$$

$$\mathrm{PKPROD} = \mathrm{f}\ (\mathrm{PKHOGSLT},\ \mathrm{TREND} \times \mathrm{PKHOGSLT},\ \mathrm{PKBAGPM/CRPFRM(t\text{-}1)})$$

$$\mathrm{PKHOGSLT} \equiv \mathrm{PKBAGKSD} + \mathrm{PKBAGKSI} + \mathrm{PKSOWKS} + \mathrm{PKBORKS}$$

$$\mathrm{PKBAGKSD} = \mathrm{f}\ (\mathrm{PKPIGCRP},\ \mathrm{TREND} \times \mathrm{PKPIGCRP},\ \mathrm{PKHOGFRM(t\text{-}1)})$$

PKBORKS = f (PKHOGNBR(t-1), ln(TREND))

PKHOGFRM ≡ (1-PKPIGD) × (PKHOGFRM(T-1) + PKPIGCRP) PKBAGKSD - PKBAGKSI

where CKYPLACE is chicks placed in the supply flock that provide hatching eggs for broiler-type chicks production. The ratio of broiler wholesale price to feed cost was used to represent the profitability of broiler feeding since gross margin data were not available. Variables are defined in Table 2.2; dummies in the original Brown model are omitted in the above description for simplicity.

Broiler production was modeled with more details in Brown (1994) than in FAP-SIM and AGMOD. Three production stages were described:

CKYPLACE = f (CKYPLACE(t-1), [(CKYWHP + CKYWHP(t-1))/2]/CKYFEED, TREND)

where CKYPLACE is chicks placed in the supply flock that provide hatching eggs for broiler-type chicks production. The ratio of broiler wholesale price to feed cost was used to represent the profitability of broiler feeding since gross margin data were not available. Variables are defined in Table 2.2; dummies in the original Brown model are omitted in the above description for simplicity.

CKYHATCH = f ([(CKYWHP + CKYWHP(t-1))/2]/CKYFEED, TREND, (CKYPLACE + CKYPLACE(t-1))/2,)

where CKYHATCH is the number of chicks hatched and it was modeled as the number of chicks placed in the supply flock and the profitability of broiler feeding. Variables are defined in Table 2.2; dummies in the original Brown model are omitted in the above description for simplicity.

Table 2.2: Brown (1994) Model Variable Names and Descriptions

Variable Names	**Description**	**Variable Names**	**Description**
BFRETPR	Beef retail price, real	PKHOGNBR	Breeding hogs on farms, Dec. 1
CKRETPR	Broiler retail price, real	PKHOGSLT	Pork, total number of hogs slaughtered
CKYFEED	Broiler grower feed	PKPCCW	Pork consumption per capita, carcass weight
CKYHATCH	Broiler chicks hatched	PKPIGCRP	Pig crop
CKYPCCRR	Broiler consumption per capita, RTC basis, excluding pet food	PKPIGD	Hog death loss
		PKPIGLIT	Pigs per litter
CKYPLACE	Chicks placed in the broiler supply flock	PKPROD	Pork production
CKYPROD	Broiler production	PKRETPR	Pork retail price, real
CKYWHP	12-city broiler price	PKSOWFAR	Sows Farrowed
CRPFRM	Corn, season average farm price	PKSOWKS	Sow slaughter
PKBAGKSD	Barrow and gilt domestic slaughter	POPTOTW	Total U.S. population
PKBAGKSI	Barrow and gilt international slaughter, exogenous	TKHATCH	Poults placed for slaughter
		TKPCCR	Turkey consumption per capita
PKBAGPM	Barrow and gilt price, U.S.1-3, Iowa/S. Minnesota, 230-250 lb.	TKPROD	Turkey production
		TKRETPR	Turkey retail price, real
PKBORKS	Boar slaughter	TKYFEED	Turkey grower feed
PKGLTADD	Gilts added to the breeding herd	TKYWHP	Young Tom turkeys (14-22 lb.), wholesale price
PKGMR	Gross margin for pork producers, real	ZCENFABWR	Consumer expenditure, food and beverages, real

CKYPROD = f (CKYHATCH, [(CKYWHP + CKYWHP(t-1))/2] /CKYFEED, ln(TREND))

where CKYPROD is broiler production. It was a function of the number of chicks hatched and the profitability of broiler feeding. Variables are defined in Table 2.2; dummies in the original Brown model are omitted in the above description for simplicity.

Two production stages were described to model turkey production:

TKHATCH = f (TKHATCH(t-1), [(TKYWHP + TKYWHP(t-1))/2]/TKFEED, TREND)

where TKHATCH is the number of turkey placed for slaughter. The lagged dependent variable was included to capture the large fixed costs turkey producers encounter. The ratio of turkey wholesale price to feed cost was used to represent the profitability of turkey feeding since gross margin data were not available. Variables are defined in Table 2.2; dummies in the original Brown model are omitted in the above description for simplicity.

TKPROD = f (TKHATCH, TKYWHP/TKFEED)

where TKPROD is turkey production, and was a function of turkey placed for slaughter. The ratio of turkey wholesale price to feed cost was included to reflect the economic response of turkey slaughter weight. Variables are defined in Table 2.2; dummies in the original Brown model are omitted in the above description for simplicity.

Per capita consumptions were explained by own price, prices of closely related meat products, food expenditures, and trend to capture structural change in meat consumption:

PKPCCW = f (PKRETPR, BFRETPR, CKRETPR, (ZCENFABWR/POPTOTW), ln(TREND))

CKYPCCRR = f (CKRETPR, PKRETPR, BFRETPR, (ZCENFABWR/POPTOTW))

ln(TKPCCR) = f (ln(TKRETPR), ln(CKRETPR), ln(ZCENFABWR/POPTOTW))

where per capita consumption is specified as a function of retail price, food expenditure, and prices of closely related commodities. Variables are defined in Table 2.2; dummies in the original FAPSIM model are omitted in the above description for simplicity.

The Brown model was estimated using annual data from 1970 to 1991. 2SLS estimation method was employed; the author also compared ordinary least squares and 3SLS estimation method, and no significant differences in the estimated parameters were found.

2.5 Other Models

A number of other research models which are smaller in scale and narrowed in scope have also provided valuable insights for understanding each of the agricultural sub-sectors. Crom and Maki developed a recursive dynamic model of the pork and beef sectors for the period of 1955 to 1964 [18]. The recursive feature of the model reproduced the sequential nature in actual livestock production and has been followed by a series of studies, including Rahn (1973) [19], Chavas (1978) [20], Chavas and Johnson (1981) [21], Chavas and Johnson (1982) [22], Buhr (1993) [23], Brown (1994), as well as some of the large scale systems mentioned above (FAPSIM and FAPRI). Similar model structures following the actual production procedures will also be specified in this study by including an equation for each important production decision.

Hoffman (1970) developed an eight-equation quarterly model for the egg industry to estimate total egg production, eggs used for hatching (to produce both egg layers and broilers), and table egg production; no disaggregation of product was considered [24]. This concise model sketched the relationship between the egg sector and the broiler sector consistently with the World Agricultural Supply and Demand Estimates data set provided by USDA. A similar model structure was also applied in Stillman (1985), and will be followed for the egg sector in the present study.

Maisashvili (2014) [5] estimated an annual econometric model for the U.S. beef and dairy sectors to analyze the economic consequences of the renewable fuel standard (RFS) and the impacts of the feed cost shocks on these two sectors. Total supply and total demand were modeled for both sectors; and each endogenous variable was explicitly expressed by other endogenous and/or exogenous variables, except for the primary endogenous variable, here beef retail price for the beef sector and wholesale prices of butter, American cheese, nonfat dry milk, and evaporated and condensed milk for the dairy sector, that were ultimately used to clear the markets and reach a partial equilibrium. Dynamic simulation was applied when projecting future values such that calculated market-clearing endogenous variables in a given year were used as if they were predetermined, together with actual exogenous variables, for the next year. These procedures in Maisashvili (2014) to solve the model and project future values will be followed in the current work; and thus these two studies constitute a consistent system for major U.S. livestock and poultry products.

Several studies analyzed the economic impacts of highly pathogenic avian influenza (HPAI), including Djunaidi and Djunaidi (2007) [25], Paarlberg Seitzinger, and Lee (2007) [8], Brown (2007) [26], and Saghaian Özertan and Spaulding (2008) [27]. Among these studies, Paarlberg et al. (2007) and Brown (2007) focused on the U.S. market. In Brown (2007), the effect of an HPAI outbreak in some areas was calculated by assuming a certain amount of decrease in total poultry production according to the historical production data (2002 Census of Agriculture) in these areas. Yet, the study did not take into account the response of other regions in the country due to the non-spatial character of the FAPRI model. Paarlberg et al. (2007) also addressed the importance of regionalization in measuring the real export and welfare losses of an HPAI outbreak. To study the poultry industry in more details and model the effect of regionalized issues, the poultry industry will be divided into different regions in this study according to Hatchery Production Annual Summary (USDA NASS) with adjustments made due to data availability.

3. METHODOLOGY

This chapter is devoted to the development of economic theory underlying the model construction and industry analysis in later chapters. Following the literature review in the previous chapter, total supply and total demand for each livestock or poultry sector will be modeled; and a vector of primary prices, one from each sector, will be calculated such that the market clears by minimizing the sum of squared excess supply from each of the individual markets.

For each commodity, total supply consists of beginning stock, imports, and production; and total demand comprises ending stock, exports, and domestic disappearance. Due to the extensive proportion of domestic production and consumption accounting for the total U.S. supply and disappearance respectively, two aspects will be considered in substantial details in constructing the model: the supply response from the livestock producers and the demand for meat from the consumers.

3.1 Production Theory

Classic supply function specified by output and input prices is derived from the profit maximization problem for a price-taking competitive firm

$$\max_{\mathbf{y}} \pi(\mathbf{p}) = \max_{\mathbf{y}} \mathbf{py} \tag{3.1}$$

where $\mathbf{y} \in Y$, the firm's production possibilities set; and $\mathbf{p}$ is the price vector.

Under the assumption that only one output is produced, and let p be the scalar representing output price, $\mathbf{x}$ be the vector of inputs, $\mathbf{w}$ be the vector of input prices, the objective function becomes equation 3.2

$$\max_{\mathbf{x}} \pi(p, \mathbf{w}) = \max_{\mathbf{x}} \mathrm{p} f(\mathbf{x}) - \mathbf{w}\mathbf{x} \tag{3.2}$$

$$F.O.C: \frac{\partial \pi}{\partial x_i} = p \frac{\partial f(x_1, \ldots, x_n)}{\partial x_i} - w_i = 0 \tag{3.3}$$

$$S.O.C: \frac{\partial^2 \pi}{\partial^2 x} = \frac{\partial^2 f(x)}{\partial^2 x} \leq 0 \tag{3.4}$$

Under first-order condition and second-order condition (equations 3.3 and 3.4), we can reach the factor demand function of the firm: $\mathbf{x}^*(P, \mathbf{w})$. The supply function of the firm $y^*(p, \mathbf{w}) = f(\mathbf{x}^*(p, \mathbf{w}))$ which is a function of output and input prices.

However, this functional form overlooks the critical sequential feature in livestock production and thus may give incorrect projections. For example, when output price increases, the quantity produced might not increase as suggested by classic production theory in the short run; especially for livestock sectors with longer production cycles such as cattle and hogs. This can be explained by the fact that output from earlier production stages constrains later production possibilities because of the necessary time taken in livestock production. Thus an unexpected price increase in the output might not be responded to immediately. The production might even decrease as a reaction toward the output price increase in the short run. This is because: (1) producers might want to raise the cattle or hog to a heavier weight; and/or (2) producers keep more animals in their breeding herd to expand production in the long run, and thus fewer animals go to the marketing herd and production decreases in the short run [28, 29, 17].

The complicated production procedure in livestock sectors cannot be described precisely by the simple production equation derived from the classic supply theory. To model the production procedure more accurately, all of the important decision points in the production processes should be included in the modeling system, each with an econometric function, as in the literatures reviewed in the previous chapter. Biological constraints are also incorporated in this way to reflect the nature of livestock production processes. A flowchart describing the supply and demand for each livestock market will be provided in the respective chapter to help illuminate the construction of the model.

3.2 Retail Demand

Classical demand theory suggests that ordinary demand functions can be derived from the constrained utility maximization problem

$$\max_{\boldsymbol{x} \in X} u(\boldsymbol{x}), \quad \text{s.t.} \quad \boldsymbol{p}\boldsymbol{x} \leq w, \tag{3.5}$$

where $\boldsymbol{x}$ is the vector of commodities to be consumed and is an element of the commodity space $X \subseteq \mathbb{R}^L$, $\boldsymbol{p}$ is the vector of corresponding prices, and w is the budget constraint; and can be solved by the Lagrangian multiplier method

$$L(\boldsymbol{x}, \lambda) = u(\boldsymbol{x}) + \lambda(w - (\boldsymbol{p}\boldsymbol{x})) \tag{3.6}$$

Under first-order conditions:

$$\frac{\partial L}{\partial x_i} = \frac{\partial u(\boldsymbol{x})}{\partial x_i} - \lambda p_i = 0, \quad \text{for} \quad i = 1, \ldots, L \tag{3.7}$$

$$\frac{\partial L}{\partial \lambda} = w - \boldsymbol{p}\boldsymbol{x} = 0 \tag{3.8}$$

optimal choice can be derived and will be of the form: $x_i^* = f(p_1, \ldots, p_l, w),$ for $i = 1, \ldots, L$

From the above derivation, all prices for the commodities in the commodity space and income should be included in the demand function. But empirical economists usually work with more feasible functional forms consisting of fewer variables by applying the assumption of weak separability of preferences.

According to Deaton and Muellbauer (1980b) [30] if the whole commodity set can be partitioned into N subsets such that the preference on goods in one subset is independent of the consumption levels in other subsets, the preferences are (weakly) separable. Separable preferences can be represented by a utility function of the form

$$u = f[v_1(q_1), v_2(q_2), \ldots, v_G(q_G), \ldots, v_N(q_N)] \tag{3.9}$$

Under the assumption of weak separability multistage budgeting is legitimate. Consumers first allocate total expenditure over the N broad groups of goods, then group expenditures are allocated over goods within each group independently such that each of v_1 to v_N is maximized. Most of the demand analyses for meat products are conducted under the assumption of weak separability explicitly or implicitly [Heien (1982), Eales and Unnevehr (1993), Huang (1994), Edgerton (1997), Kinnucan et al. (1997), Eales, Hyde, and Schrader (1998), Jones, Hahn, and Davis (2003)]. Thus, the meat demand function in the current study will concentrate within the food group and only the prices of closely related meat commodities, price index for non-meat food, and total expenditures on food need to be included in the set of explanatory variables.

Ferris (2005) suggested some other factors that should be considered when measuring domestic demand for a given product in empirical practices. These include population, demographic effects, income distribution, general inflation, others factors, such as living patterns and health concerns, and seasonality and weather effects. Since annual per capita consumption will be modeled in our system, more attention will be paid to the effect of general inflation and living patterns while other factors will not be accounted for. General inflation will be treated by using GPD deflated prices and food expenditures in the econometric functions. The effect of living patterns will be represented by trend terms or lagged consumptions levels will be included in the explanatory variables to represent sluggish consumption behavior, whichever gives a better fit in a prior functional form tests.

A variety of model specifications have been applied to demand analysis since economic theory is not informative about functional forms [Alston and Chalfant 1991]. Smallwood et al. (1990) provided a thorough review of the literature on meat demand analysis, in which different demand models and their applications were described. Double-log functional form will be specified due to the straight interpretation of its parameters as elasticities in this large system. The selection of the double-log functional form is also justified since functional form did not play a determining role in the estimation of meat demand elasticities for the region of North America [Gallet 2012].

To sum up, (1) a double-log functional form will be specified for the demand equation in each livestock sector. (2) The primary explanatory variables are: own price, price for closely related meat products, non-meat food price index, food expenditures, and a trend term or lagged quantity demanded if needed. (3) Following the procedure in Eales and Unnevehr (1993), non-meat food price index is calculated as the ratio of non-meat food expenditure to non-meat food quantity, where non-meat food expenditure is food expenditure minus total meat expenditures and non-meat food quantity is food quantity minus the sum of meat quantities. Food quantity is the ratio of food expenditure to food CPI.

3.3 Model Specification

Critical decision points in pork production include breeding herd investment (gilts added to the breeding herd) and disinvestment (slaughter of breeding herd), the number of sows farrowed and pig crop, and slaughter of hogs. Contribution margin calculated from the gross revenue less variable costs is the direct factor affecting the number of gilts added to the breeding herd and slaughter of sows, which in turn determines the hog breeding herd inventory, and thus the number of sows farrowed and pig crop, and finally the number of hogs available for slaughter.

Pork production is expressed as the product of the number of hogs slaughtered and average hog slaughter weight with unit adjustment. Average hog slaughter weight is affected by the profitability of hog feeding, represented by the price ratio of barrow and gilt price to feed price, and a trend term representing technology progress. Slaughter of barrows and gilts is modeled as a function of pig crop, net hog import, beginning marketing hog inventory, and pork wholesale price. Major functions include:

$$\text{PKPROD} \equiv \text{PKSLHOG} \times \text{PKHOGSLW} \,/\, 1000$$

$$\text{PKHOGSLW} = \text{f (PKBAGLTP\_MIXFEED, YEAR)}$$

$$\text{PKSLHOG} \equiv \text{PKSLBAGLT} + \text{PKSLBRH}$$

$$\text{PKSLBAGLT} = \text{f (PKPIGCROP, PKHOGNIMPT, PKHOGMKTINV\_LAG1, PKWHPR)}$$

$$\text{PKPIGCROP} \equiv \text{PKSOWFAR} \quad \text{PKPIGPL}$$

$$\text{PKSOWFAR} = \text{f (PKSOWFAR\_LAG1, PKADDBRH, PKSLBRH)}$$

$$\text{PKADDBRH} = \text{f (PKSLBRH, PKCMR)}$$

$$\text{PKSLBRH} \equiv \text{PKSLSOW} + \text{PKSLBRSTG}$$

PKSLSOW = f (PKHOGBRH_LAG1, PKCMR)

PKSLBRSTG = f (PKHOGBRH_LAG1)

where variables are defined in Appendix A, dummies and time shifters in the original system are omitted in the above description for simplicity.

Critical decision points in broiler production include hatching egg production[1], which provides fertilized eggs to be hatched and raised for slaughter and is decided by the number of hatching egg layers and the average laying rate, broiler-type hatching eggs being set in incubators, broiler-type chicks being hatched, placed on feed, and slaughtered. Contribution margin data are not available for the broiler industry; the price ratio of broiler wholesale price/broiler-type chick price to feed price is used to represent the profitability of broiler feeding in different production stages and affect the final broiler production. The poultry industry is divided into four regions in this study: the South Central (SC), the South Atlantic (SA), the North Atlantic (NA), and Other Regions (OTH), according to Hatchery Production Annual Summary (USDA NASS) with adjustments made due to data availability. Major functions include:

CKPROD ≡ CKSLW × CKSLT / 1000

CKSLW = f (CKSLW_LAG1, CKWHP_FEED)

$\text{CKSLT} \equiv \sum_i \text{CKSLT}_i, \quad i\text{=SC, SA, NA, OTH}$

$\text{CKSLT}_i = \text{f (CKPLACE}_i), \quad i\text{=SC, SA, NA, OTH}$

$\text{CKPLACE}_i = \text{f (CKHATCH}_i), \quad i\text{=SC, SA, NA, OTH}$

$\text{CKHATCH}_i = \text{f (CKEGGSET}_i), \quad i\text{=SC, SA, NA, OTH}$

[1]Broiler-type hatching egg production would be more accurate; yet this data is not available in regional level. And (total) hatching egg production, which is the summation of broiler-type hatching egg production and egg-type hatching egg production, is used as a proxy.

CKEGGSET_i = f (CKEGGSET_LAG1$_i$,HEGGPROD$_i$), i=SC, SA, NA, OTH

$\text{HEGGPROD}_i \equiv \text{HEGGLAYER}_i \times \text{HEGGLR}_i$, i=SC, SA, NA, OTH

HEGGLAYER_i = f (HEGGLAYER_LAG1$_i$, CKCHKP_FEED), i=SC, SA, NA, OTH

HEGGLR_i = f (HEGGLR_LAG1$_i$, CKCHKPR), i=SC, SA, NA, OTH

where variables are defined in Appendix A, dummies and time shifters in the original system are omitted in the above description for simplicity.

Egg production is comprised of hatching egg production and table egg production, where regional hatching egg production is specified in the broiler model and U.S. total hatching egg production is simply the summation of the regional production. Critical decision points in table egg production include egg-type hatching egg production, which provides fertilized eggs to be hatched and raised to table egg layers and is decided by the number of egg-type hatching egg layers and their average laying rate, egg-type hatching eggs being set in incubators, egg-type chicks being hatched, placed on feed and lay eggs. Contribution margin data are not available for the egg industry; egg wholesale price/egg-type chick price and egg layers feed cost are used to represent the profitability and cost in different production stages for egg layer feeding and affect the final table egg production. Major functions include:

EGGPROD ≡ HEGGPROD + TBEGGPROD

HEGGPROD $\equiv \sum_i \text{HEGGPROD}_i$, i=SC, SA, NA, OTH, specified in the broiler model

TBEGGPROD ≡ TBEGGLR × TBEGGLAYER / 1200000

TBEGGLR = f (YEAR, EGGWHPR)

TBEGGLAYER = f (TBEGGLAYER_LAG1, TBEGGHATCH)

TBEGGHATCH = f (TBEGGSET)

TBEGGSET = f (TBHEGGPROD)

TBHEGGPROD = TBHEGGLR × TBHEGGLAYER / 1200000

TBHEGGLR = f (YEAR, EGGCKPR)

TBHEGGLAYER = f (TBHEGGLAYER_LAG1, EGGCKPR, EGGFEEDR)

where variables are defined in Appendix A, dummies and time shifters in the original system are omitted in the above description for simplicity.

Major decision points in the turkey production model start with turkey eggs being set in incubators since no data is available for earlier production stages. Also because of data availability, the next step to be modeled is turkey poults being placed on feed. And the final step is turkey being slaughtered. Turkey production is modeled as the product of average turkey slaughter weight and the number of turkey slaughtered. Turkey wholesale price and feed cost are used to represent the profitability and cost for turkey feeding respectively. Major functions include:

TKPROD ≡ TKSLW × TKSLT / 1000

TKSLW = f (YEAR, TKWHP_FEED)

TKSLT = f (TKPLACE, TKSLT_LAG1)

TKPLACE = f (TKEGGSET, YEAR)

TKEGGSET = f (TKEGGSET_LAG1, TKWHPR, TKFEEDR)

where variables are defined in Appendix A, dummies and time shifters in the original system are omitted in the above description for simplicity.

For the demand side, per capita consumptions of pork, broiler, egg, and turkey are specified in double-log functional form:

PKPCCR_LOG = f (FOODEXPR_LOG, PKRETPR_LOG, BFCKRETPR_LOG, OTHFOODPR_LOG, YEAR_LOG)

CKPCCR_LOG = f (FOODEXPR_LOG, CKRETPR_LOG, BFPKTKRETPR_LOG, OTHFOODPR_LOG, TIME_LOG)

TKPCCRBL_LOG = f (FOODEXPR_LOG, TKRETPR_LOG, CKRETPR_LOG, OTHFOODPR_LOG, TKPCCRBL_LOG_LAG1)

EGGPCCR_LOG =f (FOODEXPR_LOG, EGGRETPR_LOG, OTHFOODPR_LOG, EGGPCCR_LOG_LAG1)

where variables are defined in Appendix A, dummies and time shifters in the original system are omitted in the above description for simplicity.

3.4 Estimation and Validation Method

Single equation ordinary least squares (OLS) method is used to estimate the production equations and two stage least squares (2SLS) method is applied to estimate the per capita consumption equations in the system. Based on the assumption that the structural errors are pairwise uncorrelated, the recursive system used to describe livestock productions is consistently estimated by OLS.

Adjusted R-squared is used to infer the goodness of fit of the model specification. P-value and t-statistics show the statistical significance of an explanatory variable. Breusch-Godfrey test is applied to test for the presence of serial correlation whenever lagged dependent variable is included in the explanatory variables. Mean Absolute Percentage Error (MAPE) and Theil's U2 (U2) are used to measure the accuracy of fitted values:

$$\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n}|\frac{y_i - f_i}{y_i}| \tag{3.10}$$

$$\mathrm{U2} = \sqrt{\frac{\sum_{i=1}^{n-1}\left(\frac{f_{i+1}-y_{i+1}}{y_i}\right)^2}{\sum_{i=1}^{n-1}\left(\frac{y_{i+1}-y_i}{y_i}\right)^2}} \tag{3.11}$$

where y_i and f_i are the actual and fitted values of observation i respectively.

Estimated elasticities are compared with literature. Midterm (2015 to 2024) projection of livestock productions, prices, and consumptions are also compared with FAPRI and USDA projections to validate the model specification.

4. THE U.S. PORK INDUSTRY

This chapter presents an econometric model for the U.S. pork industry. The model describes the supply and the demand for the pork sector within the U.S. economy; retail price is the primary variable that adjusts and clears the market. Total supply consists of beginning stock, import, and production; total demand comprises ending stock, export, and domestic disappearance. Due to the extensive proportion of domestic production and consumption accounting for the total U.S. pork supply and disappearance respectively, the model focuses on modeling these two parts based on the theoretical underpinnings developed in the previous chapter. A one-equation description will be used to approximate the U.S. pork imports, exports, and stocks for the current study.

The chapter is organized as follows. In the first section, the general flow in pork production is presented as a background. Critical decision points in pork production have been discussed in Chapter III. More detailed information about the industry will be provided in this section. In the second section, the dataset that will be used for estimating the econometric model will be discussed. In the third section, the model specification and estimation results will be presented.

4.1 Pork Production

Pork production has a sequential feature starting with breeding herd inventory management. The breeding herd inventory is determined by the number of breeding hogs at the beginning of the period, hogs added to the breeding herd, and slaughter of the breeding herd. The number of breeding hogs added or removed depends upon the contribution margin hog producers receive where contribution margin is defined as revenue minus variable costs (when these two data series are not available, in the case of the U.S. poultry sector, wholesale price and feed cost will be used as a proxy).

The contribution margin of two types of hog farms, farrow-to-finish hog farms and farrow-to-feeder hog farms, are considered since they are where most breeding hogs are kept. As mentioned in the introduction, drastic structural changes occurred in the U.S. pork industry during the study period. Traditional farrow-to-finish producers have given way to more specialized hog operations focusing in particular production stages. According to the Census of Agriculture (USDA 2012) the production share for farrow-to-finish producers has declined to 25 percent by 2009 and remained around 25 percent thereafter. Thus during the period of 1985 to 2008, the industry contribution margin is dominated by farrow-to-finish hog farms; and after 2008 both farrow-to-finish and farrow-to-feeder hog farms profitability are counted. The industry contribution margin as a result is represented by a farrow-to-finish farm contribution margin for the period of 1985 to 2008, and a weighted contribution margin (25 percent of farrow-to-finish farm and 75 percent of farrow-to-feeder farm) for the period of 2009 to 2014.

The number of sows or gilts that can be bred is constrained by the dynamic status of the hog breeding herd inventory and in turn determines the number of sows farrowed and thus the number of pig crops. However, no dataset recording the breeding stage of pork production is published consistently; and the number of sows farrowed will be the next production stage that is modeled.

Once a swine is bred, the gestation period is around 114 days; the feeding period for barrows and gilts usually lasts around 6 months before they reach slaughter weight. Producers can decide the slaughter weight of barrows and gilts and also the portion of the herd to be slaughtered, retained in the marketing inventory, or added into the breeding herd. Total domestic supply of pork is thus the multiplication of the average slaughter weight and the summation of barrows and gilts slaughtered and breeding herd slaughtered.

Not all pig crops will be placed on feed and either slaughtered in the contemporaneous period or kept in the marketing inventory for later slaughter due to death loss caused by illness or other reasons. Net pig crop, calculated as pig crop less death loss, will be included in the explanatory variables in both barrow-and-gilt slaughter function and year-end marketing hog inventory function.

The U.S. pork model is schematically described in Figure 4.1.

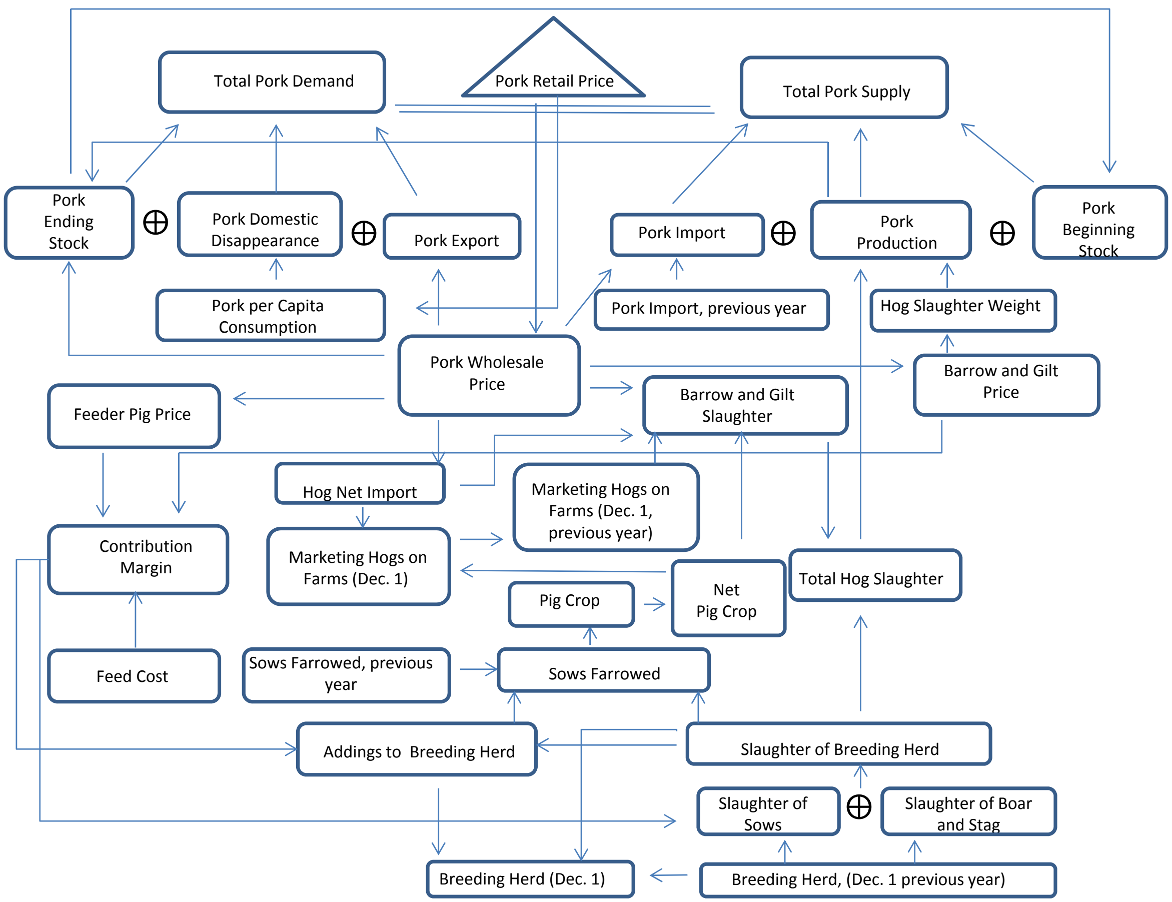
4.2 Pork Data

Macro-level pork supply and demand data, including pork production, imports, exports, stocks, and consumption, are available from Agricultural Supply and Demand Estimates provided by USDA. Most of the production data are documented by National Agricultural Statistics Service (NASS, USDA), including breeding herd inventory, slaughter of different types of hogs, the number of sows farrowed, pig crop, pigs per litter, hog death loss, marketing hog inventory, and prices for hogs. Live hog trade (net import of hogs), even though it accounts for only a small portion of the total hog supply compared to domestic pig crops, it is statistically significant in affecting the marketing hog inventory and the slaughter of hogs; the data are documented by Economic Research Service (ERS USDA). Data used to calculate revenue and variable cost in pork production are also provided by ERS under the subject of Commodity Costs and Returns.

The number of gilts and boars added to the breeding herd is not explicitly provided by USDA, and is recovered from breeding herd level in this period, breeding herd level in the last period, slaughter of sows, and slaughter of boars and stags.

No data for the number of sows bred is available, so this production stage will be skipped in the modelling of pork production. Sows farrowed, pig crop, and pigs

Figure 4.1: U.S. Pork Model



per litter data are all published by USDA; yet, to maintain the identity such that annual pig crop is the number of sows farrowed multiplying pigs per litter, pigs per litter data are recovered from the ratio of pig crop to the number of sows farrowed. The same procedure is applied to recover the average slaughter weight of hogs which equals the ratio of pork production over total number of hogs slaughtered.

4.3 The U.S. Pork Model

The U.S. pork model is schematically delineated in Figure 4.1. Total U.S. pork demand equals the summation of pork ending stock, pork export, and pork domestic disappearance. Total U.S. pork supply equals the summation of pork beginning stock, pork import, and pork production.

Starting from the demand side, the pork total demand identity is

PKDEM ≡ PKSTK + PKEXPT + PKCDIS

where PKDEM is the total demand for pork, PKSTK is pork ending stock, PKEXPT is pork export, and PKCDIS is pork domestic disappearance.

U.S. pork ending stock is specified as:

PKSTK = f (PKWHPR,PKPROD,SHIFT11,D87898018)

where PKWHPR is the real pork wholesale price, PKPROD is the U.S. pork production and will be discussed in the supply side; variables starting with SHIFT and D are time shifters and dummy variables, and will are presented in Appendix A. Estimation results are presented in Table 4.1. Pork wholesale price has a negative effect on pork ending stock, reflecting the fact that when price is high more meat is sold and thus ending stock is low. Pork production has a positive effect on ending stocks.

U.S. pork export accounts more than 20 percent of total pork production during the past couple of years. Primary foreign markets for U.S. pork products include

Table 4.1: Pork Ending Stock

PKSTK	Estimate	Std. Error	t value	Pr(>| t |)
(Intercept)	158.9486	118.3049	1.3400	0.1912
PKWHPR	-113.6838	38.9016	-2.9200	0.0073
PKPROD	0.0231	0.0036	6.4600	0.0000
SHIFT11	64.2776	23.2116	2.7700	0.0104
D87898018	85.8107	12.5291	6.8500	0.0000
Adjusted R-squared:		0.9407	MAPE	0.0431
Breusch-Godfrey test p-value:		0.4443	Theil's U2	0.3272

Japan, Mexico, Hong Kong, Russia, and Canada. To model the U.S. pork export with sufficient accuracy, descriptions for the demand from these markets to certain extent are needed yet are beyond the research scale of the current study. A single equation description for the U.S. pork export will be specified as:

PKEXPT = f (PKEXPT_LAG1, PKPROD, D09, D0811, D13, D14, D0458)

where PKEXPT is pork export, PKEXPT_LAG1 is the lagged dependent variable, and PKPROD is pork production. Based on the assumption that not all the trading partners will change drastically, the lagged dependent variable can explain partially the current quantity of pork export. Total pork production sets a limit on the amount the domestic producers are willing to trade. Estimation results are presented in Table 4.2. Both lagged dependent variable and pork production are positively correlated with pork export as expected.

The last and largest proportion of the quantity demanded for pork is pork domestic disappearance, which is the product of U.S. population and carcass weight per capita consumption:

PKCDIS $\equiv$ USPOP $\times$ PKPCCC

where PKCDIS is civilian pork disappearance, USPOP is U.S. population, and

Table 4.2: Pork Exports

PKEXPT	Estimate	Std. Error	t value	Pr(>| t |)
(Intercept)	-607.3912	244.5428	-2.4800	0.0211
PKEXPT_LAG1	0.9574	0.0289	33.1600	0.0000
PKPROD	0.0420	0.0153	2.7500	0.0117
D09	-717.9520	90.7285	-7.9100	0.0000
D0811	867.3548	66.9377	12.9600	0.0000
D13	-525.5513	98.8853	-5.3100	0.0000
D14	-302.7638	95.0906	-3.1800	0.0043
D0458	334.3924	56.1343	5.9600	0.0000
Adjusted R-squared:		0.9981	MAPE	0.0797
Breusch-Godfrey test p-value:		0.7232	Theil's U2	0.4874

PKPCCC is carcass weight per capita consumption for pork.

Carcass weight per capita consumption for pork is recovered from pork retail weight per capita consumption by dividing the carcass to retail conversion factor:

$$\text{PKPCCC} \equiv \text{PKPCCR} \div 0.776$$

where PKPCCC is pork carcass weight per capita consumption, PKPCCR is pork retail weight per capita consumption, and the ratio of 0.776 is achieved from the historical data series of these two variables.

Following the discussions in the previous chapter, retail weight per capita consumption for pork is modeled by a double-log functional form:

PKPCCR_LOG = f (FOODEXPR_LOG, PKRETPR_LOG, BFCKRETPR_LOG, OTHFOODPR_LOG, YEAR_LOG, D98T04, D86112)

where PKPCCR_LOG is pork retail weight per capita consumption in log form, FOODEXPR_LOG is real food expenditure in log form, PKRETPR_LOG is real pork retail price in log form, BFCKRETPR_LOG is comprised of real beef and chicken retail price in log form, OTHFOODPR_LOG is the real price index of other food commodities in log form, and YEAR_LOG is trend in log form.

Estimation results are presented in Table 4.3. Food expenditure has a positive effect on pork consumption; income elasticity is 0.38. Pork retail price is negatively affecting pork consumption; own price elasticity is -0.51. Beef and broiler are substitutes for pork and their composited retail price is positively affecting pork consumption; cross price elasticity is 0.24. Other food price index is insignificant both statistically (p-value is greater than 0.1) and economically (the corresponding coefficient is as low as 0.03), indicating that this variable has no effect on pork consumption and thus will be omitted in the projection system. The functional specification that will be applied in the projection system is presented in Table 4.4.

Table 4.3: Pork Per Capita Consumption Without OTHFOODPR (Retail Weight)

PKPCCR_LOG	Estimate	Std. Error	t value	Pr(>| t |)
(Intercept)	106.5907	34.0270	3.1300	0.0048
FOODEXPR_LOG	0.3757	0.1739	2.1600	0.0418
PKRETPR_LOG	-0.5118	0.0547	-9.3500	0.0000
BFCKRETPR_LOG	0.2372	0.0625	3.7900	0.0010
OTHFOODPR_LOG	0.0320	0.1421	0.2300	0.8239
YEAR_LOG	-13.6486	4.5495	-3.0000	0.0066
D98T04	0.0548	0.0064	8.5300	0.0000
D86112	-0.0253	0.0089	-2.8400	0.0095
Adjusted R-squared:		0.9114	MAPE	0.0024
Breusch-Godfrey test p-value:		0.1116	Theil's U2	0.3243

The variable BFCKRETPR_LOG in the pork retail weight per capita consumption function is defined as:

$$\text{BFCKRETPR\_LOG} \equiv \ln\left[(\text{BFRETPR} + \text{CKRETPR})/2\right]$$

Table 4.4: Pork Per Capita Consumption With OTHFOODPR (Retail Weight)

PKPCCR_LOG	Estimate	Std. Error	t value	Pr(>| t |)
(Intercept)	87.9194	26.6778	3.3000	0.0033
FOODEXPR_LOG	0.3470	0.1598	2.1700	0.0410
PKRETPR_LOG	-0.4987	0.0491	-10.1500	0.0000
BFCKRETPR_LOG	0.2086	0.0530	3.9400	0.0007
YEAR_LOG	-11.1740	3.5806	-3.1200	0.0050
D98T04	0.0538	0.0061	8.8800	0.0000
D8892	0.0272	0.0091	3.0000	0.0066
D10T13	-0.0232	0.0087	-2.6700	0.0140
Adjusted R-squared:		0.9266	MAPE	0.0022
Breusch-Godfrey test p-value:		0.2949	Theil's U2	0.2856

where BFRETPR is real beef retail price and CKRETPR is real chicken retail price. These two retail prices are the primary endogenous variables in the two respective sectors used to clear the markets. This equation ends the description for the demand side of the pork industry.

The U.S. pork total supply identity is:

PKSUPP ≡ PKSTK_LAG1+PKIMPT+PKPROD

where PKSTK_LAG1 is pork beginning stock that can be recovered from pork ending stock in the previous period, PKIMPT is U.S. pork import, and PKPROD is U.S. pork production.

Following similar reasoning logic in specifying the U.S. pork export function, the U.S. pork import will be specified as:

PKIMPT = f(PKIMPT_LAG1,PKWHPR,D90T97,D08112,D89,D023)

where PKIMPT is pork import, PKIMPT_LAG1 is the lagged dependent variable, and PKWHPR is real pork wholesale price. Based on the assumption that not all of the trading partners will change drastically, the lagged pork import can explain partially the current quantity of pork imports. And the real pork wholesale price also helps explain the domestic wholesalers willingness to trade. Estimation results are presented in Table 4.5. The lagged dependent variable and pork wholesale price are both positively correlated with pork imports as expected.

Table 4.5: Pork Imports

PKIMPT	Estimate	Std. Error	t value	Pr(>| t |)
(Intercept)	168.9498	69.4149	2.4300	0.0231
PKIMPT_LAG1	0.5262	0.0706	7.4500	0.0000
PKWHPR	211.0859	44.6653	4.7300	0.0001
D90T97	-173.4262	25.2625	-6.8600	0.0000
D08112	-111.4530	29.0796	-3.8300	0.0009
D89	-209.4795	48.4622	-4.3200	0.0003
D023	173.1800	37.3109	4.6400	0.0001
Adjusted R-squared:		0.9289	MAPE	0.0383
Breusch-Godfrey test p-value:		0.6432	Theil's U2	0.5047

The main component of total pork supply is pork production, which is explained by two factors, the number of hogs slaughtered and the average hog slaughter weight. Since the measurement unit for pork production is million pounds in our data set, a conversion rate of 1/ 1000 is needed:

$$\text{PKPROD} \equiv \text{PKSLHOG} \times \text{PKHOGSLW} \div 1{,}000$$

where PKPROD is pork production, PKSLHOG is the number of hogs slaughtered, and PKHOGSLW is the average hog slaughter weight.

Hog slaughter weight is determined by the benefit of holding and raising hogs, which is represented by the ratio of barrow and gilt price to a weighted feed cost (a mixture of corn price and soybean meal price). There is also a trend term in this function representing technology improvement:

PKHOGSLW = f (PKBAGLTP_MIXFEED, YEAR, D14, D023)

where PKHOGSLW is average hog slaughter weight, PKBAGLTP_MIXFEED is the ratio of barrow and gilt price (PKBAGLTP) over a weighted feed cost (PKMIXFEED), and YEAR is the trend term. Estimation results are presented in Table 4.6. When the benefit of holding and raising hogs increases, farmers would keep the hogs longer to reach a heavier weight, and vice versa. Thus the coefficient of the ratio of barrow and gilt price over feed cost should be positive. Trend term representing technology improvement should also be positively correlated with the slaughter weight.

Table 4.6: Average Hog Slaughter Weight

PKHOGSLW	Estimate	Std. Error	t value	Pr(>| t |)
(Intercept)	-2025.8508	45.6902	-44.3400	0.0000
PKBAGLTP_MIXFEED	0.4819	0.1010	4.7700	0.0001
YEAR	1.1088	0.0226	49.0800	0.0000
D14	3.3356	0.8282	4.0300	0.0005
D023	1.8402	0.5613	3.2800	0.0031
Adjusted R-squared:		0.9936	MAPE	0.0028
Breusch-Godfrey test p-value:		0.3407	Theil's U2	0.4095

Total number of hogs slaughtered is the summation of all types of hogs slaughtered:

PKSLHOG ≡ PKSLBAGLT + PKSLBRSTG + PKSLSOW

where PKSLHOG is total number of hogs slaughtered, PKSLBAGLT is barrow and gilt slaughter, PKSLBRSTG is boar and stag slaughter, and PKSLSOW is sow slaughter.

Barrow and gilt slaughter is determined by marketing hog inventory at the beginning of the year, net pig crop, net hog imports, and pork wholesale price:

PKSLBAGLT = f (PKPIGCROPNET, PKHOGMKTINV_LAG1, PKHOGNIMPT, PKWHPR, D93T98, D078)

where PKSLBAGLT is barrow and gilt slaughter, PKPIGCROPNET is net pig crop which equals pig crop less pig death loss, PKHOGMKTINV is marketing hog inventory on December 1st, and PKHOGMKTINV_LAG1 is used to approximate the beginning marketing hog inventory of the current period, PKHOGNIMPT is net hog import which equals hog import less hog export, and PKWHPR is real pork wholesale price. Slaughter of barrows and gilts are expected to be positively correlated to net pig crop, net hog import, beginning stock of marketing hog inventory, and negatively related to real pork wholesale price according to the inventory theory discussed in the literature review. Estimation results are presented in Table 4.7. All coefficients have the expected sign.

Table 4.7: Slaughter of Barrows and Gilts

PKSLBAGLT	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-13814.4194	2229.1463	-6.2000	0.0000
PKPIGCROPNET	0.4601	0.0352	13.0600	0.0000
PKHOGMKTINV_LAG1	1.1838	0.0613	19.3200	0.0000
PKHOGNIMPT	0.6990	0.0613	11.4100	0.0000
PKWHPR	-1555.1227	632.1907	-2.4600	0.0218
D93T98	-1314.2411	271.7880	-4.8400	0.0001
D078	-1389.0596	430.5688	-3.2300	0.0037
Adjusted R-squared:		0.9980	MAPE	0.0040
Breusch-Godfrey test p-value:		0.9843	Theil's U2	0.1274

Hog marketing inventory on December 1st, is expressed as a function of net pig crop, net hog import, and slaughter of barrow and gilt:

PKHOGMKTINV = f (PKPIGCROPNET, PKHOGNIMPT, PKSLBAGLT, SHIFT14, D89, D85T87)

where PKHOGMKTINV is hog marketing inventory on December 1st, PKPIGCROPNET is net pig crop, PKHOGNIMPT is net hog imports, and PKSLBAGLT is barrow and gilt slaughter. Net pig crop and net hog import are assumed to be positively correlated with hog marketing inventory, and slaughter of barrows and gilts is assumed to be negatively correlated with hog marketing inventory. Estimation results are presented in table 4.8. All explanatory variables have the expected sign.

Table 4.8: Hog Marketing Inventory on Dec. 1st

PKHOGMKTINV	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	402.6357	1310.3605	0.3100	0.7614
PKPIGCROPNET	0.6881	0.0349	19.7300	0.0000
PKHOGNIMPT	0.6396	0.0469	13.6400	0.0000
PKSLBAGLT	-0.1617	0.0298	-5.4200	0.0000
SHIFT14	2653.4136	347.6773	7.6300	0.0000
D89	-1146.4416	353.6764	-3.2400	0.0036
D85T87	1610.5354	278.6291	5.7800	0.0000
Adjusted R-squared:		0.9955	MAPE	0.0046
Breusch-Godfrey test p-value:		0.3098	Theil's U2	0.1486

Net pig crop is calculated as:

PKPIGCROPNET ≡ PKPIGCROP-PKHOGDL

where PKPIGCROP is pig crop, PKHOGDL is hog death loss.

Hog death loss is fitted as a function of pig crop, indicating that a certain proportion of the pig crop will die and not be available for feeding, and a lagged dependent variable representing technology progress (and thus the coefficient is supposed to be less than 1). Estimation results are presented in Table 4.9.

PKHOGDL = f (PKPIGCROP, PKHOGDL_LAG1, D09T11)

Table 4.9: Hog Death Loss

PKHOGDL	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-3616.0916	690.6207	-5.2400	0.0000
PKPIGCROP	0.043	0.0087	4.9400	0.0000
PKHOGDL_LAG1	0.9139	0.0454	20.1500	0.0000
D09T11	-698.0304	180.5607	-3.8700	0.0007
Adjusted R-squared:		0.9811	MAPE	0.0294
Breusch-Godfrey test p-value:		0.3688	Theil's U2	0.6211

Pig crop is a non-fitted function as discussed in the data section:

PKPIGCROP ≡ PKPIGPL × PKSOWFAR

where PKPIGCROP is pig crop, PKPIGPL is pigs per litter, and PKSOWFAR is the number of sows farrowed.

Pigs per litter is a function of a lagged dependent variable representing technology progress. Estimation results are presented in Table 4.10.

PKPIGPL = f (PKPIGPL_LAG1, D88, D98T06, D14)

The number of sows farrowed is fitted as a function of lagged dependent variable, gilts added to the breeding herd, and slaughter of breeding herd:

PKSOWFAR = f (PKSOWFAR_LAG1, PKADDBRH, PKSLBRH, D88924807, D869600)

where PKSOWFAR is the number of sows farrowed, PKSOWFAR_LAG1 is the lagged dependent variable, PKADDBRH is hogs added to the breeding herd, and PKSLBRH is slaughter of the breeding herd. Estimation results are presented in

Table 4.10: Pigs per Litter

PKPIGPL	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-0.112	0.1102	-1.0200	0.3193
PKPIGPL_LAG1	1.0277	0.0128	80.1400	0.0000
D88	-0.1603	0.0507	-3.1600	0.0041
D98T06	-0.0873	0.0199	-4.3800	0.0002
D14	-0.4275	0.0539	-7.9200	0.0000
Adjusted R-squared:		0.9962	MAPE	0.0041
Breusch-Godfrey test p-value:		0.4714	Theil's U2	0.3710

Table 4.11. The lagged dependent variable is used to approximate the beginning breeding capacity, and should be positively correlated to the dependent variable. The number of hogs added to the breeding herd positively affects the number of sows farrowed. Slaughter of breeding herd negatively affects the number of sows farrowed.

Table 4.11: Sows Farrowed

PKSOWFAR	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	3212.0395	988.9664	3.2500	0.0034
PKSOWFAR_LAG1	0.7352	0.0901	8.1600	0.0000
PKADDBRH	0.9039	0.1713	5.2800	0.0000
PKSLBRH	-0.9596	0.1900	-5.0500	0.0000
D88924807	645.6551	72.3611	8.9200	0.0000
D869600	-431.9589	81.9791	-5.2700	0.0000
Adjusted R-squared:		0.8824	MAPE	0.0078
Breusch-Godfrey test p-value:		0.1900	Theil's U2	0.3034

The number of hogs added to the breeding herd is fitted as a function of the number of breeding herd hogs slaughtered and the real contribution margin of pig farms.

PKADDBRH = f (PKSLBRH, PKCMR, SHIFT09, D14, D87917, D99) where PKADDBRH is the number of hogs added to the breeding herd, PKSLBRH is the number of breeding herd hogs slaughtered, and PKCMR is the real contribution margin of pig farms. The number of hogs added to the breeding herd should be positively correlated to the number of breeding herd hogs slaughtered to represent the renewal of breeding herd inventory; and it should be positively correlated to the real contribution margin of pig farms, so the more profitable the industry is the larger the breeding herd should be and vice versa. Estimation results are presented in Table 4.12. Both the coefficients estimated are of the expected sign.

Table 4.12: Hogs Added to the Breeding Herd

PKADDBRH	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	267.3967	142.9795	1.8700	0.0742
PKSLBRH	0.9147	0.0351	26.0400	0.0000
PKCMR	382.0789	157.3683	2.4300	0.0234
SHIFT09	-195.2676	82.5024	-2.3700	0.0267
D14	-311.9042	156.3041	-2.0000	0.0580
D87917	409.3547	59.6693	6.8600	0.0000
D99	-345.9299	95.2262	-3.6300	0.0014
Adjusted R-squared:		0.9527	MAPE	0.0153
Breusch-Godfrey test p-value:		0.9471	Theil's U2	0.2966

The number of breeding herd hogs slaughtered is a non-fitted equation and is the sum of slaughters of both genders in the breeding herd:

$$\text{PKSLBRH} \equiv \text{PKSLSOW} + \text{PKSLBRSTG}$$

where PKSLBRH is the number of breeding herd hogs slaughtered, PKSLSOW is the number of sows slaughtered, and PKSLBRSTG is the number of boars and stags slaughtered.

The number of sows slaughtered is fitted as a function of the beginning breeding herd inventory and the real contribution margin in pig production:

PKSLSOW = f (PKHOGBRH_LAG1, PKCMR, D85T95, SHIFT03, D879357)

where PKSLSOW is the number of sows slaughtered, PKHOGBRH_LAG1 is the breeding herd level on December 1st of the previous period used to represent the beginning breeding herd level, and PKCMR is the real contribution margin of pig farms. Slaughter of sows represents the replacement of the breeding herd; thus, the larger the beginning breeding herd level the more sows should be slaughtered. The number of sows slaughtered should be negatively correlated to the real contribution margin of pig farms, so the more profitable the industry the larger the breeding herd should be and vice versa. Estimation results are presented in Table 4.13. Both coefficients estimated are of the expected sign.

Table 4.13: The Number of Sows Slaughtered

PKSLSOW	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-679.2131	591.8386	-1.1500	0.2624
PKHOGBRH_LAG1	0.6051	0.0898	6.7400	0.0000
PKCMR	-261.5977	71.6932	-3.6500	0.0013
D85T95	362.7407	59.9934	6.0500	0.0000
SHIFT03	318.4982	57.7784	5.5100	0.0000
D879357	-206.8408	44.8635	-4.6100	0.0001
Adjusted R-squared:		0.9527	MAPE	0.0153
Breusch-Godfrey test p-value:		0.9471	Theil's U2	0.2966

The number of boars and stags slaughtered is fitted as a function of the beginning breeding herd inventory:

PKSLBRSTG = f (PKHOGBRH_LAG1, D98T05, D9806) where PKSLBRSTG is the number of boars and stags slaughtered, PKHOGBRH_LAG1 is the breeding herd inventory level on December 1st of the previous period used to represent the beginning breeding herd level. Slaughter of boars and stags represents renewal of the breeding herd; thus, the larger the beginning breeding herd level, the more boars and stags should be slaughtered. Estimation results are presented in Table 4.14.

Table 4.14: The Number of Boars and Stags being Slaughtered

PKSLBRSTG	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-1863.0213	100.6689	-18.5100	0.0000
PKHOGBRH_LAG1	0.3808	0.0154	24.7600	0.0000
D98T05	-202.1735	17.0461	-11.8600	0.0000
D9806	-87.4204	29.5855	-2.9500	0.0066
Adjusted R-squared:		0.9698	MAPE	0.0551
Breusch-Godfrey test p-value:		0.3203	Theil's U2	0.5740

The breeding herd inventory is a non-fitted equation of the beginning breeding herd inventory, the number of hogs added to the breeding herd and the number of breeding hogs slaughtered:

$$\text{PKHOGBRH} \equiv \text{PKHOGBRH\_LAG1} + \text{PKADDBRH} \;\; \text{PKSLSOW} - \text{PKSLBRSTG}$$

where PKHOGBRH is the breeding herd inventory of hogs, PKHOGBRH_LAG1 is the beginning breeding herd inventory level, PKADDBRH is the number of hogs added to the breed herd, PKSLSOW is the number of sows slaughtered, and PKSLBRSTG is the number of boars and stags slaughtered.

Net hog import appearing in the functions of slaughter of barrows and gilts (PKSLBAGLT) and hog marketing inventory (PKHOGMKTINV) is calculated as:

PKHOGNIMPT ≡ PKHOGIMPT - PKHOGEXPT

where PKHOGNIMPT is net hog import, PKHOGIMPT is hog import, and PKHOGEXPT is hog export.

Hog import is fitted as a function of lagged dependent variable:

PKHOGIMPT = f(PKHOGIMPT_LAG1, D09, D95T04, D86058103, D037)

where PKHOGIMPT is hog imports and PKHOGIMPT_LAG1 is the lagged dependent variable.

Hog import is assumed to be positively correlated with real barrow and gilt price. However, the amount of hogs imported remained at a relatively low level (less than 2000 heads) during the period of 1985 to 1996 compared to later years and no significant response of hog import to barrow and gilt price fluctuations was observed during this period; also during the short period of 1996 to 2014, shifts that cannot be explained by barrow and gilt price occurred in the hog import data series. These two reasons prevent a statistically significant fit of the price information in the hog import equation and more than usual dummy variables are included to account for the historical deviations in the data set. Estimation results are presented in Table 4.15.

Hog export is fitted as a function of lagged dependent variable and real barrow and gilt price.

PKHOGEXPT = f (PKHOGEXPT_LAG1, PKBAGLTPR, D91, D9509, D88914802, D9200)

where PKHOGEXPT is hog export, PKHOGEXPT_LAG1 is lagged dependent variable, and PKBAGLTPR is real barrow and gilt price. Estimation results are presented in Table 4.16. The lagged dependent variable is positively correlated with

Table 4.15: Hog Import

PKHOGIMPT	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	16.2384	100.0548	0.1600	0.8724
PKHOGIMPT_LAG1	1.0189	0.0227	44.9200	0.0000
D09	-3176.6524	340.8517	-9.3200	0.0000
D95T04	563.4294	123.8006	4.5500	0.0001
D86058103	-738.0142	175.6031	-4.2000	0.0003
D037	1030.7872	237.1639	4.3500	0.0002
Adjusted R-squared:		0.9905	MAPE	0.1072
Breusch-Godfrey test p-value:		0.7845	Theil's U2	0.6300

hog export and real barrow and gilt price is negatively correlated with hog exports indicating that when domestic price is high, more hogs will be sold domestically and fewer hogs will be exported.

Table 4.16: Hog Export

PKHOGEXPT	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	95.8709	37.6024	2.5500	0.0179
PKHOGEXPT_LAG1	0.6407	0.0988	6.4900	0.0000
PKBAGLTPR	-120.7365	49.4364	-2.4400	0.0227
D91	116.9627	28.9207	4.0400	0.0005
D9509	-92.7782	18.4331	-5.0300	0.0000
D88914802	104.8675	15.9808	6.5600	0.0000
D9200	-83.0919	21.0794	-3.9400	0.0006
Adjusted R-squared:		0.8915	MAPE	0.3459
Breusch-Godfrey test p-value:		0.9772	Theil's U2	0.3782

Contribution margin of pig farms (PKCMR) appearing in the breeding herd investment and disinvestment equations is calculated as:

$$\text{PKCM} \equiv \text{D85T08} \times \text{PKFFCM} + \text{SHIFT09} \times \text{PKMIXCM}$$

where PKCM is the contribution margin of pig industry, PKFFCM is the contribution margin of farrow-to-finish pig farms, and PKMIXCM is the weighted average of farrow-to-finish pig farm contribution margin (25 percent) and farrow-to-feeder pig farm contribution margin (75 percent), i.e.:

$$\text{PKMIXCM} \equiv 0.25 \times \text{PKFFCM} + 0.75 \times \text{PKFFDCM}$$

Contribution margin is defined as revenue less variable cost:

PKFFCM ≡ PKFFR PKFFFC PKFFOVC

PKFFDCM ≡ PKFFDR PKFFDFC PKFFDOVC

where PKFFCM is the contribution margin of farrow-to-finish pig farms, PKFFR is farrow-to-finish farm revenue, PKFFFC is farrow-to-finish farm feed cost, PKFFOVC is farrow-to-finish farm other variable cost; PKFFDCM is the contribution margin of farrow-to-feeder pig farms, PKFFDR is farrow-to-feeder farm revenue, PKFFDFC is farrow-to-feeder farm feed cost, and PKFFDOVC is farrow-to-feeder farm other variable cost.

Farrow-to-finish pig farm revenue is fitted as a function of barrow and gilt price:

PKFFR = f(PKBAGLTP,SHIFT13,D09T12)

where PKFFR is farrow-to-finish pig farm revenue, PKBAGLTP is barrow and gilt price. Farm revenue should be positively correlated to the price of the product. Estimation results are presented in Table 4.17.

Farrow-to-finish pig farm feed cost is fitted as a function of the lagged dependent variable and a weighted corn and soybean meal price, which represents feed conversion efficiency and feed ingredient costs respectively:

PKFFFC = f (PKFFFC_LAG1, PKMIXFEED, D96, D09102)

Table 4.17: Farrow-to-finish Pig Farm Revenue

PKFFR	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-0.2912	2.0621	-0.1400	0.8888
PKBAGLTP	1.0285	0.0448	22.9300	0.0000
D09T12	5.8721	1.0406	5.6400	0.0000
SHIFT13	27.4849	1.7130	16.0400	0.0000
Adjusted R-squared:		0.9898	MAPE	0.0282
Breusch-Godfrey test p-value:		0.5169	Theil's U2	0.1873

where PKFFFC is farrow-to-finish pig farm feed cost, PKMIXFEED is the weighted average of corn and soybean meal prices. Estimation results are presented in Table 4.18. Both estimated coefficients have the correct sign. Improvement in feed conversion rate is represented by the less than 1 coefficient of the lagged dependent variable.

Table 4.18: Farrow-to-finish Pig Farm Feed Cost

PKFFFC	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	4.3691	1.5387	2.8400	0.0088
PKMIXFEED	2.1553	0.1711	12.6000	0.0000
PKFFFC_LAG1	0.3237	0.0697	4.6400	0.0001
D09102	-9.7459	1.2793	-7.6200	0.0000
D96	7.5140	1.8618	4.0400	0.0005
Adjusted R-squared:		0.9265	MAPE	0.0532
Breusch-Godfrey test p-value:		0.7117	Theil's U2	0.3625

Farrow-to-finish pig farm other variable cost is a composite variable consisting of veterinary and medicine, bedding and litter, marketing, customer service, fuel, lube, and electricity, repairs, interest on operating capital, hired labor, and feeder pig costs when farmers decide to feed more than their own raised pigs. It is fitted as a function of the lagged dependent variable; estimation results are presented in Table 4.22

PKFFOVC=f(PKFFOVC_LAG1,D13)

Table 4.19: Farrow-to-finish Pig Farm Other Variable Cost

PKFFOVC	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.8253	0.2544	3.2400	0.0031
PKFFOVC_LAG1	0.9107	0.0263	34.5900	0.0000
D13	20.7445	0.6293	32.9600	0.0000
Adjusted R-squared:		0.9882	MAPE	0.0540
Breusch-Godfrey test p-value:		0.4400	Theil's U2	0.1829

Farrow-to-feeder pig farm revenue is fitted as a function of feeder pig price:

PKFFDR = f (PKFDPIGP,D85T91,D04T08)

where PKFFDR is farrow-to-feeder pig farm revenue and PKFDPIGP is feeder pig price. Farm revenue should be positively correlated to the price of the product. Estimation results are presented in Table 4.20.

Table 4.20: Farrow-to-feeder Pig Farm Revenue

PKFFDR	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	2.0220	4.0443	0.5000	0.6215
PKFDPIGP	1.0873	0.0387	28.0800	0.0000
D85T91	-22.1358	2.3960	-9.2400	0.0000
D04T08	-28.8816	2.8110	-10.2700	0.0000
Adjusted R-squared:		0.9866	MAPE	0.0422
Breusch-Godfrey test p-value:		0.3662	Theil's U2	0.2298

Farrow-to-feeder pig farm feed cost is fitted as a function of the lagged dependent variable and the weighted corn and soybean meal price for the pork industry:

PKFFDFC = f (PKFFDFC_LAG1, PKMIXFEED, D04678, D0912)

where PKFFDFC is farrow-to-feeder pig farm feed cost, PKMIXFEED is the weighted average of corn and soybean meal prices. Estimation results are presented in Table 4.21. Both estimated coefficients have the correct sign. Improvement in feed conversion rate is represented by the less than one coefficient on the lagged dependent variable.

Table 4.21: Farrow-to-feeder Pig Farm Feed Cost

PKFFDFC	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-1.7648	3.0242	-0.5800	0.5650
PKMIXFEED	4.1486	0.4724	8.7800	0.0000
PKFFDFC_LAG1	0.3927	0.0984	3.9900	0.0005
D04678	16.9437	2.4855	6.8200	0.0000
D0912	-15.2346	4.3187	-3.5300	0.0017
Adjusted R-squared:		0.9384	MAPE	0.0712
Breusch-Godfrey test p-value:		0.8119	Theil's U2	0.4271

Farrow-to-feeder pig farm other variable cost is a composite variable consisting of veterinary and medicine, bedding and litter, marketing, customer service, fuel, lube, and electricity, repairs, interest on operating capital, hired labor, and feeder pig costs if occurred. It is fitted as a function of the lagged dependent variable; estimation results are presented in Table 4.22:

PKFFDOVC = f(PKFFOVC_LAG1,D92,D8809,D9804)

The pork industry weighted feed cost is comprised of 78 percent corn price and 22 percent soybean meal price with unit adjusted:

Table 4.22: Farrow-to-feeder Pig Farm Other Variable Cost

PKFFDOVC	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.6392	0.8457	0.7600	0.4571
PKFFDOVC_LAG1	1.0119	0.0378	26.7700	0.0000
D92	9.5243	1.0088	9.4400	0.0000
D8809	-11.0030	0.6912	-15.9200	0.0000
D9804	-4.5455	0.6995	-6.5000	0.0000
Adjusted R-squared:		0.9682	MAPE	0.0300
Breusch-Godfrey test p-value:		0.4591	Theil's U2	0.1777

$$\text{PKMIXFEED} \equiv 100 \times (0.78 \times \text{CORNPCY}/56 + 0.22 \times \text{SBMPCY}/2000)$$

where CORNPCY is annual average calendar year corn price in dollars per bushel and SBMPCY is annual average calendar year soybean meal price in dollars per short ton. These two variables are taken as exogenous in the current study, but corn and soybean meal are included in Rhews (2014) work studying major U.S. crop sectors. The crop sectors modeled by Rhew(2014), beef and dairy sectors modeled by Maisashvili (2014) and the pork and poultry sectors modeled in the current study will be combined and interact with each other in making projections and policy evaluations via important variables, such as feed demand for grains and grain prices for livestock sectors.

Barrow and gilt price is explained by pork wholesale price:

$$\text{PKBAGLTPR} = f\,(\text{PKWHPR, D12, D99, D9802})$$

where PKBAGLTPR is real barrow and gilt price, and PKWHPR is real pork wholesale price. Estimation results are presented in Table 4.23. Pork wholesale price has the correct sign.

Feeder pig price is explained by pork wholesale price and feed cost:

$$\text{PKFDPIGP} = f\,(\text{PKWHP, PKFFFC, D112, D906})$$

Table 4.23: Barrow and Gilt Price (Real)

PKBAGLTPR	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-0.1835	0.0271	-6.7800	0.0000
PKWHPR	0.5330	0.0178	30.0200	0.0000
D12	0.0540	0.0209	2.5900	0.0159
D99	-0.0638	0.0214	-2.9900	0.0062
D9802	-0.0505	0.0159	-3.1800	0.0039
Adjusted R-squared:		0.9762	MAPE	0.0253
Breusch-Godfrey test p-value:		0.6769	Theil's U2	0.2118

where PKFDPIGP is feeder pig price, PKWHP is pork wholesale price, and PKFFFC is farrow-to-finish pig farm feed cost. Feeder pig price should be positively correlated to pork wholesale and negatively correlated to the feed cost. Both feed and feeder pig are inputs for pork producers, when the price of one input increases the derived quantity demanded for the other input decreases and thus its price will decrease. Estimation results are presented in Table 4.24. Both coefficients have the correct signs.

Table 4.24: Feeder Pig Price

PKFDPIGP	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-128.6186	11.5998	-11.0900	0.0000
PKWHP	2.3818	0.1285	18.5300	0.0000
PKFFFC	-1.8526	0.3757	-4.9300	0.0000
D112	-34.9722	7.8291	-4.4700	0.0001
D906	-20.3945	7.0565	-2.8900	0.0078
Adjusted R-squared:		0.9399	MAPE	0.0411
Breusch-Godfrey test p-value:		0.8663	Theil's U2	0.1970

Nominal pork wholesale price is fitted as a function of pork retail price and grocery store labor cost:

PKWHP=f(PKRETP,LBCPGS,D9802)

where PKWHP is pork wholesale price, PKRETP is pork retail price which is the primary endogenous variable for the pork industry, and LBCPGS is grocery store labor cost. Estimation results are presented in Table 4.25. Functions are estimated using data from 1987 to 2014 and non-fitted functional form is used in our simulation system because no grocery store labor cost data is available for the years 1985 and 1986.

Table 4.25: Pork Wholesale Price

PKWHP	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	33.8316	5.0736	6.6700	0.0000
PKRETP	0.7092	0.0511	13.8800	0.0000
LBCPGS	-0.0017	0.0002	-8.1400	0.0000
D9802	-16.4621	3.9037	-4.2200	0.0003
Adjusted R-squared:		0.9365	MAPE	0.0331
Breusch-Godfrey test p-value:		0.9117	Theil's U2	0.3711

Pork retail price is assumed to positively affect pork wholesale price. Grocery store labor compensation cost, which is used to approximate the efficiency of the pork marketing system at retail level, is assumed to negatively affect pork wholesale price. According to Hahn (2004) retail-wholesale price spread increases as the retail-level marketing efficiency decreases, which is represented by the increase of grocery store labor cost in our model specification. This function ends the description for the pork supply side.

Other methods for modeling the wholesale price, such as a non-fitted identity with wholesale price equals retail price minus price spread, are also available and plausible (Ferris 2005). The method that gives the best forecasting result is chosen for each industry based on a priori tests.

All fitted equations have acceptable adjusted R-squares. Mean Absolute Percentage Error (MAPE) and Theils U2 indicating the forecasting ability of the model specifications are at a satisfactory scale. Breusch-Godfrey tests are all passed with p-values greater than 0.1. Estimated price elasticities of demand are in the range of the estimated elasticities in literature listed in Table 4.26[1]. Pork industry 2015 to 2024 projections are listed in Table 4.31. Also listed in Table 4.26 are USDA and FAPRIs projections for the purpose of comparison. The short-run (year 2015, 2016) and long-run (year 2019) supply elasticities are calculated as:

$$e_{PORK,SR15} = \frac{(23547 - 23482)/23482}{10\%} = 0.028 \tag{4.1}$$

$$e_{PORK,SR16} = \frac{(24665 - 24514)/24514}{10\%} = 0.062 \tag{4.2}$$

$$e_{PORK,LR} = \frac{(25853 - 25856)/25856}{10\%} = -0.001 \tag{4.3}$$

[1]When inverse demand functional forms are specified in the studies listed, flexibilities are estimated directly and elasticities are recovered from the estimated flexibilities. When both compensated and uncompensated elasticities are provided, uncompensated elasticities are included in Table 4.31 to keep consistent with the estimation result from the current study.

Table 4.26: Estimates of Pork Demand Elasticities From Literature

Own Price Elasticity	**Cross Price Elasticity with Chicken**	**Cross Price Elasticity with Beef**	**Study**	**Data**	**Period**	**Model Specification**
-0.830	NA	NA	Tomek (1965)	Quarterly	1949 Q4 to 1956 Q1	Linear Inverse
-0.900	NA	NA	Tomek (1965)	Quarterly	1956 Q2 to 1964 Q1	Linear Inverse
-0.691	0.059	0.398	Menkhaus et al. (1985)	Annual	1965-1981	Budget Share Translog Indirect Utility Function with Habit Formation
-1.403	-19.608	-4.673	Buhr (1993)	Quarterly	1973-1989	Approximate Almost Ideal Inverse Demand System
-0.610	-3.257	-1.453	Dahlgran (1988)	Annual	1950-1985	Income-constrained Utility Maximization Model
-0.762	0.007	0.314	Eales and Unnevehr (1988)	Annual	1965-1985	Dynamic AIDS
-0.818	-9.804	-15.152	Huang (1988)	Annual	1947-1983	Rotterdam
-1.010	-3.145	-2.849	Eales and Unnevehr (1992)	Quarterly	1966-1988	Inverse AIDS
-0.502	-0.141	-0.011	Tonsor and Marsh (2007)	Quarterly	1976-2001	Generalized AIDS
-0.740	0.008	0.030	Tonsor, Mintert, and Schroeder (2010)	Quarterly	1982-2007	Weighted First Difference Double -log Function with Demand Shifters
-0.499	**0.209**		**This Study**	**Annual**	**1985-2014**	**Double-log**

Table 4.27: Pork Industry 2015-2024 Projections

		2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
PKPROD	USDA	22,662	23,620	24,664	25,052	25,402	25,681	25,922	26,129	26,327	26,554	26,808
	FAPRI	22,866	24,036	25,281	26,133	26,290	26,189	26,143	26,315	26,635	27,188	27,750
	Current Study, No Shock	22,866	23,482	24,514	25,059	25,490	25,856	26,227	26,619	27,056	27,506	27,972
	Current Study, With Shock	22,866	23,547	24,665	25,086	25,504	25,853	26,218	26,607	27,043	27,492	27,958
PKIMPT	USDA	973	900	900	913	926	939	952	965	978	991	1,004
	FAPRI	1,000	925	913	916	923	939	957	968	981	986	987
	Current Study, No Shock	1,000	1,039	1,020	994	972	957	948	944	942	940	937
	Current Study, With Shock	1,000	1,036	1,012	989	969	956	948	945	944	942	939
PKEXPT	USDA	5,066	5,250	5,375	5,500	5,600	5,675	5,750	5,825	5,900	5,975	6,050
	FAPRI	4,829	5,145	5,449	5,657	5,852	6,009	6,161	6,325	6,501	6,705	6,913
	Current Study, No Shock	4,829	5,001	5,210	5,432	5,663	5,900	6,142	6,390	6,646	6,910	7,182
	Current Study, With Shock	4,829	5,004	5,219	5,442	5,673	5,909	6,150	6,398	6,653	6,916	7,187
PKPCCR	USDA	45.3	46.6	48.5	48.8	49.1	49.3	49.4	49.4	49.4	49.4	49.5
	FAPRI	46.5	47.8	49.6	50.7	50.3	49.4	48.6	48.2	48.2	48.6	49.1
	Current Study, No Shock	46.5	47.0	48.6	49.0	49.0	48.9	48.8	48.8	48.8	48.9	49.0
	Current Study, With Shock	46.5	47.2	48.9	49.0	49.0	48.9	48.8	48.7	48.8	48.8	48.9
PKSTK	USDA	580	605	600	600	600	600	600	600	600	600	600
	FAPRI	540	569	621	657	659	647	638	638	646	663	681
	Current Study, No Shock	540	580	625	646	661	671	681	689	699	710	722
	Current Study, With Shock	540	583	632	648	661	671	680	688	698	709	721

Table 4.27: Continued

		2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
PKHOGMK -TINV	USDA	64,775	65,400	66,916	67,480	67,987	68,393	68,743	69,043	69,331	69,661	70,030
	FAPRI	59,000	60,100	64,400	67,400	67,900	67,300	66,600	66,200	66,400	67,200	68,100
	Current Study, No Shock	60,082	62,489	63,439	64,144	64,629	65,104	65,597	66,183	66,806	67,442	68,100
	Current Study, With Shock	60,082	62,942	63,479	64,168	64,600	65,059	65,539	66,120	66,741	67,374	68,031
PKBAGLTP	USDA	77.98	66.96	59.26	56.44	54.59	53.63	52.85	52.59	53.06	54.05	55.65
	FAPRI	76.03	62.11	54.91	51.77	52.49	54.72	57.13	58.76	59.16	58.24	57.49
	Current Study, No Shock	77.10	72.70	62.88	59.30	57.69	57.75	58.08	59.45	60.19	60.69	61.09
	Current Study, With Shock	77.10	79.97	61.08	59.06	57.67	57.92	58.30	59.71	60.45	60.95	61.34
PKSLBAGLT	FAPRI	103,800	109,400	116,300	120,000	120,400	119,600	119,100	119,400	120,500	122,500	124,600
	Current Study, No Shock	103,731	107,651	111,882	113,826	115,225	116,282	117,335	118,457	119,748	121,105	122,498
	Current Study, With Shock	103,731	107,806	112,563	113,905	115,237	116,208	117,230	118,333	119,615	120,967	122,357
PKPIGCROP	FAPRI	112,700	121,800	127,800	129,300	128,600	127,500	127,200	128,000	129,900	132,200	134,600
	Current Study, No Shock	112,700	117,599	120,537	122,610	124,242	125,780	127,344	129,069	130,901	132,781	134,718
	Current Study, With Shock	112,700	118,318	120,792	122,701	124,237	125,726	127,260	128,967	130,786	132,656	134,584
PKSOWFAR	FAPRI	11,350	11,890	12,150	12,100	11,880	11,660	11,520	11,480	11,530	11,630	11,730
	Current Study, No Shock	11,350	11,667	11,781	11,805	11,783	11,751	11,719	11,700	11,688	11,678	11,670
	Current Study, With Shock	11,350	11,739	11,806	11,814	11,783	11,746	11,711	11,691	11,678	11,667	11,658
PKPIGPL	FAPRI	9.93	10.24	10.52	10.69	10.82	10.93	11.04	11.15	11.27	11.37	11.47
	Current Study, No Shock	9.93	10.08	10.23	10.39	10.54	10.70	10.87	11.03	11.20	11.37	11.54
	Current Study, With Shock	9.93	10.08	10.23	10.39	10.54	10.70	10.87	11.03	11.20	11.37	11.54

Table 4.27: Continued

		2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
PKHOGBRH	FAPRI	5,760	5,970	6,190	6,190	6,070	5,930	5,820	5,750	5,740	5,760	5,800
	Current Study, No Shock	5,696	5,950	6,088	6,168	6,211	6,238	6,258	6,283	6,312	6,340	6,370
	Current Study, With Shock	5,696	6,026	6,138	6,211	6,248	6,272	6,289	6,312	6,338	6,364	6,390
PKSOWP	FAPRI	73.52	55.07	49.34	47.08	47.70	49.54	51.60	52.87	53.30	52.69	52.28
	Current Study, No Shock	77.08	73.73	61.09	56.64	54.78	55.11	55.83	57.92	59.20	60.19	61.06
	Current Study, With Shock	77.08	72.65	58.69	56.22	54.58	55.13	55.87	57.99	59.24	60.18	60.98
PKRETP	FAPRI	402	390	376	368	372	383	399	409	414	413	412
	Current Study, No Shock	402	397	376	371	372	377	383	392	399	405	411
	Current Study, With Shock	402	395	371	371	372	378	384	392	399	406	412
PKHOGNIMPT	FAPRI	4.9	5.1	5.1	5.2	5.2	5.3	5.3	5.4	5.4	5.4	5.4
	Current Study, No Shock	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.7	5.8	5.9	6.0
	Current Study, With Shock	4.9	5.0	5.1	5.2	5.3	5.4	5.6	5.7	5.8	5.9	6.0
PKCDIS	FAPRI	19,114	19,787	20,693	21,354	21,360	21,130	20,948	20,958	21,108	21,451	21,805
	Current Study, No Shock	19,115	19,479	20,279	20,600	20,784	20,904	21,023	21,165	21,342	21,525	21,716
	Current Study, With Shock	19,115	19,535	20,410	20,618	20,786	20,891	21,007	21,147	21,324	21,507	21,699

The applied shock is a 10 percent increase in 2015 barrow and gilt price

5. THE U.S. BROILER INDUSTRY

This chapter presents an econometric model for the U.S. broiler industry. The model describes the supply and the demand for the broiler sector within the U.S. economy; retail price is the primary variable that adjusts and clears the market. Following the construction of the U.S. pork industry, total supply consists of beginning stocks, imports, and production; total demand comprises ending stocks, exports, and domestic disappearance. Due to the extensive proportion of domestic production and consumption accounting for the total U.S. broiler supply and disappearance respectively, the model focuses on these two parts based on the theoretical foundation developed in the methodology chapter. A one-equation description will be used to approximate the U.S. broiler imports, exports, and stocks.

The chapter is organized as follows. In the first section, the general flow in broiler production is presented as a background. Critical decision points in broiler production have been discussed in Chapter III to assist present the model specification. More detailed information about the industry will be provided in this section. In the second section, the dataset that will be used for estimating the econometric model will be discussed. In the third section, the model specification and estimation results will be presented.

5.1 Broiler Production

Broiler production has a sequential feature starting with inventory management of the hatchery supply flock which provides fertilized eggs that will be hatched and the chicks fed to become broiler-type hatching egg layers. Broiler-type hatching egg layers then lay fertilized broiler-type hatching eggs. The eggs are then set in incubators and hatched to broiler-type chicks. Finally broiler-type chicks are placed on feed and slaughtered at an average weight around 4.5 pounds after about 35 to 49 days of feeding.

As discussed in the literature review section, to study the poultry industry in more detail and model the effects of regionalized issues, such as an outbreak of avian influenza and regional policy changes, the poultry industry will be divided into different regions in this study according to Hatchery Production Annual Summary (USDA NASS) with adjustments made due to data availability. The U.S. broiler model is schematically described in Figure 5.1.

5.2 Broiler Data

Macro-level broiler supply and demand data, including broiler production, imports, exports, stocks, and consumption, are available from World Agricultural Supply and Demand Estimates (WASDE) provided by USDA. Broiler production data are mainly collected from three sources: (1) annual state-level broilers slaughtered, broiler-type chicks placed on feed, and broiler-type chick price are available from the National Agricultural Statistics Service (NASS, USDA); (2) annual state-level broiler-type chicks hatched, first day of month regional-level broiler-type hatching eggs set in incubators are available in Hatchery Production (NASS, USDA); (3) during month state-level hatching egg production[1], number of hatching egg layers (1994-2014), and hatching egg layers laying rate (1994-2014) are available in Chickens and Eggs (NASS, USDA)[2].

Historical data for national level broiler production and the number of broilers

[1]Monthly, and thus calendar year, state production is published in Chickens and Eggs starting from 1994. For the period of 1985 to 1993, only marketing year (proceeding December to current November) hatching egg production data are available in Hatching Egg Production, and this is transformed and used as calendar year data.

[2]To be more accurate, broiler-type hatching egg production, number of broiler-type hatching egg layers and the corresponding laying rate should be used in the model specification. However, they are not available at the state or regional level. (Total) Hatching egg production, (total) number of hatching egg layers and their laying rate are thus used as a proxy.

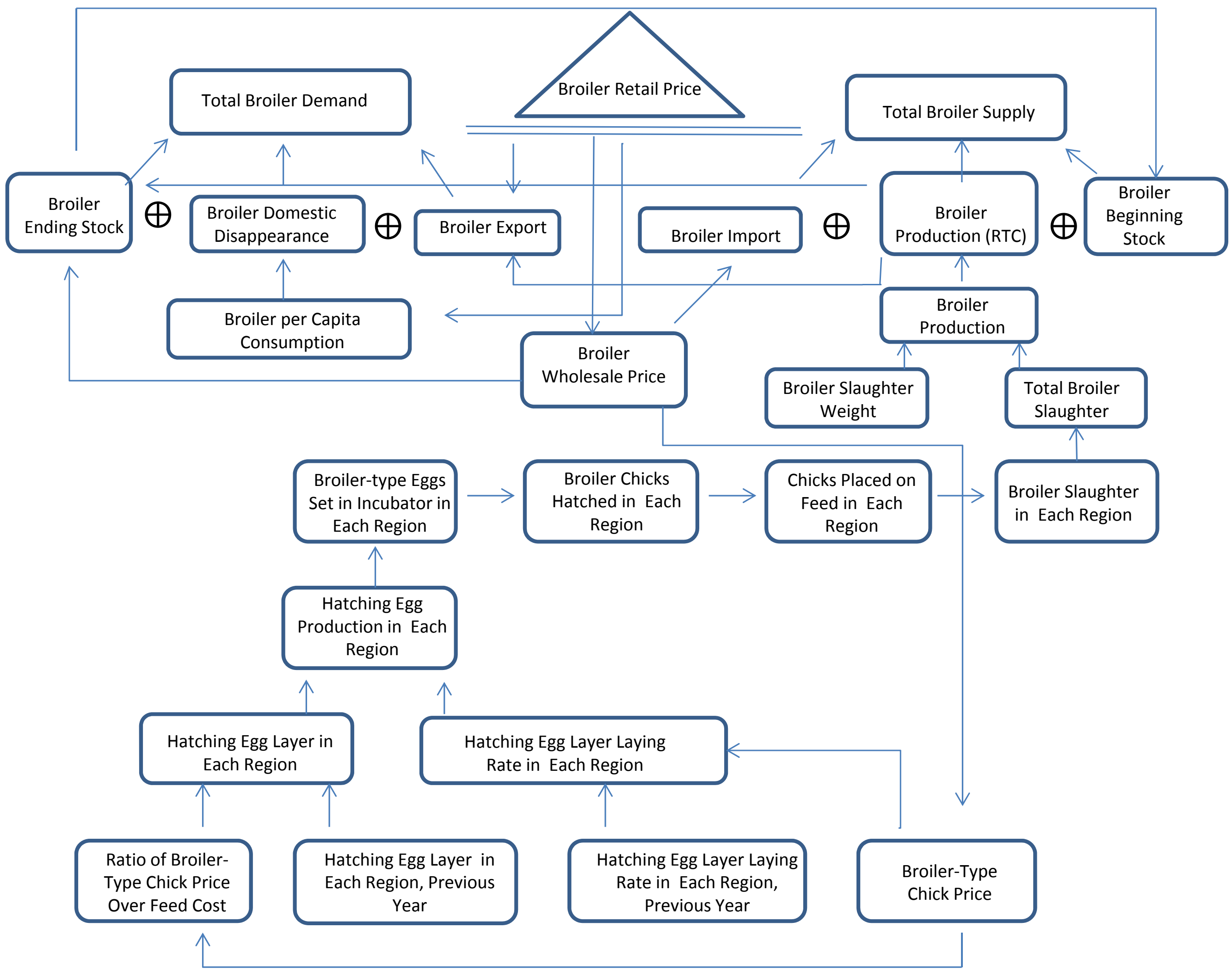


Figure 5.1: The U.S. Broiler Model

slaughtered are available. We assume the average broiler slaughter weight follows the same pattern all across the country and it is calculated from the ratio of national broiler production divided by total number of broilers slaughtered.

Intended placement into hatchery supply flocks was modeled as the first production step by Brown (1994). However, no state or regional level data are available for this production stage; and thus it is omitted in the current model. Hatching egg layer inventory is explained by price and cost variables directly.

The number of hatching egg layers and their laying rate are state-level data and collected monthly. The following steps are performed to calculate the during-month, state-level hatching egg layers and laying rate into meaningful annual regional data:

1. $\sum_j$ during month production in state$_j$ = during month production in region$_i$, state$_j$ from region$_i$

2. $\sum_j$ during month layer in state$_j$ =during month layer in region$_i$, state$_j$ from region$_i$

3. $\frac{\text{during month production in region}_i}{\text{during month layer in region}_i}$=during month laying rate for region$_i$,

4. $\sum_j$ during month laying rate for region$_i$ =during year laying rate for region$_i$, $j = 1, 2, ..., 12$

5. $\frac{\text{during year production in region}_i}{\text{during year laying rate for region}_i}$=during year layers in region$_i$,

5.3 The U.S. Broiler Model

The U.S. broiler model is schematically delineated in Figure 5.1. Total U.S. broiler demand equals the sum of broiler ending stocks, broiler exports, and broiler domestic disappearance. Total U.S. broiler supply equals the sum of broiler beginning stocks, broiler imports, and broiler production.

Starting from the demand side, the broiler total demand identity is

$$\text{CKDEM} \equiv \text{CKSTK} + \text{CKEXPT} + \text{CKCDIS}$$

where CKDEM is the total demand for broiler, CKSTK is broiler ending stocks, CKEXPT is broiler exports, and CKCDIS is broiler domestic disappearance.

U.S. broiler ending stock is specified as:

$$\text{CKSTK} = \text{f}\ (\text{CKPRODRTC},\text{CKWHPR},\text{D95T05},\text{D0311})$$

where CKPRODRTC is broiler production (ready-to-cook) and CKWHPR is the GPD deflated real broiler wholesale price. Estimation results are presented in Table 5.1. Broiler production has a positive effect on ending stocks. And broiler wholesale price has a negative effect on broiler ending stocks, reflecting the fact that when price is high more meat is sold and thus ending stock should be lower. U.S. broiler production will be discussed in the supply side.

Table 5.1: Broiler Ending Stock

CKSTK	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	302.0260	123.6437	2.4400	0.0220
CKPRODRTC	0.0208	0.0013	16.0800	0.0000
CKWHPR	-476.6694	121.7834	-3.9100	0.0006
D95T05	158.9646	16.5001	9.6300	0.0000
D0311	-164.5735	31.3419	-5.2500	0.0000
Adjusted R-squared:		0.9660	MAPE	0.0683
Breusch-Godfrey test p-value:		0.1323	Theil's U2	0.5918

The amount of U.S. broiler exports approaches 20 percent of total broiler production during the past couple of years (WASDE, USDA). Major foreign markets for the U.S. broiler products include Russia, China, and Mexico. To model the U.S. broiler exports with sufficient accuracy, descriptions for the demand from these markets are needed yet beyond the research scale of the current study. A single equation description for the U.S. broiler exports is specified as:

CKEXPT = f(CKEXPT_LAG1, CKPRODRTC, CKRETPR, D02, D85067, D04, D9508)

where CKEXPT is broiler exports, CKEXPT_LAG1 is the lagged dependent variable, CKPRODRTC is broiler production (ready-to-cook), and CKRETPR is real broiler retail price. Based on the assumption that not all the trading partners will change drastically, the lagged dependent variable can explain partially the current quantity of broiler exports. The total (ready-to-cook) broiler production sets a limit on the amount the domestic producers are willing to trade. Broiler selling price has a negatively effect on broiler exports indicating that when domestic price is high more meat will be sold in the home market and less will be exported, and vice versa. Estimation results are presented in Table 5.2. All the signs of the estimated coefficients are as expected.

Table 5.2: Broiler Exports

CKEXPT	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	3150.7088	2203.5503	1.4300	0.1668
CKEXPT_LAG1	0.7169	0.0764	9.3900	0.0000
CKPRODRTC	0.0531	0.0251	2.1100	0.0461
CKRETPR	-1701.6622	932.0210	-1.8300	0.0815
D02	-838.9863	226.3871	-3.7100	0.0012
D85067	-387.5231	209.6789	-1.8500	0.0781
D04	-496.1707	234.0011	-2.1200	0.0455
D9508	624.6213	171.9337	3.6300	0.0015
Adjusted R-squared:		0.9914	MAPE	0.0601
Breusch-Godfrey test p-value:		0.6007	Theil's U2	0.6190

The last and largest proportion of the quantity demanded for broiler is broiler domestic disappearance, which is the product of U.S. population and carcass weight per capita consumption:

$$\text{CKCDIS} \equiv \text{USPOP} \times \text{CKPCCC}$$

where CKCDIS is broiler civilian disappearance, USPOP is U.S. population, and CKPCCC is carcass weight per capita consumption for broiler.

Carcass weight per capita consumption for broiler is calculated from broiler retail weight per capita consumption by dividing the carcass to retail conversion factor:

$$\text{CKPCCC} \equiv \text{CKPCCR} \div 0.859$$

where CKPCCC is broiler carcass weight per capita consumption, CKPCCR is broiler retail weight per capita consumption, and the ratio of 0.859 is calculated from the historical data series of these two variables.

Following the discussions in the methodology chapter, retail weight per capita consumption for broiler is modeled by a double-log functional form:

CKPCCR_LOG = f (FOODEXPR_LOG, CKRETPR_LOG, BFPKTKRETPR_LOG,
TIME_LOG, D92T10, D990245, D0910, D91003, D14)

where CKPCCR_LOG is broiler retail weight per capita consumption in log form, FOODEXPR_LOG is real food expenditure in log form, CKRETPR_LOG is real broiler retail price in log form, BFPKTKRETPR_LOG is the composite real beef and chicken retail price in log form, and TIME_LOG is time in log form.

Estimation results are presented in Table 5.3. Food expenditure has a positive effect on broiler consumption; income elasticity is 0.42. Broiler retail price is negatively affecting broiler consumption; own price elasticity is -0.55. Beef, pork and turkey, as substitutes for broiler, their composited retail price is positively affecting broiler consumption; cross price elasticity is 0.19. Functional form with other food price index included in the explanatory variables has also been tried as listed in Table 5.4, where other food price index has a negative effect on broiler consumption which contradicts economic theory and is statistically insignificant, thus it is removed.

Table 5.3: Broiler Per Capita Consumption Without OTHFOODPR (Retail Weight)

CKPCCR_LOG	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	2.6689	0.6650	4.0100	0.0006
FOODEXPR_LOG	0.4227	0.2009	2.1000	0.0476
CKRETPR_LOG	-0.5510	0.0904	-6.1000	0.0000
BFPKTKRETPR_LOG	0.1917	0.1036	1.8500	0.0784
TIME_LOG	0.0747	0.0181	4.1300	0.0005
D92T10	0.0788	0.0146	5.4000	0.0000
D990245	0.0650	0.0093	6.9900	0.0000
D950910	-0.0342	0.0098	-3.4700	0.0023
D91003	0.0328	0.0095	3.4400	0.0024
Adjusted R-squared:		0.9917	MAPE	0.0023
Breusch-Godfrey test p-value:		0.3485	Theil's U2	0.4073

The beef-pork-turkey composite price, BFPKTKRETPR_LOG in the broiler retail weight per capita consumption function is defined as:

$$\text{BFPKTKRETPR\_LOG} \equiv \ln\left[(\text{BFRETPR} + \text{PKRETPR} + \text{TKRETPR})/3\right]$$

where BFRETPR is real beef retail price, PKRETPR is real pork retail price, and TKRETPR is real turkey retail price. The three retail prices are the primary endogenous variables in the three respective sectors used to clear the markets. This equation ends the description for the demand side of broiler industry.

The U.S. broiler total supply identity is:

Table 5.4: Broiler Per Capita Consumption With OTHFOODPR (Retail Weight)

CKPCCR_LOG	Estimate	Std. Error	t value	$\Pr(> \lvert t \rvert)$
(Intercept)	1.9071	0.6081	3.1400	0.0054
FOODEXPR_LOG	0.5884	0.1818	3.2400	0.0044
CKRETPR_LOG	-0.4827	0.0836	-5.7700	0.0000
BFPKTKRETPR_LOG	0.3514	0.1003	3.5000	0.0024
TIME_LOG	0.0617	0.0174	3.5400	0.0022
OTHFOODPR_LOG	-0.0415	0.1345	-0.3100	0.7609
D92T10	0.1009	0.0143	7.0800	0.0000
D990245	0.0618	0.0083	7.4600	0.0000
D0910	-0.0445	0.0126	-3.5200	0.0023
D91003	0.0333	0.0084	3.9900	0.0008
D14	-0.0593	0.0181	-3.2800	0.0039
Adjusted R-squared:		0.9114	MAPE	0.0024
Breusch-Godfrey test p-value:		0.1116	Theil's U2	0.3243

CKSUPP ≡ CKSTK_LAG1+CKIMPT+CKPRODRTC

where CKSTK_LAG1 is broiler beginning stock that can be recovered from broiler ending stock of the previous period, CKIMPT is U.S. broiler imports, and CKPRODRTC is U.S. ready-to-cook broiler production.

Following similar reasoning logic in specifying the U.S. broiler exports function, the U.S. broiler imports will be specified as:

CKIMPT=f(CKIMPT_LAG1,CKWHPR,SHIFT06,D91T99,D0314)

where CKIMPT is broiler imports, CKIMPT_LAG1 is the lagged dependent variable, and CKWHPR is real broiler wholesale price. Based on the assumption that not all the trading partners will change drastically, the lagged broiler imports can explain partially the current quantity of broiler imports. And the real broiler wholesale price also helps explaining the domestic wholesalers' willingness to trade. Estimation results are presented in Table 5.5. The lagged dependent variable and broiler wholesale price are both positively correlated with pork imports as expected.

Table 5.5: Broiler Imports

CKIMPT	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-9.5176	7.3614	-1.2900	0.2133
CKIMPT_LAG1	0.7314	0.0426	17.1900	0.0000
CKWHPR	31.1036	10.4541	2.9800	0.0085
SHIFT06	20.0363	3.3800	5.9300	0.0000
D91T99	-14.4766	1.9812	-7.3100	0.0000
D0314	-10.1763	2.2885	-4.4500	0.0004
Adjusted R-squared:		0.9962	MAPE	0.3836
Breusch-Godfrey test p-value:		0.5698	Theil's U2	0.7025

The main component of total broiler supply is ready-to-cook broiler production which equals total broiler production less broiler condemnation:

CKPRODRTC ≡ CKPROD - CKCONDM

where CKPRODRTC is ready-to-cook broiler production, CKPROD is broiler production, and CKCONDM is broiler condemnation.

Broiler condemnation is fitted as a function of total broiler production, indicating that a certain proportion of the broiler production will be disposed due to illness or management practices at the farm and the processing plant:

CKCONDM=f(CKPROD,D880123)

where CKCONDM is broiler condemnation and CKPROD is broiler production. The coefficient of broiler production in Table 5.6 has a positive sign as expected; and the magnitude shows that around 1 percent of the total broiler production is condemned, in accordance with historical data.

Broiler production is explained by two factors, the number of broilers slaughtered and the average broiler slaughter weight:

CKPROD ≡ CKSLT × CKSLW ÷ 1,000

Table 5.6: Broiler Condemnation

CKCONDM	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-96.5158	2.1971	-43.9300	0.0000
CKPROD	0.0133	0.0001	179.2400	0.0000
D880123	9.7576	1.7552	5.5600	0.0000
Adjusted R-squared:		0.9991	MAPE	0.0124
Breusch-Godfrey test p-value:		0.2105	Theil's U2	0.2342

where CKPROD is broiler production, CKSLT is the number of broilers slaughtered, and CKSLW is the average broiler slaughter weight. Since the measurement unit for broiler production is in millions of pounds, a conversion rate of 1/1000 is needed.

Broiler slaughter weight is fitted as a function of the lagged dependent variable representing technology improvement:

CKSLW = f (CKSLW_LAG1, SHIFT12, D969, D05)

where CKSLW is average broiler slaughter weight and CKSLT_LAG1 is the lagged dependent variable. Estimation results are presented in Table 5.7. The coefficient of the lagged dependent variable is greater than 1, representing technology improvement.

Table 5.7: Average Broiler Slaughter Weight

CKSLW	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-0.0789	0.0353	-2.2300	0.0347
CKSLW_LAG1	1.0339	0.0099	104.7500	0.0000
SHIFT12	-0.0300	0.0144	-2.0800	0.0477
D969	0.0643	0.0141	4.5500	0.0001
D05	0.0492	0.0198	2.4800	0.0202
Adjusted R-squared:		0.9982	MAPE	0.0039
Breusch-Godfrey test p-value:		0.7433	Theil's U2	0.3180

Starting from the total number of broilers slaughtered, the broiler production model is divided into different regions. According to Hatchery Production Annual Summary (1985 to 2014) there should be six production regions:

North Atlantic: CT, ME, MA, NH, NJ, NY, PA, RI, VT;

South Atlantic: DE, FL, GA, MD, NC, SC, VA, WV;

South Central: AL, AR, KY, LA, MS, OK, TN, TX;

East North Central: IL, IN, MI, OH, WI;

West North Central: IA, KS, MN, MO, NE, ND, SD;

West: AK, AZ, CA, CO, HI, ID, MT, NM, NV, OR, UT, WA, WY.

However, in our broiler production model we only retain the following three regions: North Atlantic (NA), South Atlantic (SA), and South Central (SC); and categorize the remaining three regions into one Other Region (OTH). The reason we do not work with East North Central, West North Central, and West individually is the lack of data disclosure at least for one production stage described in the broiler industry flow chart.

For some production stages, data are available at the regional level, like eggs set in incubators; for others, data are available only at the state level. To calculate regional data, we add up the corresponding state level data that are available for our complete study period, from 1985 to 2014. State level data that are published for some years but not the whole period are not counted nor used to represent that region and are lumped into the Other Region.

To sum up, (1) we divide broiler industry into four regions: North Atlantic, South Atlantic, South Central, and Other Region. (2) For each production stage, a state is incorporated into its corresponding region if it has data available for the whole study period from 1985 to 2014. (3) Data for the Other Region is the difference between national total and the sum of the first three regions[3].

Thus the total number of broilers slaughtered is the sum of the four regional level numbers of broilers slaughtered:

$$\text{CKSLT} \equiv \text{CKSLTNA+CKSLTSA+CKSLTSC+CKSLTOTH}$$

where CKSLT is the national total number of broilers slaughtered; states in each region for the production stage of slaughter are listed below:

NA: PA;

SA: DE, GA, MD, NC, SC, VA;

SC: AL, AR, LA, MS, TN, TX.

The number of broilers slaughtered in each region is fitted as a function of broiler-type chicks placed on feed in that region:

CKSLTSC=f(CKPLACESC,D068112);

CKSLTSA=f(CKPLACESA,D038);

CKSLTNA=f(CKPLACENA,SHIFT13);

CKSLTOTH=f(CKPLACEOTH,SHIFT02,D85,D87T94,D9504T08,D00123);

where CKSLT is the number of broilers slaughtered, and CKPLACE is the number of broiler-type chicks placed on feed. Estimation results are listed through Table 5.8 to Table 5.11. The number of broilers slaughtered is positively related to the number of broiler-type chicks placed on feed in all four regions as expected.

[3]We will list the states in NA, SA, and SC for each production stage because of the minor changes in data availability for future reference.

Table 5.8: Broiler Slaughter in South Central

CKSLTSC	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-47084.2189	46275.4361	-1.0200	0.3180
CKPLACESC	1.0654	0.0142	75.1300	0.0000
D068112	109858.3346	24383.2598	4.5100	0.0001
Adjusted R-squared:		0.9954	MAPE	0.0101
Breusch-Godfrey test p-value:		0.0093	Theil's U2	0.2918

Table 5.9: Broiler Slaughter in South Atlantic

CKSLTSA	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	21548.4029	27212.5334	0.7900	0.4353
CKPLACESA	0.8955	0.0092	97.8200	0.0000
D038	72729.7970	17003.3102	4.2800	0.0002
Adjusted R-squared:		0.9971	MAPE	0.0070
Breusch-Godfrey test p-value:		0.6522	Theil's U2	0.3013

Table 5.10: Broiler Slaughter in North Atlantic

CKSLTNA	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	12515.7070	6373.6197	1.9600	0.0599
CKPLACENA	0.6867	0.0459	14.9700	0.0000
SHIFT13	-25355.5314	4139.0258	-6.1300	0.0000
Adjusted R-squared:		0.8892	MAPE	0.0012
Breusch-Godfrey test p-value:		0.5039	Theil's U2	0.0535

Broiler-type chicks placed on feed in each region is fitted as a function of broiler-type chicks hatched in that region; states in each region for the production stage of placement are listed below:

CKPLACESC=f(CKHATCHSC,SHIFT09,D14);

CKPLACESA=f(CKHATCHSA);

Table 5.11: Broiler Slaughter in Other Region

CKSLTOTH	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	150629.5802	53186.5410	2.8300	0.0094
CKPLACEOTH	2.3754	0.1126	21.0900	0.0000
SHIFT02	-2302017.6773	125402.9192	-18.3600	0.0000
D85	-659430.6359	40653.4087	-16.2200	0.0000
D87T94	-250345.0949	20744.6513	-12.0700	0.0000
D9504T08	-165807.4182	21678.0252	-7.6500	0.0000
D00123	121315.9814	24771.6226	4.9000	0.0001
Adjusted R-squared:		0.9892	MAPE	0.0234
Breusch-Godfrey test p-value:		0.8995	Theil's U2	0.6008

CKPLACENA=f(CKHATCHNA,SHIFT14);

CKPLACEOTH=f(CKHATCHOTH,SHIFT02,D85,D86);

NA: PA;

SA: DE, FL, GA, MD, NC, SC, VA;

SC: AL, AR, MS, TX;

where CKPLACE is the number of broiler-type chicks placed on feed and CKHATCH is the number of broiler-type chicks hatched. Estimation results are provided in Table 5.12 to Table 5.15. The number of broiler-type chicks placed on feed is positively related to the number of broiler-type chicks hatched on feed in all four regions as expected.

Broiler-type chicks hatched in each region is fitted as a function of broiler-type hatching eggs set in incubators in that region; feed cost and time trend are also included in the explanatory variables for some region. States in each region for the production stage of hatchery are listed below:

CKHATCHSC=f(CKEGGSETSC,CKFEEDR,D024);

Table 5.12: Broiler-type Chicks Placed on Feed in South Central

CKPLACESC	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-220743.2415	36094.8109	-6.1200	0.0000
CKHATCHSC	1.0024	0.0104	96.0000	0.0000
SHIFT09	102129.2928	16063.3010	6.3600	0.0000
D14	124089.1265	35184.0057	3.5300	0.0016
Adjusted R-squared:		0.9971	MAPE	0.0081
Breusch-Godfrey test p-value:		0.0045	Theil's U2	0.2494

Table 5.13: Broiler-type Chicks Placed on Feed in South Atlantic

CKPLACESA	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-241581.5608	23104.8852	-10.4600	0.0000
CKHATCHSA	1.0708	0.0077	139.9400	0.0000
Adjusted R-squared:		0.9985	MAPE	0.0051
Breusch-Godfrey test p-value:		0.0356	Theil's U2	0.1955

Table 5.14: Broiler-type Chicks Placed on Feed in North Atlantic

CKPLACENA	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-12855.9434	5365.0674	-2.4000	0.0238
CKHATCHNA	1.0142	0.0355	28.6000	0.0000
SHIFT14	17415.4129	4082.1522	4.2700	0.0002
Adjusted R-squared:		0.9729	MAPE	0.0187
Breusch-Godfrey test p-value:		0.0003	Theil's U2	0.4249

CKHATCHSA=f(CKEGGSETSA,D867989);

CKHATCHNA=f(CKEGGSETNA,YEAR,D88905,D0910);

CKHATCHOTH=f(CKEGGSETOTH,D9300T04);

NA: PA;

Table 5.15: Broiler-type Chicks Placed on Feed in Other Region

CKPLACEOTH	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	231138.3947	31568.5575	7.3200	0.0000
CKHATCHOTH	0.1839	0.0259	7.1000	0.0000
SHIFT02	1010209.7452	23071.2336	43.7900	0.0000
D85	149533.3232	40947.6696	3.6500	0.0012
D86	-144727.1368	40044.6394	-3.6100	0.0013
Adjusted R-squared:		0.9962	MAPE	0.0236
Breusch-Godfrey test p-value:		0.0018	Theil's U2	0.0939

SA: DE, FL, GA, MD, NC, SC, VA & WV;

SC: AL, AR, MS, TX;

where CKHATCH is the number of broiler-type chicks hatched, CKEGGSET is the number of broiler-type hatching eggs set in incubators, CKFEEDR is GPD deflated real broiler feed cost, and YEAR is time trend. Estimation results are presented in Table 5.16 to Table 5.19.

Table 5.16: Broiler-type Chicks Hatched in South Central

CKHATCHSC	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	815185.8893	56246.7482	14.4900	0.0000
CKEGGSETSC	0.8337	0.0145	57.3500	0.0000
CKFEEDR	-50701.4960	10066.8098	-5.0400	0.0000
D024	160895.6496	39387.0338	4.0800	0.0004
Adjusted R-squared:		0.9920	MAPE	0.0124
Breusch-Godfrey test p-value:		0.0005	Theil's U2	0.4275

The number of broiler-type chicks hatched is positively related to the number of broiler-type hatching eggs set in incubators in all four regions as expected. Feed cost

Table 5.17: Broiler-type Chicks Hatched in South Atlantic

CKHATCHSA	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	85638.0644	32351.5027	2.6500	0.0134
CKEGGSETSA	1.1365	0.0123	92.3300	0.0000
D867989	-73202.9669	13536.4813	-5.4100	0.0000
Adjusted R-squared:		0.9969	MAPE	0.0058
Breusch-Godfrey test p-value:		0.0004	Theil's U2	0.2724

Table 5.18: Broiler-type Chicks Hatched in North Atlantic

CKHATCHNA	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-3707242.1920	279434.3024	-13.2700	0.0000
CKEGGSETNA	0.6467	0.1337	4.8400	0.0001
YEAR	1883.2837	147.3170	12.7800	0.0000
D88905	12038.9441	2451.8389	4.9100	0.0000
D0910	-10104.2091	3024.4042	-3.3400	0.0026
Adjusted R-squared:		0.9660	MAPE	0.0214
Breusch-Godfrey test p-value:		0.0557	Theil's U2	0.4652

Table 5.19: Broiler-type Chicks Hatched in Other Region

CKHATCHOTH	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-441921.0284	22371.9676	-19.7500	0.0000
CKEGGSETOTH	3.0796	0.0359	85.7700	0.0000
D9300T04	154129.3666	14125.5319	10.9100	0.0000
Adjusted R-squared:		0.9962	MAPE	0.0229
Breusch-Godfrey test p-value:		0.0440	Theil's U2	0.4274

is supposed to have a negative effect on the number of broiler-type chicks hatched. Since both feed and chicks are input for broiler production; when the price for one input increases the derived quantity demanded for the other will decrease. The feed cost variable is insignificant for other regions and thus not included in other hatchery functions.

For the North Atlantic there is a trend term in the equation indicating that there is a positive trend in the number of eggs that have been hatched comparing to the number of eggs being set in incubators as time passes (Table 5.18). This might be caused by technology improvement in this region and/or that more hatching cycles have been performed by producers over time. The reason we need a trend term to represent the second possible cause is that we dont have the exact number of eggs set in incubators by year, but only the sum of first day of month data as an approximation when the incubation period is 21 days. For the South Atlantic region, the coefficient before CKEGGSETSA is higher than one, which means more eggs are hatched than eggs set in incubators. This is possible because of the same reason that more than one hatching cycles per month may have been performed by producers but this is not reflected in egg set data that we are using which is an approximation of the exact during-year egg set.

For the Other Region the coefficient for CKEGGSETOTH is very high (Table 5.19). This might be because we put all the states that belong to NA, SA, and SC but do not have a complete data set during the study period of 1985 to 2014 for hatchery of broiler-type chicks into this region; yet the number of broiler-type hatching eggs set in incubators is already available at the regional level, and does not include egg set out of the East North Central, West North Central, and West.

Broiler-type hatching eggs set in incubators in each region is fitted as a function of the lagged dependent variable representing the beginning production capacity and the hatching egg production in that region:

CKEGGSETSC=f(HEGGPRODSC,CKEGGSETSC_LAG1,D02911);

CKEGGSETSA=f(HEGGPRODSA,CKEGGSETSA_LAG1,SHIFT13,D93,D09);

CKEGGSETNA=f(HEGGPRODNA,CKEGGSETNA_LAG1,D9000,D879804813);

CKEGGSETOTH=f(HEGGPRODOTH,CKEGGSETOTH_LAG1,D94T9705);

where CKEGGSET is the number of broiler-type hatching eggs set in incubators and HEGGPROD[4] is hatching egg production. Regional level data for first day of month broiler-type hatching egg set in incubators are available in Hatchery Production Annual Summary, so we do not list the states in each region for this production stage.

Both the lagged dependent variable and the hatching egg production should be positively correlated with broiler-type hatching eggs set in incubators as presented through Table 5.20 to Table 5.23. Because of the presence of the lagged dependent variable on the right hand side of the fitted equations, Breusch-Godfrey test is applied and with all p-values greater than 0.4, we cannot reject the null hypothesis that there is no serial correlation.

Table 5.20: Broiler-type Hatching Eggs Set in Incubators in South Central

CKEGGSETSC	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	146779.5467	58544.7763	2.5100	0.0188
CKEGGSETSC_LAG1	0.8128	0.0432	18.8000	0.0000
HEGGPRODSC	126.6135	37.6429	3.3600	0.0024
D02911	-244547.6229	36015.9980	-6.7900	0.0000
Adjusted R-squared:		0.9933	MAPE	0.0130
Breusch-Godfrey test p-value:		0.8923	Theil's U2	0.3653

Hatching egg production[5] in each region is determined by the number of hatching

[4]Broiler-type hatching egg production would be more accurate, but we only have (all-type) hatching egg production in state and regional level.

[5]Total hatching egg production, the sum of both broiler-type and egg-type, from large flocks (30000 and more) is used due to data availability.

Table 5.21: Broiler-type Hatching Eggs Set in Incubators in South Atlantic

CKEGGSETSA	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	237914.8856	37679.8354	6.3100	0.0000
CKEGGSETSA_LAG1	0.6630	0.0631	10.5100	0.0000
HEGGPRODSA	163.2424	36.5750	4.4600	0.0002
SHIFT13	92117.7373	23648.4482	3.9000	0.0007
D09	-84089.4892	33893.7532	-2.4800	0.0205
D93	132988.3182	31394.1449	4.2400	0.0003
Adjusted R-squared:		0.9937	MAPE	0.0085
Breusch-Godfrey test p-value:		0.4215	Theil's U2	0.3463

Table 5.22: Broiler-type Hatching Eggs Set in Incubators in North Atlantic

CKEGGSETNA	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	84102.8390	8789.6286	9.5700	0.0000
CKEGGSETNA_LAG1	0.2000	0.0792	2.5200	0.0183
HEGGPRODNA	144.5982	18.9890	7.6100	0.0000
D9000	-12272.6342	2081.7321	-5.9000	0.0000
D879804813	8089.0426	1384.1227	5.8400	0.0000
Adjusted R-squared:		0.9071	MAPE	0.0146
Breusch-Godfrey test p-value:		0.5218	Theil's U2	0.3823

Table 5.23: Broiler-type Hatching Eggs Set in Incubators in Other Region

CKEGGSETOTH	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	4439.3457	18045.2721	0.2500	0.8076
CKEGGSETOTH_LAG1	0.8753	0.0411	21.3200	0.0000
HEGGPRODOTH	26.5634	11.1701	2.3800	0.0250
D94T9705	63051.7394	14262.8310	4.4200	0.0002
Adjusted R-squared:		0.9864	MAPE	0.0232
Breusch-Godfrey test p-value:		0.8667	Theil's U2	0.5064

egg layers and their laying rate. States in each region for the production stage of hatching egg production are listed below:

HEGGPRODSC ≡ HEGGLAYERSC × HEGGLRSC/100,000;

HEGGPRODSA ≡ HEGGLAYERSA × HEGGLRSA/100,000;

HEGGPRODNA ≡ HEGGLAYERNA × HEGGLRNA/100,000;

HEGGPRODOTH ≡ HEGGLAYEROTH × HEGGLROTH/100,000;

NA: PA;

SA: FL, GA, MD, NC, SC, VA;

SC: AL, AR, MS;

where HEGGPROD is hatching egg production, HEGGLAYER is the number of hatching egg layers on farm during the year, and HEGGLR is the average hatching egg layers laying rate. Since the measurement unit for hatching egg production is million eggs, for hatching egg layers is 1000 layers, and for hatching egg layers laying rate is eggs per 100 layers in our data set, we need a conversion rate of 1/ 100,000.

The number of hatching egg layers in each region is fitted as a function of the lagged dependent variable and the ratio of boiler-type chick price over feed cost. States in each region for the production stage of hatching egg production are listed below:

HEGGLAYERSC = f (HEGGLAYERSC_LAG1, CKCHKP_FEED, D11, D12, D95036)

HEGGLAYERSA = f (HEGGLAYERSA_LAG1, CKCHKP_FEED, D9509112, D96)

HEGGLAYERNA = f (HEGGLAYERNA_LAG1, CKCHKP_FEED, D0311, D078, D13)

HEGGLAYEROTH = f (HEGGLAYEROTH_LAG1, CKCHKP_FEED, D980613, D07, D11, D03)

NA: PA;

SA: FL, GA, MD, NC, SC, VA;

SC: AL, AR, MS;

where HEGGLAYER is the number of hatching egg layers and CKCHKP_FEED is the ratio of broiler-type chicks price over broiler feed cost. Broiler-type chick price and broiler feed cost are used to represent revenue and cost for raising hatching egg layers respectively. The ratio of these two variables is expected to have positive effect on the number of hatching egg layers. Estimation results are presented through Table 5.24 to Table 5.27. Because of the presence of the lagged dependent variable on the right hand side of the fitted equations, the Breusch-Godfrey test was applied. Breusch-Godfrey tests are all passed and the null hypothesis that there is no serial correlation cannot be rejected. Functions are fitted using data from 1994 to 2014 and non-fitted functional form is used in the simulation system because no regional data are available for the period of 1985 to 1993.

Table 5.24: Hatching Egg Layers in South Central

<table>
<tr><th>HEGGLAYERSC</th><th>Estimate</th><th>Std. Error</th><th>t value</th><th>Pr(>|t|)</th></tr>
<tr><td>(Intercept)</td><td>7065.0024</td><td>2495.4627</td><td>2.8300</td><td>0.0133</td></tr>
<tr><td>HEGGLAYERSC_LAG1</td><td>0.5747</td><td>0.1389</td><td>4.1400</td><td>0.0010</td></tr>
<tr><td>CKCHKP_FEED</td><td>38015.2456</td><td>13448.3168</td><td>2.8300</td><td>0.0135</td></tr>
<tr><td>D11</td><td>1710.2887</td><td>515.6616</td><td>3.3200</td><td>0.0051</td></tr>
<tr><td>D12</td><td>-2347.4665</td><td>637.9837</td><td>-3.6800</td><td>0.0025</td></tr>
<tr><td>D95036</td><td>-1237.1276</td><td>370.7484</td><td>-3.3400</td><td>0.0049</td></tr>
<tr><td colspan="2">Adjusted R-squared:</td><td>0.8747</td><td>MAPE</td><td>0.0142</td></tr>
<tr><td colspan="2">Breusch-Godfrey test p-value:</td><td>0.8837</td><td>Theil's U2</td><td>0.3872</td></tr>
</table>

Table 5.25: Hatching Egg Layers in South Atlantic

HEGGLAYERSA	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	13931.2080	2305.3736	6.0400	0.0000
HEGGLAYERSA_LAG1	0.2486	0.1267	1.9600	0.0686
CKCHKP_FEED	21146.5868	6154.9939	3.4400	0.0037
D96	-716.3302	321.3266	-2.2300	0.0415
D9509112	-1028.1210	187.1763	-5.4900	0.0001
Adjusted R-squared:		0.8669	MAPE	0.0095
Breusch-Godfrey test p-value:	0.4628	Theil's U2	0.4656	

Table 5.26: Hatching Egg Layers in North Atlantic

HEGGLAYERNA	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-252.4370	110.6911	-2.2800	0.0388
HEGGLAYERNA_LAG1	1.0640	0.0703	15.1400	0.0000
CKCHKP_FEED	2270.9214	1074.1272	2.1100	0.0529
D0311	249.3178	50.9787	4.8900	0.0002
D078	-424.9934	53.5680	-7.9300	0.0000
D13	768.7917	74.5431	10.3100	0.0000
Adjusted R-squared:		0.9431	MAPE	0.0356
Breusch-Godfrey test p-value:		0.5632	Theil's U2	0.2348

Table 5.27: Hatching Egg Layers in Other Region

HEGGLAYEROTH	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-1478.2277	913.9800	-1.6200	0.1298
HEGGLAYEROTH_LAG1	1.0248	0.0335	30.5500	0.0000
CKCHKP_FEED	14859.8460	7950.8676	1.8700	0.0843
D980613	6545.6812	321.3359	20.3700	0.0000
D07	-7661.5548	634.9061	-12.0700	0.0000
D11	-2698.7733	534.2196	-5.0500	0.0002
D03	1834.1479	533.0798	3.4400	0.0044
Adjusted R-squared:		0.9849	MAPE	0.0172
Breusch-Godfrey test p-value:	0.4919	Theil's U2	0.1413	

Hatching egg layers laying rate is fitted as a function of the lagged dependent variable and real boiler-type chick price. States in each region for the production stage of hatching egg production are listed below:

HEGGLRSC = f (HEGGLRSC_LAG1, CKCHKPR, D970214, D98, D0512, D9611)

HEGGLRSA = f (HEGGLRSA_LAG1, CKCHKPR , D9604T07, D134, D05)

HEGGLRNA = f (HEGGLRNA_LAG1, CKCHKPR, D09T12, D08, D0313)

HEGGLROTH = f (HEGGLROTH_LAG1, CKCHKPR, D0512, D06134, D0712, D04)

NA: PA;

SA: FL, GA, MD, NC, SC, VA;

SC: AL, AR, MS;

where HEGGLR is hatching egg layers' laying rate and CKCHKPR is GDP deflated real broiler-type chick price. Both variables should be positively related to the dependent variable. Estimation results are presented through Table 5.28 to Table 5.31. Breusch-Godfrey tests have been applied due to the presence of the lagged dependent variable on the right hand side of the fitted functions. All p values are greater than 0.15 indicating that there is statistically no serial correlation problem. Functions are estimated using data from 1994 to 2014 and non-fitted functional form is used in the simulation system because no regional data are available for the period of 1985 to 1993.

Boiler-type chick price is fitted as a function of broiler wholesale price:

CKCHKP = f (CKWHP, SHIFT99, D04, D05, D8711, D013)

Table 5.28: Hatching Egg Layers' Laying Rate in South Central

HEGGLRSC	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	8514.6500	1344.0648	6.3300	0.0000
HEGGLRSC_LAG1	0.4504	0.0862	5.2200	0.0002
CKCHKPR	13564.5126	2747.5085	4.9400	0.0003
D970214	-309.2113	70.3477	-4.4000	0.0007
D98	-574.0469	112.0095	-5.1200	0.0002
D0512	542.2665	84.3903	6.4300	0.0000
D9611	259.9596	82.6894	3.1400	0.0078
Adjusted R-squared:		0.9572	MAPE	0.0029
Breusch-Godfrey test p-value:		0.2152	Theil's U2	0.2742

Table 5.29: Hatching Egg Layers' Laying Rate in South Atlantic

HEGGLRSA	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	7867.5024	993.2774	7.9200	0.0000
HEGGLRSA_LAG1	0.4616	0.0595	7.7500	0.0000
CKCHKPR	14780.8373	1635.1054	9.0400	0.0000
D9604T07	375.7271	30.8390	12.1800	0.0000
D134	-315.4991	44.3284	-7.1200	0.0000
D05	287.9507	63.5666	4.5300	0.0005
Adjusted R-squared:		0.9735	MAPE	0.0015
Breusch-Godfrey test p-value:		0.1862	Theil's U2	0.2128

where CKCHKP is broiler-type chick price and CKWHP is broiler wholesale price. Estimation results are presented in Table 5.32.

Following the same reasoning logic as the pork wholesale price, nominal boiler wholesale price is fitted as a function of the broiler retail price and grocery store labor cost:

CKWHP=f(CKRETP,LBCPGS,D047,D99T05)

where CKWHP is broiler wholesale price, CKRETP is broiler retail price, and LBCPGS is grocery store labor cost. Estimation results are presented in Table 5.33.

Table 5.30: Hatching Egg Layers' Laying Rate in North Atlantic

HEGGLRNA	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-4339.5515	2803.8293	-1.5500	0.1440
HEGGLRNA_LAG1	0.5822	0.1149	5.0700	0.0002
CKCHKPR	42023.8717	15666.8101	2.6800	0.0179
D09T12	1664.2579	665.3745	2.5000	0.0254
D08	5622.8551	596.7795	9.4200	0.0000
D0313	-2920.8154	496.7218	-5.8800	0.0000
Adjusted R-squared:		0.9751	MAPE	0.0253
Breusch-Godfrey test p-value:		0.5636	Theil's U2	0.2358

Table 5.31: Hatching Egg Layers' Laying Rate in Other Region

HEGGLROTH	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-2148.0913	1826.9356	-1.1800	0.2608
HEGGLROTH_LAG1	0.5612	0.0576	9.7500	0.0000
CKCHKPR	38454.4534	7935.6319	4.8500	0.0003
D0514	2353.3009	332.0051	7.0900	0.0000
D06134	-4038.0109	313.2317	-12.8900	0.0000
D0712	3153.2441	361.1978	8.7300	0.0000
D04	1041.9770	459.7292	2.2700	0.0411
Adjusted R-squared:		0.9507	MAPE	0.0161
Breusch-Godfrey test p-value:		0.3031	Theil's U2	0.1414

Functions are estimated using data from 1987 to 2014 and non-fitted functional form is used in the simulation system because no grocery store labor cost data are available for the years 1985 and 1986.

Grower chicken feed cost is used to represent the feed cost for the broiler industry. It is fitted as a function of the lagged dependent variable and a weighted corn and soybean meal price, which represents feed conversion efficiency and feed ingredient costs, respectively:

CKFEED = f (CKFEED_LAG1, CKMIXFEED, D029, D8595)

Table 5.32: Broiler-type Chick Price

CKCHKP	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	2.7750	0.9749	2.8500	0.0091
CKWHP	0.2599	0.0161	16.1600	0.0000
SHIFT99	4.2848	0.3460	12.3800	0.0000
D04	-6.3928	0.7709	-8.2900	0.0000
D05	-4.0524	0.7678	-5.2800	0.0000
D8711	2.9291	0.5488	5.3400	0.0000
D013	-2.8029	0.5750	-4.8700	0.0001
Adjusted R-squared:		0.9694	MAPE	0.0246
Breusch-Godfrey test p-value:		0.0477	Theil's U2	0.6713

Table 5.33: Broiler Wholesale Price

CKWHP	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-32.3227	10.0820	-3.2100	0.0039
CKRETP	0.7611	0.1144	6.6500	0.0000
LBCPGS	-0.0004	0.0002	-2.4700	0.0213
D047	12.0863	2.6981	4.4800	0.0002
D99T05	-5.8082	1.5926	-3.6500	0.0013
Adjusted R-squared:		0.8882	MAPE	0.0417
Breusch-Godfrey test p-value:		0.3061	Theil's U2	0.4338

Table 5.34: Broiler Industry Feed Cost

CKFEED	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-40.6179	7.6178	-5.3300	0.0000
CKFEED_LAG1	0.6278	0.0508	12.3500	0.0000
CKMIXFEED	19.9988	1.9722	10.1400	0.0000
D029	41.4770	10.6092	3.9100	0.0006
D8595	-24.5367	10.7478	-2.2800	0.0312
Adjusted R-squared:		0.9891	MAPE	0.0429
Breusch-Godfrey test p-value:		0.6036	Theil's U2	0.4082

where CKFEED is broiler industry feed cost, CKMIXFEED is the weighted average of corn and soybean meal prices. Estimation results are presented in Table 5.34. Both estimated coefficients have the correct sign. Improvement in feed conversion rate is represented by the less than one coefficient of the lagged dependent variable. Breusch-Godfrey test shows that there is statistically no serial correlation problem with a p-value of 0.6036.

The weighted corn and soybean meal costs in the broiler industry feed cost function is based on 58 percent corn price and 42 percent soybean meal price with unit adjustment[6]

$$\text{CKMIXFEED} \equiv 100 \times (0.58 \times \frac{\text{CORNPCY}}{56} + 0.42 \times \frac{\text{SBMPCY}}{2000})$$

where CKMIXFEED is the weighted corn and soybean meal prices, CORNPCY is calendar year annual average corn price and SBMPCY is calendar year annual average soybean meal price. This this equation ends the description for the broiler supply side.

All fitted equations have acceptable adjusted R-squares. Mean absolute percentage error (MAPE) and Theil's U2 indicating the forecasting ability of the model specifications are at a satisfactory scale. Breusch-Godfrey tests are all passed with p-values greater than 0.1 for the functions with the lagged dependent variable included in the explanatory variables. Estimated price elasticities of demand are in the range of the estimated elasticities in literature listed in Table 5.35[7]. Broiler industry 2015 to 2024 projections are listed in Table 5.36. Also listed in Table 5.36 are USDA and FAPRI's projections for the purpose of comparison. The short-run (year 2015)

[6]In USDA Agricultural Projections to 2024 (USDA 2015), broiler feed price is comprised of 58 percent corn price and 42 percent soybean price.

[7]When inverse demand functional forms are specified in the studies listed, flexibilities are estimated directly and elasticities are recovered from the estimated flexibilities. When both compensated and uncompensated elasticities are provided, uncompensated elasticities are included in Table 5.35 to keep consistent with the estimation result from the current study.

and long-run (year 2019) supply elasticities are calculated as:

$$e_{BROILER,SR} = \frac{(39517 - 39274)/39274}{10\%} = 0.076 \tag{5.1}$$

$$e_{BROILER,LR} = \frac{(42573 - 42479)/42479}{10\%} = 0.022 \tag{5.2}$$

Table 5.35: Estimates of Broiler Demand Elasticities From Literature

Own Price Elasticity	**Cross Price Elasticity with Pork**	**Cross Price Elasticity with Beef**	**Cross Price Elasticity with Turkey**	**Study**	**Data**	**Period**	**Model Specification**
-2.680	NA	NA	NA	Tomek (1965)	Quarterly	1949 Q4 to 1956 Q1	Linear Inverse
-2.330	NA	NA	NA	Tomek (1965)	Quarterly	1956 Q2 to 1964 Q1	Linear Inverse
-0.531	0.264	0.293	-0.049	Huang (1985)	Annual	1953 to 1983	Differential-form Demand System
-0.682	0.461	0.911	NA	Menkhaus et al. (1985)	Annual	1965-1981	Budget Share Translog Indirect Utility Function with Habit Formation
-1.838	-9.709	-2.538	13.333	Buhr (1993)	Quarterly	1973-1989	Approximate Almost Ideal Inverse Demand System
-0.372	0.047	0.103	-0.023	Huang (1993)	Annual	1953 to 1990	Differential-form Demand System
-0.426	-1.429	-0.533	NA	Dahlgran (1988)	Annual	1950-1985	Income-constrained Utility Maximization Model
-0.276	0.021	0.250	NA	Eales and Unnevehr (1988)	Annual	1965-1985	Dynamic AIDS
-0.944	-3.584	-2.137	NA	Huang (1988)	Annual	1947-1983	Rotterdam
-1.325	-1.112	-1.075	NA	Eales and Unnevehr (1992)	Quarterly	1966-1988	Inverse AIDS
-0.205	-0.120	-0.015	NA	Tonsor and Marsh (2007)	Quarterly	1976-2001	Generalized AIDS
-0.099	0.012	-0.111	NA	Tonsor, Mintert, and Schroeder (2010)	Quarterly	1982-2007	Weighted First Difference Double-log Function with Demand Shifters
-0.551	**0.192**			**This Study**	**Annual**	**1985-2014**	**Double-log**

Table 5.36: Broiler Industry 2015-2024 Projections

		2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Production	USDA	38,484	39,630	40,586	41,525	42,307	43,081	43,805	44,421	44,967	45,483	45,997
	FARPRI	38,173	40,176	41,209	41,868	42,389	42,812	43,279	43,867	44,499	45,202	45,895
	Current Study, No Shock	38,173	39,274	40,203	41,032	41,776	42,479	43,165	43,862	44,573	45,291	46,026
	Current Study, With Shock	38,173	39,571	40,366	41,175	41,893	42,573	43,239	43,920	44,620	45,329	46,058
Production (Ready-to-cook)	USDA	38,072	39,206	40,151	41,081	41,854	42,620	43,336	43,946	44,486	44,997	45,505
	Current Study, No Shock	37,759	38,846	39,763	40,581	41,315	42,009	42,686	43,373	44,075	44,783	45,508
	Current Study, With Shock	37,759	39,139	39,924	40,722	41,431	42,101	42,759	43,431	44,122	44,821	45,540
Retail Price	FARPRI	196	197	196	196	201	206	211	214	215	215	215
	Current Study, No Shock	195	202	200	201	203	206	210	214	218	222	226
	Current Study, With Shock	195	199	200	200	203	206	210	214	218	222	226
Ending Stocks	USDA	610	645	650	650	650	650	650	650	650	650	650
	FARPRI	675	726	752	760	759	754	752	754	757	765	772
	Current Study, No Shock	675	723	756	779	796	809	820	830	841	852	865
	Current Study, With Shock	675	691	761	785	800	812	823	831	842	853	866
Exports	USDA	7,319	7,400	7,629	7,805	7,952	8,098	8,234	8,350	8,452	8,549	8,646
	FARPRI	7,291	7,407	7,556	7,753	8,005	8,240	8,462	8,691	8,894	9,090	9,289
	Current Study, No Shock	7,291	7,336	7,487	7,673	7,861	8,031	8,183	8,311	8,428	8,541	8,653
	Current Study, With Shock	7,291	7,400	7,552	7,740	7,924	8,087	8,231	8,351	8,462	8,569	8,676
Per Capita Consumption	USDA	83.4	85.4	86.7	88.1	89.2	90.2	91.1	91.7	92.2	92.7	93.1
	FARPRI	83.5	87.8	89.5	90.0	90.0	89.8	89.7	90.0	90.4	91.0	91.5
	Current Study, No Shock	82.4	84.4	85.8	86.9	87.6	88.3	89.0	89.8	90.6	91.4	92.3
	Current Study, With Shock	82.4	85.1	86.0	87.1	87.8	88.4	89.1	89.8	90.6	91.4	92.3
Civillian Disappearance	USDA	30,930	31,887	32,634	33,394	34,021	34,642	35,223	35,718	36,157	36,572	36,984
	Current Study, No Shock	30,575	31,580	32,365	33,008	33,561	34,090	34,618	35,180	35,764	36,359	36,972
	Current Study, With Shock	30,575	31,845	32,425	33,083	33,616	34,128	34,643	35,198	35,778	36,370	36,981

The applied shock is a 10 percent increase in 2015 turkey wholesale price

6. THE U.S. EGG INDUSTRY

This chapter presents an econometric model for the U.S. egg industry. The model describes the supply and the demand for the broiler sector within the U.S. economy; wholesale price is the primary variable that adjusts and clears the market. Following the construction of the U.S. pork industry, total supply consists of beginning stocks, imports, and production; total demand comprises ending stocks, exports, hatching use, and domestic disappearance. Due to the extensive proportion of domestic production and consumption accounting for the total U.S. egg supply and disappearance respectively, the model focuses on these two parts following the theoretical establishment outlined in the methodology chapter. A one-equation description will be used to approximate the U.S. egg imports, exports, and stocks.

The chapter is organized as follows. In the first section, the general flow in egg production is presented as a background. Critical decision points in egg production have been discussed in Chapter III to assist presenting the model specification. More detailed information about the industry will be provided in this section. In the second section, the dataset that will be used for estimating the econometric model will be presented. In the third section, the model specification and estimation results will be presented.

6.1 Egg Production

Egg production consists of table egg production and hatching egg production. Table egg production has a sequential feature starting with inventory management of the hatchery supply flock which provides fertilized eggs that will be hatched and the chicks fed to become egg-type hatching egg layers. Egg-type hatching egg layers then lay fertilized egg-type hatching eggs. The eggs are then set in incubators and hatched to egg-type chicks. Egg-type chicks are raised to table egg layers. Finally table egg layers are placed on feed and produce table eggs. Hatching egg production comprises egg-type hatching egg production mentioned above and broiler-type hatching egg production mentioned in the U.S. broiler model. The U.S. egg model is schematically described in Figure 6.1.

6.2 Egg Data

Macro-level egg supply and demand data, including table egg production, hatching egg production, imports, exports, stocks, hatching use, and consumption, are available from World Agricultural Supply and Demand Estimates (WASDE) provided by USDA. Egg-type hatching egg production, egg-type hatching egg layers laying rate, egg-type hatching eggs set in incubators, and table egg layers' laying rate are available from Chickens and Eggs Annual Summary (NASS, USDA); egg-type chicks hatched is available from Hatchery Production (NASS, USDA).

During-month egg-type hatching egg layers' laying rate are added to get during-year egg-type hatching egg layers' laying rate; monthly egg-type hatching egg production are added to get annual egg-type hatching egg production; the average number of egg-type hatching egg layers is calculated as annual egg-type hatching egg production divided by during-year egg-type hatching egg layers' laying rate.

Similarly, during-month table egg layers' laying rate are added to get during-year table egg layers' laying rate; annual table egg production is available in WASDE; the average number of table egg layers is calculated as annual table egg production divided by during-year table egg layers' laying rate.

6.3 The U.S. Egg Model

The U.S. egg model is schematically delineated in Figure 6.1. Total U.S. egg demand equals the sum of egg ending stocks, egg exports, egg hatching use, and

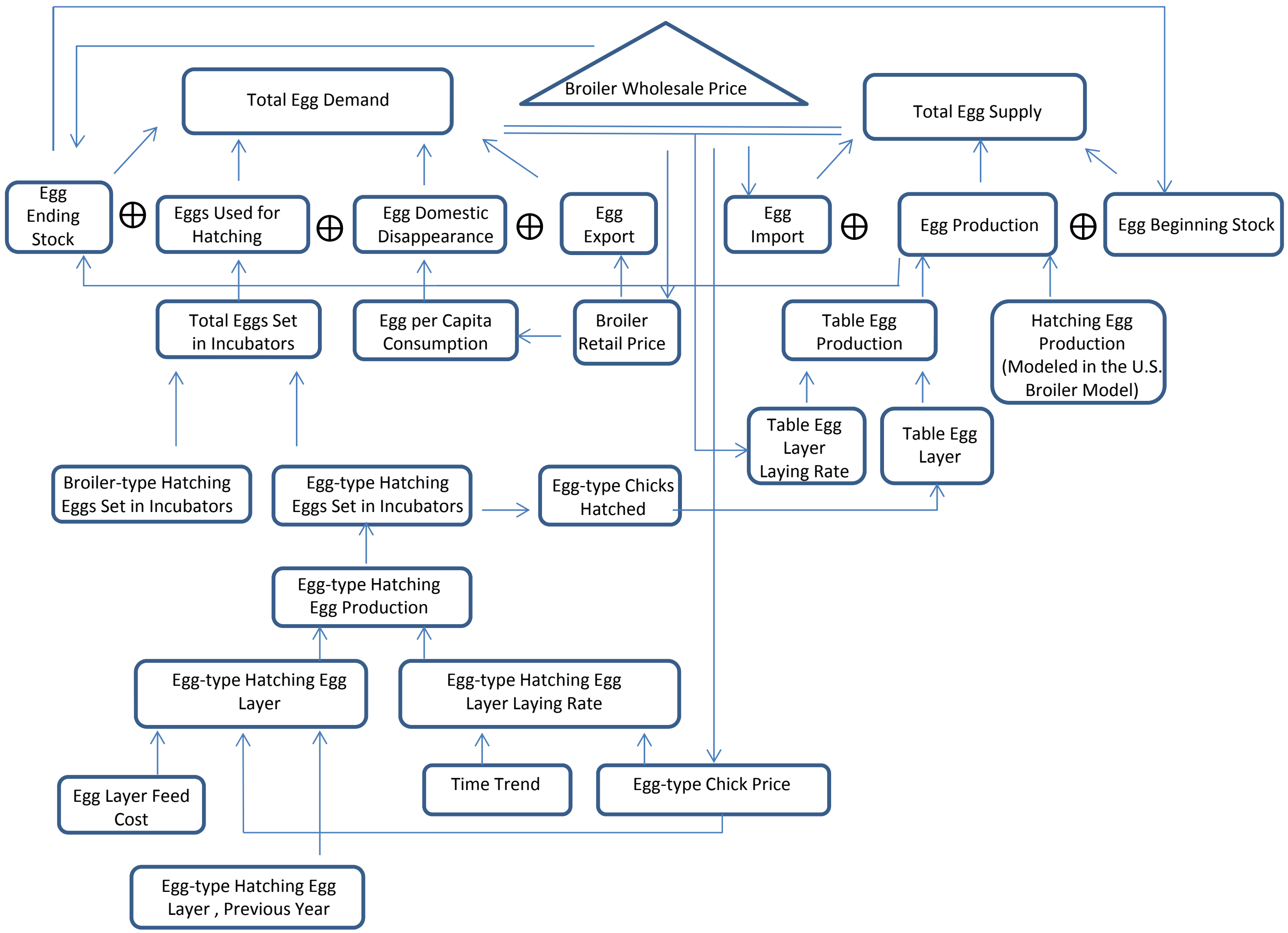


Figure 6.1: The U.S. Egg Model

egg domestic disappearance. Total U.S. egg supply equals the sum of egg beginning stocks, egg imports, hatching egg production, and table egg production.

Starting from the demand side, the egg total demand identity is

$$\text{EGGDEM} \equiv \text{EGGSTK+EGGEXPT+EGGHATCHUSE+EGGCDIS}$$

where EGGDEM is the total demand for eggs, EGGSTK is egg ending stocks, EGGEXPT is egg exports, EGGHATCHUSE is egg hatching use, and EGGCDIS is egg domestic disappearance.

U.S. egg ending stock is specified as:

EGGSTK=f(EGGPROD,EGGWHPR,SHIFT08,D11,D85T95,D9359,D01267,D87896)

where EGGSTK is egg ending stocks, EGGPROD is total egg production and EGGWHPR is the GPD deflated real egg wholesale price. Estimation results are presented in Table 6.1. Egg production has a positive effect on ending stocks. And egg wholesale price has a negative effect on egg ending stocks, reflecting the fact that when price is high the wholesalers intend to sell more eggs and thus ending stock should be lower. Total egg production will be discussed in the supply side.

A small proportion of the U.S. egg production is exported (less than 5 percent of total egg production) during the past couple of years (WASDE, USDA). Major foreign markets for U.S. egg products include Canada and Mexico. To model the U.S. egg exports with sufficient accuracy, descriptions for the demand from these markets are needed yet beyond the research scale of the current study. A single equation description for the U.S. egg exports is specified as:

EGGEXPT = f(EGGEXPT_LAG1, EGGRETPR, SHIFT07, D916, D13)

where EGGEXPT is egg exports, EGGEXPT_LAG1 is the lagged dependent variable, and EGGRETPR is real egg retail price. Based on the assumption that not

Table 6.1: Egg Ending Stock

EGGSTK	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-36.7785	2.8635	-12.8400	0.0000
EGGPROD	0.0071	0.0004	18.9200	0.0000
EGGWHPR	-2.7409	0.8681	-3.1600	0.0048
SHIFT08	3.4880	0.4957	7.0400	0.0000
D11	8.2331	0.5802	14.1900	0.0000
D85T95	9.8964	0.4667	21.2000	0.0000
D9359	-3.6188	0.3531	-10.2500	0.0000
D01267	-3.3769	0.3672	-9.2000	0.0000
D87896	2.3435	0.3548	6.6100	0.0000
Adjusted R-squared:		0.9884	MAPE	0.0305
Breusch-Godfrey test p-value:		0.1153	Theil's U2	0.1633

all the trading partners will change drastically, the lagged dependent variable can explain partially the current quantity of egg exports. Egg selling price has a negative effect on egg exports indicating that when domestic price is high more eggs will be sold in the home market and less will be exported, and vice versa. Estimation results are presented in Table 6.2.

Table 6.2: Egg Exports

EGGEXPT	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	134.2964	51.9411	2.5900	0.0162
EGGEXPT_LAG1	0.7869	0.0870	9.0500	0.0000
EGGRETPR	-75.3493	36.6248	-2.0600	0.0507
SHIFT07	70.6367	22.2902	3.1700	0.0041
D916	55.2884	18.0319	3.0700	0.0053
D13	63.6221	25.5333	2.4900	0.0200
Adjusted R-squared:		0.9037	MAPE	0.0944
Breusch-Godfrey test p-value:		0.9998	Theil's U2	0.6322

U.S. egg hatching use is specified as a function of the total number of hatching eggs set in incubators:

EGGHATCHUSE=f(TEGGSET,D024,D8503)

where EGGHATCHUSE is eggs used for hatching and TEGGSET is the total number of hatching eggs set in incubators. Estimation results are presented in Table 6.3.

Table 6.3: Egg Hatching Use

EGGHATCHUSE	Estimate	Std. Error	t value	$Pr(>\vert t\vert)$
(Intercept)	4.5695	1.9846	2.3000	0.0296
TEGGSET	1.4427	0.0033	435.6900	0.0000
D024	21.9217	1.3282	16.5000	0.0000
D8503	13.4889	1.3359	10.1000	0.0000
Adjusted R-squared:		0.9999	MAPE	0.0015
Breusch-Godfrey test p-value:	0.4869	Theil's U2	0.0552	

The total number of hatching eggs set in incubators is the sum of broiler-type hatching eggs set in incubators and egg-type hatching eggs set in incubators:

TEGGSET $\equiv$ CKEGGSET+TBEGGSET

where TEGGSET is the total number of hatching eggs set in incubators, CKEGGSET is broiler-type hatching eggs set in incubators discussed in the broiler model, and TBEGGSET is egg-type hatching eggs set in incubators that will be discussed in the egg production part.

In the U.S. broiler model discussed in the previous chapter, the number of broiler-type hatching eggs set in incubators in each of the four regions has been fitted as the lagged dependent variable and hatching egg production in the respective region. The national total broiler-type hatching eggs set in incubators is the sum of the regional data with unit adjustment:

CKEGGSET≡(CKEGGSETSC+CKEGGSETSA+CKEGGSETNA+

CKEGGSETOTH)/12,000

The last and largest proportion of the quantity demanded for eggs is egg domestic disappearance (in million dozen), which is the product of U.S. population (in million persons) and per capita consumption (in number):

$$\text{EGGCDIS} \equiv \text{USPOP} \times \text{EGGPCCR}/12$$

where EGGCDIS is egg civilian disappearance, USPOP is U.S. population, and EGGPCCR is (shell egg equivalent) per capita consumption for egg.

Following the discussions in the methodology chapter, per capita consumption for eggs is modeled by a double-log functional form:

EGGPCCR_LOG = f (FOODEXPR_LOG, EGGRETPR_LOG, SHIFT12, SHIFT14, D85T88, D89T98, D0789, D85, D8895, D8904)

where EGGPCCR_LOG is egg per capita consumption in log form, FOODEXPR_LOG is real food expenditure in log form, and EGGRETPR_LOG is real egg retail price in log form.

Estimation results are presented in Table 6.4. Functional form with other food price index included in the explanatory variables has also been tried as listed in Table6.5, where other food price index has a negative effect on egg consumption which contradicts economic theory and thus it is removed. Own price elasticity is -0.14; income elasticity is 0.30; cross price elasticities with broiler, turkey, pork, or beef are not estimated due to the functional specification. This equation ends the description for the demand side of broiler industry.

Table 6.4: Egg Per Capita Consumption Without OTHFOODPR (Retail Weight)

EGGPCCR	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	4.4993	0.2179	20.6500	0.0000
FOODEXPR_LOG	0.2953	0.0610	4.8400	0.0001
EGGRETPR_LOG	-0.1364	0.0210	-6.4800	0.0000
SHIFT12	0.0276	0.0072	3.8600	0.0011
SHIFT14	0.0191	0.0079	2.4100	0.0263
D0789	0.0160	0.0071	2.2600	0.0360
D85T88	0.0643	0.0144	4.4700	0.0003
D89T98	-0.0369	0.0078	-4.7400	0.0001
D85	0.0472	0.0090	5.2400	0.0000
D8895	-0.0287	0.0056	-5.0900	0.0001
D8904	0.0223	0.0049	4.5400	0.0002
Adjusted R-squared:		0.9734	MAPE	0.0007
Breusch-Godfrey test p-value:		0.7371	Theil's U2	0.3280

Table 6.5: Egg Per Capita Consumption With OTHFOODPR (Retail Weight)

EGGPCCR	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	4.3249	0.2088	20.7100	0.0000
FOODEXPR_LOG	0.3639	0.0619	5.8800	0.0000
EGGRETPR_LOG	-0.1332	0.0189	-7.0400	0.0000
OTHFOODPR_LOG	-0.1210	0.0511	-2.3700	0.0292
SHIFT12	0.0280	0.0064	4.3500	0.0004
SHIFT14	0.0161	0.0072	2.2200	0.0398
D0789	0.0137	0.0064	2.1400	0.0465
D85T88	0.0566	0.0133	4.2700	0.0005
D89T98	-0.0393	0.0071	-5.5600	0.0000
D85	0.0490	0.0081	6.0400	0.0000
D8895	-0.0286	0.0050	-5.6600	0.0000
D8904	0.0175	0.0049	3.5900	0.0021
Adjusted R-squared:		0.9786	MAPE	0.0006
Breusch-Godfrey test p-value:		0.1092	Theil's U2	0.2866

The U.S. egg total supply identity is:

$$\text{EGGSUPP} \equiv \text{EGGSTK\_LAG1} + \text{EGGIMPT} + \text{EGGPROD}$$

where EGGSTK_LAG1 is egg beginning stock that can be recovered from egg ending stock of the previous period, EGGIMPT is U.S. egg imports, and EGGPROD is U.S. egg production. Following similar logic in specifying the U.S. egg exports function, the U.S. egg imports is specified as:

EGGIMPT=f(EGGWHPR,SHIFT99,SHIFT14,D89,D0210,D910789)

where EGGIMPT is egg imports and EGGWHPR is real egg wholesale price. The real egg wholesale price helps explain the domestic sellers' willingness to trade. Estimation results are presented in Table 6.6. Egg wholesale price is positively correlated with egg imports as expected.

Table 6.6: Egg Imports

EGGIMPT	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-12.5881	2.5558	-4.9300	0.0001
EGGWHPR	25.5012	3.3425	7.6300	0.0000
SHIFT99	8.6955	0.9781	8.8900	0.0000
SHIFT14	11.6426	2.5187	4.6200	0.0001
D89	13.2601	2.2618	5.8600	0.0000
D02101	6.3995	1.3742	4.6600	0.0001
D910789	-4.1599	1.2910	-3.2200	0.0038
Adjusted R-squared:		0.9173	MAPE	0.1857
Breusch-Godfrey test p-value:		0.3980	Theil's U2	0.2939

The main component of total egg supply is egg production which is the sum of hatching egg production and table egg production:

$$\text{EGGPROD} \equiv \text{HEGGPROD+TBEGGPROD}$$

where EGGPROD is total egg production, HEGGPROD is hatching egg production, and TBEGGPROD is table egg production.

Regional hatching egg production has been discussed in the U.S. broiler model. For each region, hatching egg production (from flocks with 30,000 heads and above, as large flocks) is calculated as the product of the number of hatching egg layers and the respective laying rate. Thus the national total hatching egg production from large flocks is simply the sum of the regional production:

$$\text{HEGGPRODLF} \equiv \text{HEGGPRODSC} + \text{HEGGPRODSA} + \text{HEGGPRODNA}$$
$$+ \text{HEGGPRODOTH}$$

where HEGGPRODLF is national total hatching egg production from large flocks.

National total hatching egg production is then fitted as a function of the hatching egg production from large flocks. Estimation results are presented in Table 6.7.

Table 6.7: Hatching Egg Production

HEGGPROD	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.8381	2.2614	0.3700	0.7139
HEGGPRODLF	0.9995	0.0023	425.4200	0.0000
D94T97	63.5313	1.1004	57.7300	0.0000
D089	-9.1600	1.5295	-5.9900	0.0000
Adjusted R-squared:		0.9998	MAPE	0.0014
Breusch-Godfrey test p-value:		0.9504	Theil's U2	0.0687

Table egg production (million dozen) is determined by the number of table egg layers (1,000 layers) and table egg layers laying rate (eggs per 100 layers):

$$\text{TBEGGPROD} \equiv \text{TBEGGLAYER} \times \text{TBEGGLR} \div 1{,}200{,}000$$

where TBEGGPROD is table egg production, TBEGGLAYER is the number of table egg layers, and TBEGGLR is table egg layers laying rate.

Table egg layers' laying rate is fitted as a function of trend representing technology improvement and egg-type chick price:

TBEGGLR = f (YEAR, EGGCKPR, D017)

where TBEGGLR is table egg layers' laying rate, YEAR is time trend, and EGGCKPR is GDP deflated real egg-type chick price. Both variables should be positively related to the dependent variable. Estimation results are presented in Table 6.8.

Table 6.8: Table Egg Layers' Laying Rate

TBEGGLR	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-196753.8361	5760.9933	-34.1500	0.0000
YEAR	111.2981	2.8789	38.6600	0.0000
EGGCKPR	1132.8555	262.6293	4.3100	0.0002
D017	-307.8903	101.1905	-3.0400	0.0053
Adjusted R-squared:		0.9811	MAPE	0.0038
Breusch-Godfrey test p-value:		0.02255	Theil's U2	0.7133

The number of table egg layers is fitted as a function of the lagged dependent variable representing the scale of production and the number of egg-type chicks hatched representing additional layers adding to the laying flock:

TBEGGLAYER=f(TBEGGLAYER_LAG1,TBEGGHATCH,D99T06,D078,
D85689,D8990)

where TBEGGLAYER is the number of table egg layers, TBEGGLAYER_LAG1 is the lagged dependent variable, and TBEGGHATCH is the number of egg-type chicks hatched. Estimation results are provided in Tables 6.8. Both explanatory variables have positive effects on the number of table egg layers as expected.

Egg-type chicks hatched is fitted as a function of egg-type hatching eggs set in incubators and feed cost:

Table 6.9: The Number of Table Egg Layers

TBEGGLAYER	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-3204.3733	5387.4289	-0.5900	0.5578
TBEGGLAYER_LAG1	0.8901	0.0368	24.1900	0.0000
TBEGGHATCH	0.0796	0.0201	3.9500	0.0006
D99T06	3169.2039	1144.9461	2.7700	0.0109
D85689	-4853.6566	1262.0554	-3.8500	0.0008
D078	-6961.9790	1733.0635	-4.0200	0.0005
D8990	-4726.1819	1576.7134	-3.0000	0.0064
Adjusted R-squared:		0.9928	MAPE	0.0054
Breusch-Godfrey test p-value:		0.4904	Theil's U2	0.3612

TBEGGHATCH=f(TBEGGSET,EGGFEEDR,D97T01,D067,D8811)

where TBEGGHATCH is the number of egg-type chicks hatched, TBEGGSET is the number of egg-type hatching eggs set in incubators, EGGFEEDR is GPD deflated real layer feed cost. Estimation results are presented in Tables 6.10.

Table 6.10: Egg-type Chicks Hatched

TBEGGHATCH	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	60516.4922	5229.3683	11.5700	0.0000
TBEGGSET	11598.2737	230.4535	50.3300	0.0000
EGGFEEDR	-4379.9611	1065.6393	-4.1100	0.0004
D97T01	9831.9472	1332.5178	7.3800	0.0000
D067	-16300.6836	2065.6012	-7.8900	0.0000
D8811	-9862.3009	1875.3922	-5.2600	0.0000
Adjusted R-squared:		0.9957	MAPE	0.0043
Breusch-Godfrey test p-value:		0.801	Theil's U2	0.0996

The number of egg-type chicks hatched (in 1,000 chicks) is positively related to the number of egg-type hatching eggs set in incubators (in million dozen eggs). Feed cost is supposed to have a negative effect on the number of egg-type chicks hatched. Since both feed and chicks are input for table egg production; when the price for one input increases the derived quantity demanded for the other will decrease.

Egg-type hatching eggs set in incubators is fitted as a function of egg-type hatching egg production:

TBEGGSET=f(TBHEGGPROD,D089,D9013,D9124,D04)

where TBEGGSET is the number of egg-type hatching eggs set in incubators and TBHEGGPROD is egg-type hatching egg production. Both the lagged dependent variable and the egg-type hatching egg production should be positively correlated with egg-type hatching eggs set in incubator as presented in Tables 6.11. Since data for egg-type hatching egg production is not available before 1990, a non-fitted functional form is used in the simulation system.

Table 6.11: Egg-type Hatching Eggs Set in Incubator

TBEGGSET	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-9.7695	3.1470	-3.1000	0.0058
TBHEGGPROD	0.6754	0.0483	13.9900	0.0000
D089	5.7305	0.8076	7.1000	0.0000
D9013	-5.1817	0.8997	-5.7600	0.0000
D9124	-2.5258	0.6519	-3.8700	0.0010
D04	2.4721	1.0812	2.2900	0.0339
Adjusted R-squared:		0.9115	MAPE	0.0217
Breusch-Godfrey test p-value:		0.2958	Theil's U2	0.6373

Egg-type hatching egg production is determined by the number of egg-type hatching egg layers and their laying rate:

TBHEGGPROD ≡ TBHEGGLAYER × TBHEGGLR/1,200,000 where TBHEGGPROD is egg-type hatching egg production, TBHEGGLAYER is the number of egg-type hatching egg layers on farm during the year, and TBHEGGLR is the egg-type hatching egg layers laying rate. Since the measurement unit for egg-type hatching egg production is million dozens of eggs, for hatching egg layers is 1000 layers, and for hatching egg layers laying rate is eggs per 100 layers, a conversion rate of 1/ 1,200,000 is needed.

The number of egg-type hatching egg layers is fitted as a function of the lagged dependent variable, real egg-type chick price, and real egg layer feed cost:

TBHEGGLAYER = f (TBHEGGLAYER_LAG1, EGGCKPR, EGGFEEDR, SHIFT10, D089, D13, D96804811, D990912, D02)

where TBHEGGLAYER is the number of egg-type hatching egg layers and EGGCKPR is GDP deflated real egg-type chick price, and EGGFEEDR is GDP deflated egg layer feed cost. Chick price and feed cost are used to represent revenue and cost for raising egg layers respectively; thus the coefficients of these two variables are expected to be positive and negative, respectively. Estimation results are presented in Table6.12. Because of the presence of the lagged dependent variable on the right hand side of the fitted equations, the Breusch-Godfrey test was applied. A p-value of 0.45 indicates that there is no serial correlation. The function is fitted using data from 1990 to 2014 and the non-fitted functional form is used in the simulation system because no egg-type hatching egg production data are available for the period of 1985 to 1989.

The actual production procedure of egg-type chicks added into the hatchery supply flock has also been tried in the explanatory variables using pullet chicks hatched for intended placement in egg-type hatchery supply flocks data. However, including this production stage does not help increase the explanatory power of the fitted model, and thus it was excluded.

Table 6.12: Egg-type Hatching Egg Layers

TBHEGGLAYER	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1595.5884	122.0115	13.0800	0.0000
TBHEGGLAYER_LAG1	0.3867	0.0542	7.1400	0.0000
EGGCKPR	581.9720	157.8604	3.6900	0.0024
EGGFEEDR	-108.6106	25.0543	-4.3400	0.0007
SHIFT10	278.3001	45.4748	6.1200	0.0000
D089	-135.6616	39.1170	-3.4700	0.0038
D13	284.0309	38.9514	7.2900	0.0000
D96804811	-100.6364	18.4041	-5.4700	0.0001
D990912	103.3262	26.0881	3.9600	0.0014
D02	-86.0768	34.1128	-2.5200	0.0243
Adjusted R-squared:		0.9725	MAPE	0.0064
Breusch-Godfrey test p-value:		0.4522	Theil's U2	0.1626

Egg-type hatching egg layers laying rate is fitted as a function of the trend variable and real egg-type chick price:

TBHEGGLR = f (HEGGLRSC_LAG1, EGGCKPR, D90T94, D98, D91913)

where TBHEGGLR is egg-type hatching egg layers' laying rate and EGGCKPR is GDP deflated real egg-type chick price. Both variables should be positively related to the dependent variable. Estimation results are presented in Table 6.13. The function is estimated using data from 1990 to 2014 and the non-fitted functional form is used in the simulation system because no egg-type hatching egg production data are available for the period of 1985 to 1989.

Egg-type chick price is fitted as a function of egg wholesale price:

EGGCKP = f (EGGWHP, D09T13, D8990, D06, D0514, D91603)

where EGGCKP is egg-type chick price and EGGWHP is egg wholesale price. Estimation results are presented in Table 6.14.

Table 6.13: Egg-type Hatching Egg Layers' Laying Rate

TBHEGGLR	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-144030.0549	15976.3069	-9.0200	0.0000
YEAR	85.5898	8.0850	10.5900	0.0000
EGGCKPR	957.2442	455.7538	2.1000	0.0501
D90T94	-846.0323	128.9579	-6.5600	0.0000
D93508	-364.6117	87.9706	-4.1400	0.0006
D98	515.7716	148.5154	3.4700	0.0027
D91913	372.7726	87.6291	4.2500	0.0005
Adjusted R-squared:		0.9803	MAPE	0.0033
Breusch-Godfrey test p-value:		0.8439	Theil's U2	0.3182

Table 6.14: Egg-type Chick Price

EGGCKP	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	25.8799	3.0511	8.4800	0.0000
EGGWHP	0.5612	0.0528	10.6400	0.0000
D09T13	15.7991	2.5197	6.2700	0.0000
D8990	-10.2492	3.1648	-3.2400	0.0035
D0610	9.7982	3.2544	3.0100	0.0060
D91603	-7.9424	2.6396	-3.0100	0.0061
Adjusted R-squared:		0.9216	MAPE	0.0490
Breusch-Godfrey test p-value:		0.3156	Theil's U2	0.9711

Following the same reasoning logic as the pork wholesale price, nominal egg retail price is fitted as a function of the egg wholesale price and grocery store labor cost:

EGGRETP=f(EGGWHP,LBCPGS,SHIFT04,D09)

where EGGRETP is egg retail price, EGGWHP is egg wholesale price, and LBCPGS is grocery store labor cost. Estimation results are presented in Table 6.15. Functions are estimated using data from 1987 to 2014 and the non-fitted functional form is used in the simulation system because no grocery store labor cost data are available for the years 1985 and 1986.

Table 6.15: Egg Retail Price

EGGRETP	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-0.7294	11.9111	-0.0600	0.9517
LBCPGS	0.0008	0.0002	3.2200	0.0038
EGGWHP	1.1787	0.1189	9.9100	0.0000
SHIFT04	23.9655	6.2711	3.8200	0.0009
D09	20.3418	9.1759	2.2200	0.0368
Adjusted R-squared:		0.9513	MAPE	0.0564
Breusch-Godfrey test p-value:		0.5926	Theil's U2	0.6362

Laying feed (complete) cost is used to represent the feed cost for the egg industry. It is fitted as a function of the lagged dependent variable and a weighted corn and soybean meal price, which represents feed conversion efficiency and feed ingredient costs, respectively:

EGGFEED = f (EGGFEED_LAG1, EGGMIXFEED, D0814, D859510)

where EGGFEED is egg industry feed cost, EGGMIXFEED is the weighted average of corn and soybean meal prices. Estimation results are presented in Table 6.16.

Table 6.16: Egg Industry Feed Cost

EGGFEED	Estimate	Std. Error	t value	Pr(>—t—)
(Intercept)	-16.3079	6.3657	-2.5600	0.0168
EGGFEED_LAG1	0.6056	0.0509	11.9000	0.0000
EGGMIXFEED	19.1245	1.8249	10.4800	0.0000
D0814	39.9360	9.5275	4.1900	0.0003
D859510	-25.9861	7.2420	-3.5900	0.0014
Adjusted R-squared:		0.9898	MAPE	0.0372
Breusch-Godfrey test p-value:		0.3389	Theil's U2	0.3980

Both estimated coefficients have the correct sign. Improvement in feed conversion rate is represented by the less than one coefficient of the lagged dependent variable. Breusch-Godfrey test shows that there is statistically no serial correlation problem with a p-value of 0.3389.

The weighted corn and soybean meal cost in the egg industry feed cost function is based on 75 percent corn price and 25 percent soybean meal price with unit adjustment[1]

$$\text{EGGMIXFEED} \equiv 100 \times (0.75 \times \frac{\text{CORNPCY}}{56} + 0.25 \times \frac{\text{SBMPCY}}{2000})$$

where EGGMIXFEED is the weighted corn and soybean meal prices, CORNPCY is calendar year annual average corn price and SBMPCY is calendar year annual average soybean meal price. This this equation ends the description of the egg supply side.

All fitted equations have acceptable adjusted R-squares. Mean absolute percentage error (MAPE) and Theil's U2 indicating the forecasting ability of the model specifications are at a satisfactory scale. Breusch-Godfrey tests are all passed with p-values greater than 0.1 for the functions with the lagged dependent variable included in the explanatory variables. Estimated price elasticities of demand are in the range of the estimated elasticities in literature listed in Table 6.17. Egg industry 2015 to 2024 projections are listed in Table 6.20. Also listed in Table 6.20 are USDA projections for the purpose of comparison. The short-run (2015) and long-run (2019) supply elasticities are calculated as:

$$e_{BROILER,SR} = \frac{(8436 - 8407)/8436}{10\%} = 0.035 \tag{6.1}$$

$$e_{BROILER,LR} = \frac{(8818 - 8813)/8813}{10\%} = 0.005 \tag{6.2}$$

[1]In USDA Agricultural Projections to 2024 (USDA 2015), egg feed price is comprised of 75 percent corn price and 25 percent soybean price.

Table 6.17: Estimates of Egg Demand Elasticities From Literature

Own Price Elasticity	Study	Data	Period	Model Specification
-0.143	Huang and Haidacher (1983)	Annual	1950-1981	Relative-change-form Demand System
-0.145	Huang (1985)	Annual	1953 to 1983	Differential-form Demand System
-0.110	Huang (1993)	Annual	1953 to 1990	Differential-form Demand System
-0.057	Huang and Lin (2000)	Cross-sectional Data	1987 to 1988	AIDS
-0.240	Okrent and Alston (2012)	Monthly	1998-2010	Generalized Ordinary Differential Demand System
-0.136	**This Study**	**Annual**	**1985-2014**	**Double-log**

Table 6.18: Egg Industry 2015-2024 Projections

		2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Production	USDA	8,237	8,430	8,540	8,651	8,780	8,912	9,019	9,127	9,228	9,329	9,432
	Current Study, No Shock	8,339	8,407	8,514	8,615	8,713	8,813	8,913	9,015	9,121	9,228	9,337
	Current Study, With Shock	8,339	8,436	8,524	8,623	8,720	8,818	8,916	9,018	9,122	9,229	9,338
Wholesale Price	USDA	120	112	100	99	95	92	90	89	89	89	89
	Current Study, No Shock	107	107	104	104	105	106	107	108	109	110	111
	Current Study, With Shock	107	117	102	102	104	105	107	108	109	110	111
Imports	USDA	33	40	40	40	40	40	40	40	40	40	40
	Current Study, No Shock	33	32	31	31	31	31	30	30	30	30	30
	Current Study, With Shock	33	35	31	30	30	30	30	30	30	30	30
Exports	USDA	362	355	358	361	364	367	370	373	376	379	382
	Current Study, No Shock	395	375	361	351	344	339	335	332	330	329	329
	Current Study, With Shock	395	369	357	349	343	338	335	332	330	329	329
Ending Stocks	USDA	23	23	23	23	23	23	23	23	23	23	23
	Current Study, No Shock	23	24	25	25	26	27	28	28	29	30	31
	Current Study, With Shock	23	24	25	26	26	27	28	28	29	30	31
Per Capita Consumption	USDA	261.1	266.0	267.5	269.0	271.2	273.5	274.9	276.4	277.7	278.9	280.2
	Current Study, No Shock	263.4	264.2	266.3	267.9	269.6	271.0	272.5	274.0	275.6	277.2	278.9
	Current Study, With Shock	263.4	262.1	266.7	268.4	269.7	271.1	272.6	274.1	275.6	277.2	278.9

Table 6.18: Continued

Hatching Use	USDA	975	1,000	1,019	1,036	1,051	1,065	1,078	1,090	1,100	1,109	1,118
	Current Study, No Shock	976	988	997	1,005	1,012	1,017	1,022	1,026	1,031	1,036	1,041
	Current Study, With Shock	976	989	997	1,005	1,012	1,017	1,022	1,026	1,031	1,036	1,041
Civillian Disappearance	USDA	6,933	7,115	7,203	7,294	7,405	7,520	7,611	7,704	7,792	7,881	7,972
	Current Study, No Shock	6,996	7,073	7,187	7,289	7,391	7,487	7,586	7,687	7,789	7,892	8,000
	Current Study, With Shock	6,996	7,017	7,199	7,300	7,395	7,492	7,589	7,689	7,790	7,893	8,001
The applied shock is a 10 percent increase in 2015 egg wholesale price												

7. THE U.S. TURKEY INDUSTRY

This chapter presents an econometric model for the U.S. turkey industry. The model describes the supply and the demand for the turkey sector within the U.S. economy; retail price is the primary variable that adjusts and clears the market. Following the construction of the U.S. pork industry, total supply consists of beginning stocks, imports, and production; total demand comprises ending stocks, exports, and domestic disappearance. Due to the extensive proportion of domestic production and consumption accounting for the total U.S. turkey supply and disappearance respectively, the model focuses on these two parts following the theoretical establishment elaborated in the methodology chapter. A one-equation description will be used to approximate the U.S. turkey imports, exports, and stocks.

The chapter is organized as follows. In the first section, the general flow in turkey production is presented as a background. Critical decision points in turkey production have been discussed in Chapter III to assist in presenting the model specification. More detailed information about the industry will be provided in this section. In the second section, the dataset used for estimating the econometric model will be discussed. In the third section, the model specification and estimation results will be presented.

7.1 Turkey Production

Turkey Production Turkey production has a sequential feature starting with inventory management of the hatchery supply flock which provides fertilized eggs that will be hatched and the turkey poults (parents) fed to become hatching egg layers. Hatching egg layers lay fertilized hatching eggs. The eggs are set in incubators and hatched to turkey poults (children). Turkey poults are raised and slaughtered at an average weight around 25 pounds. The U.S. turkey model is schematically described in Figure 7.1.

7.2 Turkey Data

Macro-level turkey supply and demand data, including turkey production, imports, exports, stocks, and consumption, are available from World Agricultural Supply and Demand Estimates (WASDE) provided by USDA. Total number of turkeys slaughtered and the number of turkey poults placed on feed are available from the National Agricultural Statistics Service (NASS, USDA). Data for turkey hatching eggs set in incubators can be found from Hatchery Production (NASS, USDA). However, no data are available for production stages prior to hatching eggs set in incubators; and thus production stages earlier than hatching eggs set in incubators are omitted in the current model. The number of turkey hatching eggs set in incubators is explained by price and cost variables directly.

7.3 The U.S. Turkey Model

The U.S. turkey model is schematically delineated in Figure 7.1. Total U.S. turkey demand equals the sum of turkey ending stocks, turkey exports, and turkey domestic disappearance. Total U.S. turkey supply equals the sum of turkey beginning stocks, turkey imports, and turkey production.

Starting from the demand side, the turkey total demand identity is

$$\text{TKDEM} \equiv \text{TKSTK+TKEXPT+TKCDIS}$$

where TKDEM is the total demand for turkey, TKSTK is turkey ending stocks, TKEXPT is turkey exports, and TKCDIS is turkey domestic disappearance.

U.S. turkey ending stocks is specified as:

$$\text{TKSTK=f(TKPRODRTC,TKWHPR,SHIFT05,D99T11,D9708)}$$

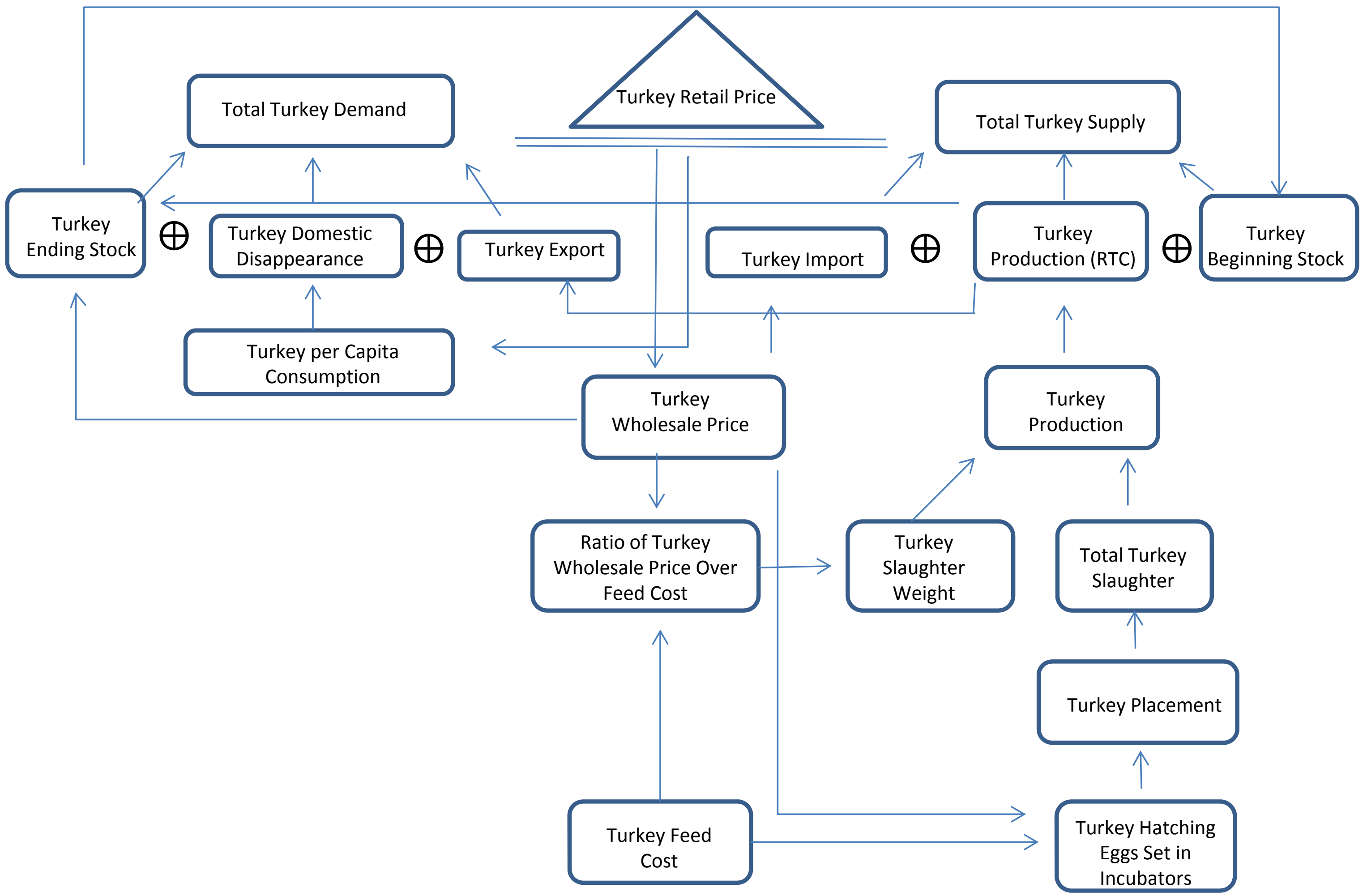


Figure 7.1: The U.S. Turkey Model

where TKSTK is turkey ending stocks, TKPRODRTC is ready-to-cook turkey production, and TKWHPR is GPD deflated real turkey wholesale price. Estimation results are presented in Table 7.1. Turkey production has a positive effect on ending stocks. And turkey wholesale price has a negative effect on turkey ending stocks, reflecting the fact that when price is high the wholesalers intend to sell more and thus ending stock should be lower. Ready-to-cook turkey production will be discussed in the supply side.

Table 7.1: Turkey Ending Stocks

TKSTK	Estimate	Std. Error	t value	Pr(>$\|t\|$)
(Intercept)	225.5816	120.3780	1.8700	0.0732
TKWHPR	-194.0245	107.1050	-1.8100	0.0826
TKPRODRTC	0.0332	0.0144	2.3000	0.0302
D99T11	-32.5147	15.1959	-2.1400	0.0428
SHIFT05	-45.2560	21.4515	-2.1100	0.0455
D9708	131.1965	23.2341	5.6500	0.0000
Adjusted R-squared:		0.7419	MAPE	0.0856
Breusch-Godfrey test p-value:		0.3687	Theil's U2	0.4692

The United States is the world's largest exporter of turkey products[1]. Approaching 15 percent of the U.S. ready-to-cook turkey production is exported during the past couple of years (WASDE, USDA). The largest foreign market for the U.S. turkey products is Mexico. To model the U.S. turkey exports with sufficient accuracy, a description for Mexicos import demand for the U.S. turkey products is needed yet beyond the research scale of the current study. A single equation description for the U.S. turkey exports is specified as:

[1]http://www.ers.usda.gov/topics/animal-products/poultry-eggs/trade.aspx

TKEXPT = f(TKEXPT_LAG1, TKPRODRTC, TKRETPR, SHIFT10, D856, D8797089, D9010)

where TKEXPT is turkey exports, TKEXPT_LAG1 is the lagged dependent variable, TKPRODRTC is ready-to-cook turkey production, and TKRETPR is GDP deflated real turkey retail price. Based on the assumption that our trading partners will not change drastically, the lagged dependent variable can explain partially the current quantity of turkey exports. When production is high, more turkey products will be exported. Thus, both the explanatory variables are expected to have positive effects on turkey exports. Turkey selling price has a negative effect on turkey exports indicating that when domestic price is high less turkey products will be exported, and vice versa. Estimation results are presented in Table 7.2. Breusch-Godfrey test shows that there is statistically no serial correlation problem with a p-value of 0.4909.

Table 7.2: Turkey Exports

TKEXPT	Estimate	Std. Error	t value	Pr(>$\|t\|$)
(Intercept)	187.3130	432.7839	0.4300	0.6692
TKPRODRTC	0.1801	0.0382	4.7100	0.0001
TKRETPR	-573.4770	188.3658	-3.0400	0.0058
SHIFT10	401.9836	63.3313	6.3500	0.0000
D856	343.9241	52.3602	6.5700	0.0000
D8797089	146.2225	34.1161	4.2900	0.0003
D9010	-142.2840	35.2661	-4.0300	0.0005
Adjusted R-squared:		0.9655	MAPE	0.2345
Breusch-Godfrey test p-value:		0.4909	Theil's U2	1.3747

The largest proportion of the quantity demanded for turkey is turkey domestic disappearance (in million pounds), which is the product of U.S. population (in million persons) and per capita consumption (in pounds):

TKCDIS ≡ USPOP × TKPCCC

where TKCDIS is broiler civilian disappearance, USPOP is U.S. population, and TKPCCC is carcass weight per capita consumption for turkey.

Carcass weight per capita consumption for turkey is calculated from turkey retail weight per capita consumption by dividing the carcass to retail conversion factor:

TKPCCC ≡ TKPCCR ÷ 0.79

where TKPCCC is turkey carcass weight per capita consumption, TKPCCR is turkey retail weight per capita consumption, and the factor of 0.79 is calculated from the historical data series of these two variables.

Following the discussions in the methodology chapter, per capita consumption for turkey is modeled by a double-log functional form:

TKPCCR_LOG = f (TKPCCR_LOG_LAG1, FOODEXPR_LOG, TKRETPR_LOG, CKRETPR_LOG, SHIFT97, D85045, D87, D906807)

where TKPCCR_LOG is turkey per capita consumption in log form, TKPCCR_LOG_LAG1 is the lagged dependent variable, FOODEXPR_LOG is real food expenditure in log form, TKRETPR_LOG is real turkey retail price in log form, CKRETPR_LOG is real broiler retail price. Estimation results are presented in Table 7.3. Breusch-Godfrey test shows that there is statistically no serial correlation problem with a p-value of 0.7415.

Functional form with other food price index included in the explanatory variables has also been tried as listed in Table7.4, where other food price index has a negative effect on turkey consumption which contradicts with economic theory since other food and turkey are considered as substitutes for each other; also the more related broiler meat price turns insignificant under the functional specification. Removing

Table 7.3: Turkey Per Capita Consumption Without OTHFOODPR (Retail Weight)

TKPCCR_LOG	Estimate	Std. Error	t value	Pr(>$\|t\|$)
(Intercept)	0.4570	0.1921	2.3800	0.0269
TKPCCR_LOG_LAG1	0.6235	0.0416	15.0000	0.0000
FOODEXPR_LOG	0.1332	0.0561	2.3700	0.0272
TKRETPR_LOG	-0.2368	0.0427	-5.5400	0.0000
CKRETPR_LOG	0.2131	0.0548	3.8900	0.0009
SHIFT97	-0.0321	0.0093	-3.4500	0.0024
D85045	-0.0436	0.0086	-5.0500	0.0001
D87	0.0588	0.0133	4.4200	0.0002
D906807	0.0268	0.0067	3.9900	0.0007
Adjusted R-squared:		0.9857	MAPE	0.0029
Breusch-Godfrey test p-value:		0.7415	Theil's U2	0.2198

other food price index from the fitted function improves the significance level for broiler retail price and the cross elasticity with respect to broiler products. Own price elasticity is -0.24; income elasticity is 0.13; cross price elasticities with broiler is 0.21. This equation ends the description for the demand side of broiler industry.

Table 7.4: Turkey Per Capita Consumption With OTHFOODPR (Retail Weight)

TKPCCR_LOG	Estimate	Std. Error	t value	Pr(>$\|t\|$)
(Intercept)	0.1754	0.2810	0.6200	0.5390
TKPCCR_LOG_LAG1	0.7786	0.0460	16.9200	0.0000
FOODEXPR_LOG	0.1750	0.0801	2.1800	0.0399
TKRETPR_LOG	-0.1052	0.0443	-2.3700	0.0269
CKRETPR_LOG	0.0843	0.0697	1.2100	0.2392
OTHFOODPR_LOG	-0.4122	0.1241	-3.3200	0.0031
D87	0.0519	0.0147	3.5300	0.0019
D8597045	-0.0456	0.0076	-5.9700	0.0000
Adjusted R-squared:		0.9822	MAPE	0.0034
Breusch-Godfrey test p-value:		0.6344	Theil's U2	0.2494

The U.S. turkey total supply identity is:

TKSUPP ≡ TKSTK_LAG1+TKIMPT+TKPROD

where TKSTK_LAG1 is turkey beginning stock that can be recovered from turkey ending stock in the previous period, TKIMPT is U.S. turkey imports, and TKPROD is U.S. turkey production.

The U.S. turkey imports are small, accounting for less than 2 percent of domestic production according to WASDE (USDA), and it is specified as a function of turkey wholesale price:

TKIMPT=f(TKWHPR,SHIFT14,D95T00,D09)

where TKIMPT is turkey imports and TKWHPR is real turkey wholesale price. When price is high, more turkey products will be imported and vice versa. Estimation results are presented in Table 7.5. The lagged dependent variable and turkey retail price are both positively correlated with turkey imports as expected. Since data for turkey import is not available before 1994, a non-fitted functional form is used in the simulation system.

Table 7.5: Turkey Imports

TKIMPT	Estimate	Std. Error	t value	Pr(>$\|t\|$)
(Intercept)	-32.3853	5.8759	-5.5100	0.0001
TKWHPR	85.3267	10.9082	7.8200	0.0000
SHIFT14	62.3073	3.8925	16.0100	0.0000
D95T00	-10.5851	1.7229	-6.1400	0.0000
D09	10.2889	3.5854	2.8700	0.0117
Adjusted R-squared:		0.9697	MAPE	1.7445
Breusch-Godfrey test p-value:		0.8800	Theil's U2	1.6365

The main component of total turkey supply is ready-to-cook turkey production which equals total turkey production less turkey condemnation:

TKPRODRTC≡TKPROD-TKCONDM

where TKPRODRTC is ready-to-cook turkey production, TKPROD is turkey production, and TKCONDM is turkey condemnation.

Turkey condemnation is fitted as a function of total turkey production, indicating that a certain proportion of the turkey production will be disposed due to illness or management practices at the farm and the processing plant, and a trend term, representing technology improvement:

TKCONDM=f(TKPROD,YEAR,D89,D878,D9608)

where TKCONDM is turkey condemnation, TKPROD is turkey production, and YEAR is the trend term. Both coefficients presented in Table 7.6 are of expected signs.

Table 7.6: Turkey Condemnation

TKCONDM	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	549.3405	142.2868	3.8600	0.0007
TKPROD	0.0250	0.0008	31.0500	0.0000
YEAR	-0.3076	0.0729	-4.2200	0.0003
D89	-35.1591	1.7303	-20.3200	0.0000
D878	13.5041	1.3365	10.1000	0.0000
D9608	-5.0162	1.2742	-3.9400	0.0006
Adjusted R-squared:		0.9932	MAPE	0.0252
Breusch-Godfrey test p-value:		0.3182	Theil's U2	0.0461

Turkey production is explained by two factors, the number of turkeys slaughtered and the average turkey slaughter weight:

TKPROD ≡ TKSLT × TKSLW ÷ 1,000

where TKPROD is turkey production, TKSLT is the number of turkeys slaughtered, and TKSLW is the average turkey slaughter weight. Since the measurement unit for turkey production is in millions of pounds, a conversion rate of 1/ 1000 is needed.

Turkey slaughter weight is fitted as a function of trend and wholesale price to feed cost ratio:

TKSLW = f (YEAR, TKWHP_FEED, D85T00, D912, D9905)

where TKSLW is average turkey slaughter weight, YEAR is trend, and TKWHP_FEED is the ratio of turkey wholesale price over turkey feed cost. The trend term is used to represent technology improvement, the turkey wholesale price and turkey feed cost are used to represent revenue and cost for raising turkeys respectively. Both variables should have positive effects on the dependent variable. Estimation results are presented in Table 7.7.

Table 7.7: Average Turkey Slaughter Weight

TKSLW	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-574.4109	19.0600	-30.1400	0.0000
YEAR	0.2970	0.0094	31.5500	0.0000
TKWHP_FEED	5.8233	1.9142	3.0400	0.0056
D85T00	-0.5776	0.1288	-4.4800	0.0002
D912	-0.3963	0.1305	-3.0400	0.0057
D9905	0.3382	0.1269	2.6600	0.0136
Adjusted R-squared:		0.9963	MAPE	0.0065
Breusch-Godfrey test p-value:		0.5224	Theil's U2	0.4382

The number of turkeys slaughtered is fitted as a function of the lagged dependent variable representing the beginning production capacity and the number of turkey poults placed on feed:

TKSLT=f(TKSLT_LAG1,TKPLACE,SHIFT09,D0813,D9506714,D90089)

where TKSLT is the number of turkeys slaughtered, TKSLT_LAG1, is the lagged dependent variable, and TKPLACE is the number of turkey poults placed on feed. Estimation results are listed in Table 7.8. The number of turkeys slaughtered is positively related to both the lagged dependent variable and the number of turkey poults placed on feed as expected. Breusch-Godfrey test shows that there is statistically no serial correlation problem with a p-value of 0.9013.

Table 7.8: The Number of Turkeys Slaughtered

TKSLT	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	2938.8127	5440.4181	0.5400	0.5940
TKSLT_LAG1	0.2235	0.0348	6.4200	0.0000
TKPLACE	0.6898	0.0407	16.9300	0.0000
SHIFT09	-4296.5345	1260.4597	-3.4100	0.0023
D0813	5749.5671	1915.3071	3.0000	0.0062
D9506714	-6428.0784	1457.8104	-4.4100	0.0002
Adjusted R-squared:		0.9904	MAPE	0.0066
Breusch-Godfrey test p-value:		0.9013	Theil's U2	0.1655

The number of turkey poults placed on feed is fitted as a function of the lagged dependent variable and the number of turkey hatching eggs set in incubators.

TKPLACE=f(TKPLACE_LAG1,TKEGGSET,SHIFT06,D85813,D90089)

where TKPLACE is the number of turkey poults placed on feed, TKPLACE_LAG1 is the lagged dependent variable representing the beginning production capacity, and TKEGGSET is the number of turkey hatching eggs set in incubators. Estimation results are provided in Table 7.9. The number of turkey poults placed on feed is positively related to the number of turkey hatching eggs set in incubators as expected. Breusch-Godfrey test shows that there is statistically no serial correlation problem with a p-value of 0.2041.

Table 7.9: The Number of Turkey Pouts Placed on Feed

TKPLACE	Estimate	Std. Error	t value	Pr(>$\|t\|$)
(Intercept)	35129.0767	5544.3934	6.3400	0.0000
TKPLACE_LAG1	0.1815	0.0277	6.5500	0.0000
TKEGGSET	0.5466	0.0268	20.3900	0.0000
SHIFT06	9699.0973	1208.6175	8.0200	0.0000
D85813	-12182.5099	1739.0438	-7.0100	0.0000
D90089	-7604.1950	1559.6323	-4.8800	0.0001
Adjusted R-squared:		0.9922	MAPE	0.0064
Breusch-Godfrey test p-value:		0.2041	Theil's U2	0.1395

Data for the number of turkey poults hatched, which is the production stage in between of turkey hatching eggs set in incubators and turkey poults placed on feed, is not available and thus the production stage of the number of turkey poults hatched is not included in the simulation system.

Turkey hatching eggs set in incubators is fitted as a function of the lagged dependent variable, real turkey wholesale price, and real turkey feed cost:

TKEGGSET=f(TKEGGSET_LAG1,TKWHPR,TKFEEDR,D98)

where TKEGGSET is the number of turkey hatching eggs set in incubators, TKEGGSET_LAG1 is the lagged dependent variable representing the beginning production capacity, TKWHPR is GPD deflated real turkey wholesale price representing the revenue for raising turkeys, and TKFEEDR is GPD deflated real turkey feed cost representing the cost for raising turkeys. Estimation results are presented in Table 7.10. All the estimated coefficients have the expected sign. Breusch-Godfrey test shows that there is statistically no serial correlation problem with a p-value of 0.6933. No data is available for production stages prior to turkey hatching eggs set in incubators, and thus this ends the description for turkey production.

Table 7.10: The Number of Turkey Hatching Eggs Set in Incubators

TKEGGSET	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	34834.7720	49048.1980	0.7100	0.4841
TKEGGSET_LAG1	0.9002	0.0867	10.3800	0.0000
TKWHPR	87009.6725	42221.2470	2.0600	0.0499
TKFEEDR	-11325.7724	3988.2551	-2.8400	0.0088
D98	-31821.8045	14784.4871	-2.1500	0.0412
Adjusted R-squared:		0.8668	MAPE	0.0277
Breusch-Godfrey test p-value:		0.6933	Theil's U2	0.6534

Turkey hen price is fitted as a function of turkey wholesale price:

TKHENP = f (TKWHP, D99T05, D11T14, D96)

where TKHENP is turkey hen price and TKWHP is turkey wholesale price. Estimation results are presented in Table 7.11.

Following the same reasoning logic as the pork wholesale price, nominal turkey wholesale price is fitted as a function of the turkey retail price and grocery store labor cost:

TKWHP=f(TKRETP,LBCPGS,D87039,D07814,D01213,D06)

where TKWHP is turkey wholesale price, TKRETP is turkey retail price, and LBCPGS is grocery store labor cost. Estimation results are presented in Table 7.12.

Table 7.11: Turkey Hen Price

TKHENP	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	14.8643	1.0548	14.0900	0.0000
TKWHP	1.2335	0.0236	52.1600	0.0000
D99T05	4.1827	0.3490	11.9800	0.0000
D11T14	2.6514	0.7400	3.5800	0.0014
D96	-1.7745	0.7695	-2.3100	0.0297
Adjusted R-squared:		0.9972	MAPE	0.0079
Breusch-Godfrey test p-value:		0.4659	Theil's U2	0.1368

Functions are estimated using data from 1987 to 2014 and a non-fitted functional form is used in the simulation system because no grocery store labor cost data are available for the years 1985 and 1986.

Table 7.12: Turkey Wholesale Price

TKWHP	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-8.6357	1.3603	-6.3500	0.0000
TKRETP	0.5220	0.0191	27.3100	0.0000
LBCPGS	-0.0001	0.0000	-2.2300	0.0366
D87039	-7.7127	0.8157	-9.4500	0.0000
D067814	5.0615	0.8510	5.9500	0.0000
D01213	-4.7601	0.8611	-5.5300	0.0000
Adjusted R-squared:		0.9874	MAPE	0.0206
Breusch-Godfrey test p-value:		0.2404	Theil's U2	0.3119

Turkey Grower Feed Cost is used to represent the feed cost for the turkey industry. It is fitted as a function of the lagged dependent variable and a weighted corn and soybean meal price, which represents feed conversion efficiency and feed ingredient costs, respectively:

$$\text{TKFEED} = \text{f}\ (\text{TKFEED\_LAG1, TKMIXFEED, D8595103, D89907, D960458})$$

where TKFEED is turkey industry feed cost, TKMIXFEED is the weighted average of corn and soybean meal prices. Estimation results are presented in Table 7.13. Both estimated coefficients have the correct sign. Improvement in feed conversion rate is represented by the less than one coefficient of the lagged dependent variable. Breusch-Godfrey test shows that there is statistically no serial correlation problem with a p-value of 0.2844.

Table 7.13: Turkey Industry Feed Cost

TKFEED	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-17.9647	4.2173	-4.2600	0.0003
TKFEED_LAG1	0.6661	0.0283	23.5300	0.0000
TKMIXFEED	18.6851	1.0367	18.0200	0.0000
D8595103	-38.9987	3.9845	-9.7900	0.0000
D89907	-19.7401	4.3781	-4.5100	0.0001
D960458	22.9866	3.9461	5.8300	0.0000
Adjusted R-squared:		0.9966	MAPE	0.0177
Breusch-Godfrey test p-value:		0.2844	Theil's U2	0.2132

The weighted corn and soybean meal costs in the turkey industry feed cost function is based on 51 percent corn price, 28 percent soybean meal price, and 21 percent wheat price with unit adjustment[2]:

$$\text{TKMIXFEED} \equiv 100 \times (0.51 \times \frac{\text{CORNPCY}}{56} + 0.28 \times \frac{\text{SBMPCY}}{2000} + 0.21 \times \frac{\text{WHEATPCY}}{60})$$

where TKMIXFEED is the weighted corn and soybean meal prices, CORNPCY is calendar year annual average corn price, SBMPCY is calendar year annual average soybean meal price, and WHEATPCY is calendar year annual average wheat price. This equation ends the description for the turkey supply side.

[2]In USDA Agricultural Projections to 2024 (USDA 2015), turkey feed price is comprised of 51 percent corn price, 28 percent soybean price, and 21 percent wheat price.

All fitted equations have acceptable adjusted R-squares. Mean absolute percentage error (MAPE) and Theils U2 indicating the forecasting ability of the model specifications are at a satisfactory scale except for the case of turkey imports and turkey exports where the historical data used to estimate the functional form increased drastically as time passes. Breusch-Godfrey tests are all passed with p-values greater than 0.1 for the functions with the lagged dependent variable included in the explanatory variables. Estimated own price elasticity of demand are more inelastic than the estimated elasticities in literature listed in Table 7.14. One reason to explain the difference is that the previous studies used data prior to 1990 while consumer preferences for poultry products changed recently. Turkey industry 2015 to 2024 projections are listed in Table 7.17. Also listed in Table 7.17 are USDA and FAPRI projections for the purpose of comparison. The short-run (year 2015) and long-run (year 2019) supply elasticities are calculated as:

$$e_{TURKEY,SR} = \frac{(6044 - 5976)/5976}{10\%} = 0.114 \tag{7.1}$$

$$e_{TURKEY,LR} = \frac{(6398 - 6358)/6358}{10\%} = 0.064 \tag{7.2}$$

Table 7.14: Estimates of Turkey Demand Elasticities From Literature

Own Price Elasticity	Cross Price Elasticity with Broiler	Study	Data	Period	Model Specification
-0.680	-0.170	Huang (1985)	Annual	1953 to 1983	Differential-form Demand System
-1.332	3.968	Buhr (1993)	Quarterly	1973-1989	Approximate Almost Ideal Inverse Demand System
-0.535	-0.077	Huang (1993)	Annual	1953 to 1990	Differential-form Demand System
-0.240	**0.210**	**This Study**	**Annual**	**1985-2014**	**Double-log**

Table 7.15: Egg Industry 2015-2024 Projections

		2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Production	USDA	5,739	5,925	6,041	6,162	6,280	6,371	6,464	6,540	6,615	6,692	6,773
	FARPRI	5,739	6,001	6,155	6,280	6,349	6,384	6,417	6,470	6,533	6,607	6,680
	Current Study, No Shock	5,739	5,976	6,066	6,157	6,254	6,358	6,470	6,594	6,732	6,882	7,045
	Current Study, With Shock	5,739	6,044	6,135	6,217	6,304	6,398	6,503	6,621	6,754	6,900	7,060
Exports	USDA	799	820	825	830	835	840	845	850	860	870	880
	FARPRI	799	814	830	842	854	870	888	906	924	942	960
	Current Study, No Shock	799	814	841	862	883	907	931	958	989	1,023	1,062
	Current Study, With Shock	799	840	859	880	898	919	941	966	995	1,029	1,066
Retail Price	FARPRI	163	162	159	158	160	163	167	170	172	174	176
	Current Study, No Shock	160	165	164	167	170	172	175	178	180	181	183
	Current Study, With Shock	160	157	164	166	169	172	174	177	179	181	182
Ending Stocks	USDA	215	275	300	300	300	300	300	300	300	300	300
	FARPRI	200	248	268	282	289	292	295	299	304	310	316
	Current Study, No Shock	200	253	260	262	265	268	272	276	281	286	292
	Current Study, With Shock	200	243	262	265	268	270	274	277	282	287	293
Turkey Hen Price	USDA	107.6	106.5	107	105.7	103.7	102.1	99.9	98.7	99.3	100.4	102.3
	FARPRI	107.6	101.9	95.9	93.3	93.6	95.4	97.5	98.9	99.7	100.0	100.4
	Current Study, No Shock	108	101	100	102	103	104	106	107	108	109	110
	Current Study, With Shock	108	110	100	101	102	104	105	107	108	109	110

Table 7.15: Continued

		2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Per Capita Consumption	USDA	15.7	15.8	16.2	16.5	16.7	16.8	17.0	17.1	17.2	17.3	17.3
	FARPRI	15.7	16.1	16.5	16.7	16.8	16.7	16.6	16.6	16.6	16.6	16.7
	Current Study, No Shock	15.7	15.9	16.1	16.2	16.3	16.4	16.5	16.7	16.9	17.1	17.3
	Current Study, With Shock	15.7	16.1	16.2	16.3	16.4	16.5	16.6	16.8	16.9	17.1	17.3
Civillian Disappearance	USDA	4,991	5,073	5,219	5,360	5,473	5,559	5,647	5,718	5,783	5,850	5,920
	Current Study, No Shock	4,991	5,112	5,219	5,294	5,365	5,443	5,528	5,622	5,725	5,836	5,955
	Current Study, With Shock	4,991	5,169	5,256	5,331	5,399	5,471	5,551	5,640	5,740	5,848	5,965

The applied shock is a 10 percent increase in 2015 turkey wholesale price

8. AN EVALUATION OF THE 2015 OUTBREAK OF AVIAN INFLUENZA IN THE U.S.

This chapter of the study focuses on the evaluation of the effects of the 2015 highly pathogenic avian influenza (HPAI) outbreak on the U.S. poultry and egg industries. Avian influenza (AI) is caused by avian influenza viruses that occur naturally among wild aquatic birds worldwide and can infect domestic poultry and other bird and animal species. The symptoms of AI mainly include internal bleeding and diarrhea in poultry (Ishida et al 2010). According to Mu et al. (2015), highly pathogenic AI spreads rapidly with a high mortality rate among infected birds (up to 90%100% within 48 hours) and can spread to humans. In the effort of controlling the spread of AI, a large number of infected flocks are removed and international trade is restricted.

Brown et al (2007) studied the effects of two hypothetical HPAI outbreaks, the 8-county outbreak scenario and the 4-state outbreak scenario, by assuming a certain percentage decrease in production and exports according to the historical data. In this study, the actual changes in 2015 poultry and egg production and trade published by USDA will be used to shock the model; the lasting effects of the AI outbreak are examined by comparing the 10-year projection results for production, exports, prices, and per capita consumption for broiler, turkey, egg, and the related pork industry with their baseline scenario projections.

USDA 2015 projections for productions and exports of the poultry and egg industries before and after the AI outbreak are listed in Table 8.1[1]. According to Livestock,

[1]Source for projections before AI: USDA Agricultural Projections to 2024 (USDA, February 2015); Source for projections after AI: World Agricultural Supply and Demand Estimates (USDA, February 2016).

Dairy, and Poultry Outlook (USDA June 16, 2015), the most affected flocks have been the turkey and table egg layers located in Midwestern States. Projections for turkey production and egg production decreased 5 percent and 6.3 percent, respectively. The primary impact for the broiler industry has been on broiler product exports. Projections for broiler, turkey, and egg exports decreased 15.5 percent, 35 percent, and 10.5 percent respectively. Since reductions in both the number of table egg layers and table egg layers laying rate have been reported[2], the decrease of egg production will be attributed to the reduction of these two factors equally, each with 3.2 percent.

Table 8.1: Actual Shocks on the Poultry and Egg Industries due to the 2015 AI Outbreak

		Broiler	**Turkey**	**Egg**
		Million Lbs	Million Lbs	Million Dozen
Production	Projection Before AI	39630	5925	8430
	Projection After AI	39614	5628	7896
	Percentage Change	-0.04%	-5.01%	-6.33%
Export	Projection Before AI	7480	820	355
	Projection After AI	6319	533	317.6
	Percentage Change	-15.52%	-35.00%	-10.54%

The effect of the AI outbreak on consumer preference for meat products has been analyzed in several studies. Beach and Zhen (2008) studied the Italian consumers response to AI outbreak and concluded that media coverage of AI outbreak either in Italy or in the rest of the world has net negative effects for fresh and frozen poultry and net positive effects on beef and pork consumptions. Ishida et al (2010) investigated the impact of BSE and AI outbreak on Japanese consumers demand for

[2]Livestock, Dairy, and Poultry Outlook (USDA, January 2016, November 2015, October 2015).

Table 8.2: Shocks Applied to the Poultry and Egg Industries Due to the 2015 AI Outbreak

	Year	Broiler	Turkey	Table Egg Laying Rate	Table Egg Layers
Production	2015	0.0%	-5.0%	-3.2%	-3.2%
	2016	0.0%	0.0%	0.0%	-1.6%
Export	2015	-15.5%	-35.0%	-10.5%	
	2016	0.0%	0.0%	0.0%	
Import	2015	0.0%	0.0%	70 Million Dozen	

meat. For an AI outbreak, negative effects on the demand for chicken were found; and the estimated impact of the AI outbreak lasted for 6 months. However, studies for the U.S. consumers response to AI outbreak found different opinions. The study of Piggott and Marsh (2004) found that the average consumers response to food safety events is small; and even though there existed larger responses corresponding with prominent food safety events, they were short-lived with no lagged effects. Mu et al (2015) studied the effects of the AI outbreak on domestic beef, pork, and broiler demand; the number of confirmed human deaths by WHO significantly affects the consumers preferences, yet the AI outbreak itself did not have a statistically significant effect on the U.S. consumers demand for broiler or pork. Also since there is no effect of the AI outbreak on domestic consumers preference for poultry and eggs has been reported in Livestock, Dairy, and Poultry Outlook (USDA, Feb 2015 to Jan 2016), we follow Brown (2007) in this study and make the assumption that there are no adverse or cross effects from the 2015 AI outbreak on domestic demand for meat.

Production shocks for egg and turkey sectors as well as trade shocks for egg, turkey, and broiler sectors that were generated according to USDA publications are described in Table 8.2 and referred to as Scenario 1. An assumption of 1.6 percent

Table 8.3: Effects of the 2015 AI Outbreak on the U.S. Broiler Industry

	2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Broiler Production, Ready-to-cook (Million lbs.)										
Baseline	38,846	39,763	40,581	41,315	42,009	42,686	43,373	44,075	44,783	45,508
Scenario 1	38,596	39,473	40,287	41,038	41,762	42,474	43,195	43,927	44,660	45,406
Change	-250	-290	-294	-277	-247	-212	-178	-148	-122	-102
% Change	-0.6	-0.7	-0.7	-0.7	-0.6	-0.5	-0.4	-0.3	-0.3	-0.2
Broiler Exports (Million lbs.)										
Baseline	7,336	7,487	7,673	7,861	8,031	8,183	8,311	8,428	8,541	8,653
Scenario 1	6,199	6,740	7,158	7,491	7,757	7,974	8,148	8,300	8,439	8,572
Change	-1,137	-747	-515	-370	-274	-209	-163	-128	-102	-82
% Change	-15.5	-10.0	-6.7	-4.7	-3.4	-2.6	-2.0	-1.5	-1.2	-0.9
Broiler Retail Price (Cents/lb.)										
Baseline	202	200	201	203	206	210	214	218	222	226
Scenario 1	192	195	199	202	206	210	214	218	222	226
Change	-10	-6	-2	-1	0	0	0	0	0	0
% Change	-5.0	-2.8	-1.2	-0.5	-0.1	0.0	0.1	0.1	0.1	0.1
Broiler Per Capita Consumption (Lbs.)										
Baseline	84.4	85.8	86.9	87.6	88.3	89.0	89.8	90.6	91.4	92.3
Scenario 1	86.7	87.1	87.5	87.9	88.4	89.0	89.7	90.5	91.4	92.2
Change	2.3	1.2	0.6	0.2	0.1	0.0	0.0	-0.1	-0.1	-0.1
% Change	2.7	1.5	0.7	0.3	0.1	0.0	0.0	-0.1	-0.1	-0.1
Broiler Ending Stocks (Million lbs.)										
Baseline	723	756	779	796	809	820	830	841	852	865
Scenario 1	751	768	781	793	804	816	825	837	849	862
Change	28	12	2	-3	-4	-5	-4	-4	-3	-3
% Change	3.9	1.6	0.2	-0.3	-0.5	-0.6	-0.5	-0.5	-0.4	-0.3

decrease in the number of table egg layers in 2016 is made because of the longer production cycle for table eggs compared to broilers. Since 90 percent of the laying flock reaches peak egg production at an age of 30 to 32 weeks, the reduction in the number of table egg layers in 2015 may last to 2016 but with a smaller scale. Also a shock of 70 million dozen increase in 2015 egg imports was added to incorporate the WASDE forecast since the estimated system cannot forecast the egg imports that high; in other words, a dummy variable were needed if we include year 2015 in our study period. Simulation results are listed through Tables 8.3 to Table 8.6.

For the broiler industry, since there is no production shock and exports have been reduced by a substantial amount (15.5 percent), significant decreases in prices and increases in ending stocks and per capita consumption are expected. Simulation results are listed in Table8.3 and confirm our expectation. Broiler production is reduced less than 1 percent in all years. Broiler exports decrease by 1137 million pounds in 2015, which leads to the decrease in broiler retail price of 10 cents per pound. Broiler per capita consumption increases by 2.3 pounds and ending stocks increase by 28 million pounds. The drop in broiler exports decreases to 747 million pounds in 2016, which is 10 percent of the baseline projection. And the impact continually diminishes over time; by 2024 broiler exports is only 0.9 percent lower than the baseline projection. As a result broiler retail price and per capita consumption return back to the baseline level in 5 years (with the differences fluctuate within 1 percent of the baseline projection).

Figure 8.1 depicts the domestic market and the international trade for the U.S. broiler industry. S_0 is broiler production (ready-to-cook), DD is broiler domestic disappearance, Q_0 is broiler total quantity demanded (sum of exports and domestic consumption). The 2015 AI outbreak decreases the demand for broiler meat from the trade partners, reflected in Figure 8.1 by the shift of D_{T0} to D_{T1}, and thus

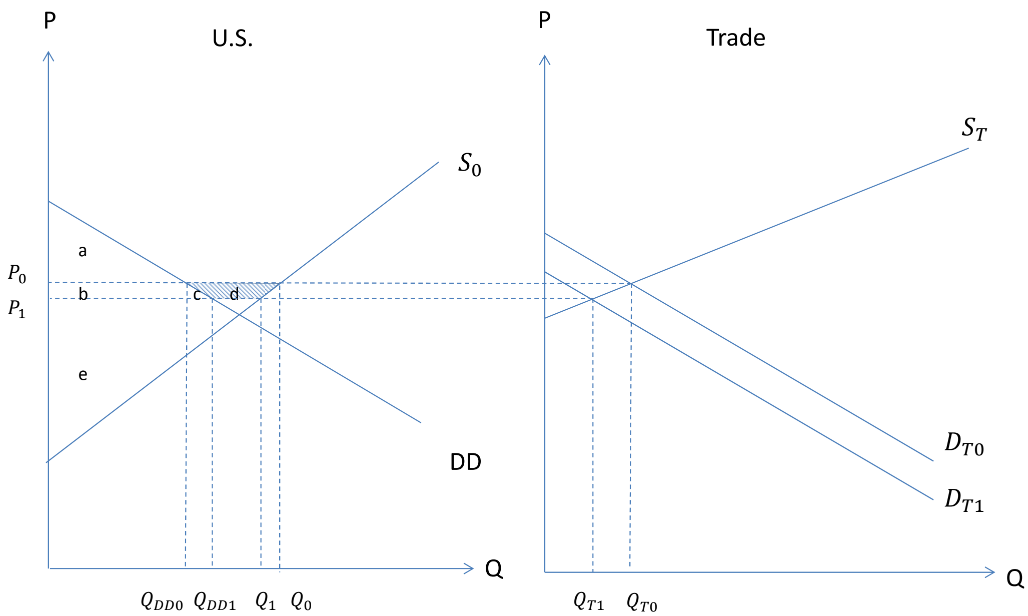


Figure 8.1: The U.S. Broiler Industry under AI Shock

the equilibrium broiler wholesale price drops from P_0 to P_1. The change in welfare (ΔWelfare) induced by the AI outbreak is -\$516.86 million, calculated by comparing the original consumer surplus (CS_0) and producer surplus (PS_0) and the new consumer surplus (CS_1) and producer surplus (PS_1).

$$\begin{aligned} CS_0 &= a \\ PS_0 &= b + c + d + e \\ CS_1 &= a + b + c \\ PS_1 &= e \end{aligned} \tag{8.1}$$

$$
\begin{aligned}
\Delta\text{Welfare} &= -d \\
&= -[(Q_0 - Q_{DD0}) + (Q_1 - Q_{DD1})] \times (P_0 - P_1) \div 2 \\
&= -[(38846 - 31580) + (38596 - 32437)] \times (89.6 - 81.9) \div 2 \\
&= -51,686 \text{million cents}
\end{aligned} \tag{8.2}
$$

For the egg industry, a greater reduction in production than exports causes prices and imports to be much higher and per capita consumption is expected to be lower than baseline projections. Simulation results are listed in Table 8.4 and confirm our expectation.

2015 reduction in egg production is 487 million dozens; this number decreases to 125 million dozens in 2016 and keeps diminishing over time. By 2024, the reduction in egg production is only 12 million dozens, which is 0.1 percent of the baseline projection. 2015 egg exports decrease by 39 million dozens. The impact on egg exports vanishes much more slowly than on egg production: by 2020, the amount of egg exports is still 5.6 percent lower than the baseline projection; by 2024, the difference drops to 2.3 percent. Egg wholesale price increases by 81 cents per dozen in 2015, which is 75.8 percent higher than the baseline projection; 2016 egg wholesale price is projected to be 15.2 percent higher than the baseline projection; it takes six years for the price to return to the baseline level (with the difference fluctuating within 1 percent of the baseline projection). 2015 domestic consumption decreases by 13.2 eggs per person. This cut in consumption recovers quickly after the shock: 2016 per capita consumption is 3.1 eggs (1.2 percent) less than the baseline projection; 2017 per capita consumption is only 0.6 percent less than the baseline projection and the difference is kept within 1 percent from then on.

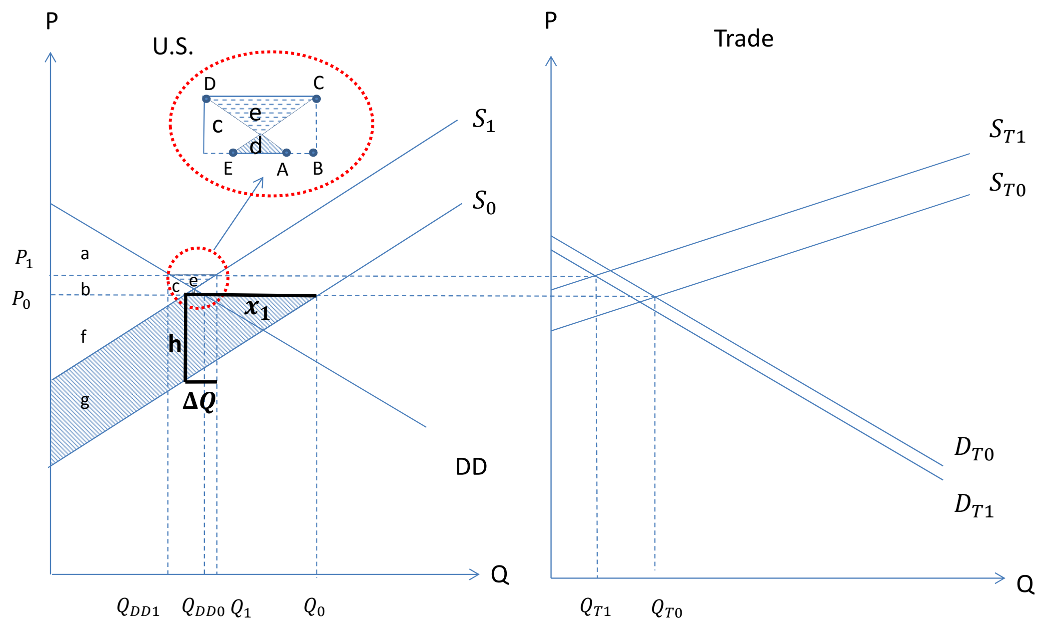


Figure 8.2: The U.S. Egg Industry under AI Shock

Table 8.4: Effects of the 2015 AI Outbreak on the U.S. Egg Industry

	2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Egg Production (Million dozens)										
Baseline	8,407	8,514	8,615	8,713	8,813	8,913	9,015	9,121	9,228	9,337
Scenario 1	7,920	8,390	8,529	8,654	8,770	8,881	8,990	9,101	9,211	9,325
Change	-487	-125	-86	-59	-43	-32	-25	-19	-17	-12
% Change	-5.8	-1.5	-1.0	-0.7	-0.5	-0.4	-0.3	-0.2	-0.2	-0.1
Egg Exports (Million dozens)										
Baseline	375	361	351	344	339	335	332	330	329	329
Scenario 1	336	322	317	315	315	316	317	318	320	321
Change	-39	-38	-34	-29	-23	-19	-15	-12	-9	-8
% Change	-10.4	-10.7	-9.7	-8.4	-6.9	-5.6	-4.4	-3.5	-2.8	-2.3
Egg Wholesale Price (Cents/dozen)										
Baseline	107	104	104	105	106	107	108	109	110	111
Scenario 1	187	120	113	110	109	109	109	110	111	112
Change	81	16	8	5	2	1	1	1	0	1
% Change	75.8	15.2	8.1	4.7	2.3	1.2	0.5	0.7	0.2	0.9
Egg Per Capita Consumption (Eggs)										
Baseline	264.2	266.3	267.9	269.6	271.0	272.5	274.0	275.6	277.2	278.9
Scenario 1	251.0	263.2	266.3	268.6	270.5	272.2	273.9	275.4	277.1	278.7
Change	-13.2	-3.1	-1.7	-1.0	-0.5	-0.3	-0.1	-0.1	0.0	-0.2
% Change	-5.0	-1.2	-0.6	-0.4	-0.2	-0.1	0.0	-0.1	0.0	-0.1
Egg Ending Stocks (Million dozens)										
Baseline	24	25	25	26	27	28	28	29	30	31
Scenario 1	18	23	25	26	27	27	28	29	30	31
Change	-5	-1	-1	-1	0	0	0	0	0	0
% Change	-23.0	-5.2	-3.2	-2.1	-1.3	-0.9	-0.7	-0.5	-0.4	-0.4

Figure 8.2 depicts the domestic market and the international trade for the U.S. egg industry. The 2015 AI outbreak decreases the production of egg from S_0 to S_1, DD is domestic disappearance of egg, Q_0 is total quantity demanded for egg (sum of exports and domestic consumption). The 2015 AI outbreak decreases the demand for egg from the trade partners, reflected in Figure 8.2 by the shift of D_{T0} to D_{T1}. Decrease in egg exports is less than the decrease in egg production, as a result the equilibrium egg wholesale price increases from P_0 to P_1. The change in welfare (ΔWelfare) induced by the AI outbreak is -\$6328.21 million, calculated by comparing the original consumer surplus (CS_0) and producer surplus (PS_0) and the new consumer surplus (CS_1) and producer surplus (PS_1)[3].

$$\begin{aligned} CS_0 &= a + b + c + d \\ PS_0 &= f + g \\ CS_1 &= a \\ PS_1 &= b + c + e + f \\ \Delta\text{Welfare} &= -g - d + e \end{aligned} \tag{8.3}$$

$$\begin{aligned} &\frac{\Delta Q}{Q_1} \times \frac{P_1}{P_1 - P_0} = \epsilon_{EGG} = 0.14 \\ &\Rightarrow \Delta Q = 0.14 \times 7920 \times (187 - 107) \div 187 = 478.11 \\ &\Rightarrow x_1 = \Delta Q + Q_0 - Q_1 = 478.11 + 8407 - 7902 = 965.44 \end{aligned} \tag{8.4}$$

[3]Egg supply elasticity, ϵ_{EGG}, is approximated by shocking egg wholesale price by 20 percent and dividing the percentage change in egg production by this 20 percent change in price.

$$
\begin{aligned}
&\frac{x_1}{Q_0} \div \frac{h}{P_0} = \epsilon_{EGG} \\
&\Rightarrow h = \frac{1}{0.14} \times \frac{965.44}{8407} \times 107 = 87.7 \\
&\Rightarrow \text{Area}_g = h \times (Q_1 - \Delta Q) + \frac{1}{2} \times h \times x_1 = 695,536.7
\end{aligned}
\tag{8.5}
$$

$$\text{Area}_e - \text{Area}_d = \text{Area}_{ABCD} - \text{Area}_{EBC}$$

$$
\begin{aligned}
&\text{Area}_{ABCD} = \frac{1}{2}(AB + CD) \times (P_1 - P_0) \\
&= \frac{1}{2}[(Q_1 - Q_{DD0}) + (Q_1 - Q_{DD1})] \times (P_1 - P_0) \\
&\Rightarrow \text{Area}_{ABCD} = \frac{1}{2} \times [(7920 - 7073) + (7920 - 6721)] \times (187 - 107) = 81840
\end{aligned}
\tag{8.6}
$$

$$
\begin{aligned}
&\text{Area}_{EBC} = \frac{1}{2}\Delta Q \times (P_1 - P_0) \\
&= \frac{1}{2} \times 478.11 \times (187 - 107) = 19124.4 \\
&\Rightarrow \Delta\text{Welfare} = -g - d + e = -632,821.1\text{million cents}
\end{aligned}
$$

For the turkey industry, the 2015 reduction in ready-to-cook turkey production (291 million pounds) is at a similar level as the reduction in turkey exports (285 million pounds); however, the spill-over effects from the broiler industry causes the decrease in retail price and per capita consumption for turkey. Simulation results are listed in Table 8.5 and confirm our expectation.

The 2015 turkey retail price decreases by 9 cents per pound and domestic consumption is maintained around the before-shock level. Turkey production recovers from the AI shock gradually and by 2019 the decrease in turkey production is within

Table 8.5: Effects of the 2015 AI Outbreak on the U.S. Turkey Industry

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Turkey Production, Ready-to-cook (Million lbs.)										
Baseline	5,896	5,985	6,074	6,169	6,270	6,380	6,501	6,636	6,782	6,942
Scenario 1	5,606	5,910	6,005	6,110	6,222	6,341	6,470	6,611	6,763	6,926
Change	-291	-75	-69	-59	-49	-40	-32	-25	-19	-15
% Change	-4.9	-1.3	-1.1	-1.0	-0.8	-0.6	-0.5	-0.4	-0.3	-0.2
Turkey Exports (Million lbs.)										
Baseline	814	841	862	883	907	931	958	989	1,023	1,062
Scenario 1	529	761	826	861	890	919	948	981	1,017	1,057
Change	-285	-80	-36	-22	-16	-12	-10	-8	-6	-5
% Change	-35.0	-9.6	-4.2	-2.5	-1.8	-1.3	-1.0	-0.8	-0.6	-0.5
Turkey Retail Price (Cents/lb.)										
Baseline	165	164	167	170	172	175	178	180	181	183
Scenario 1	156	158	169	171	173	176	178	180	182	183
Change	-9	-6	1	2	1	1	1	1	1	0
% Change	-5.6	-3.7	0.7	0.9	0.6	0.5	0.4	0.3	0.3	0.2
Turkey Per Capita Consumption (Lbs.)										
Baseline	15.9	16.1	16.2	16.3	16.4	16.5	16.7	16.9	17.1	17.3
Scenario 1	15.9	16.1	16.1	16.2	16.3	16.5	16.6	16.8	17.0	17.3
Change	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	0.0
% Change	-0.2	0.0	-0.5	-0.7	-0.6	-0.5	-0.4	-0.3	-0.2	-0.2
Turkey Ending Stocks (Million lbs.)										
Baseline	253	260	262	265	268	272	276	281	286	292
Scenario 1	252	263	259	262	266	270	274	279	285	291
Change	-1	3	-3	-3	-3	-2	-2	-1	-1	-1
% Change	-0.5	1.1	-1.3	-1.2	-0.9	-0.7	-0.6	-0.5	-0.4	-0.3

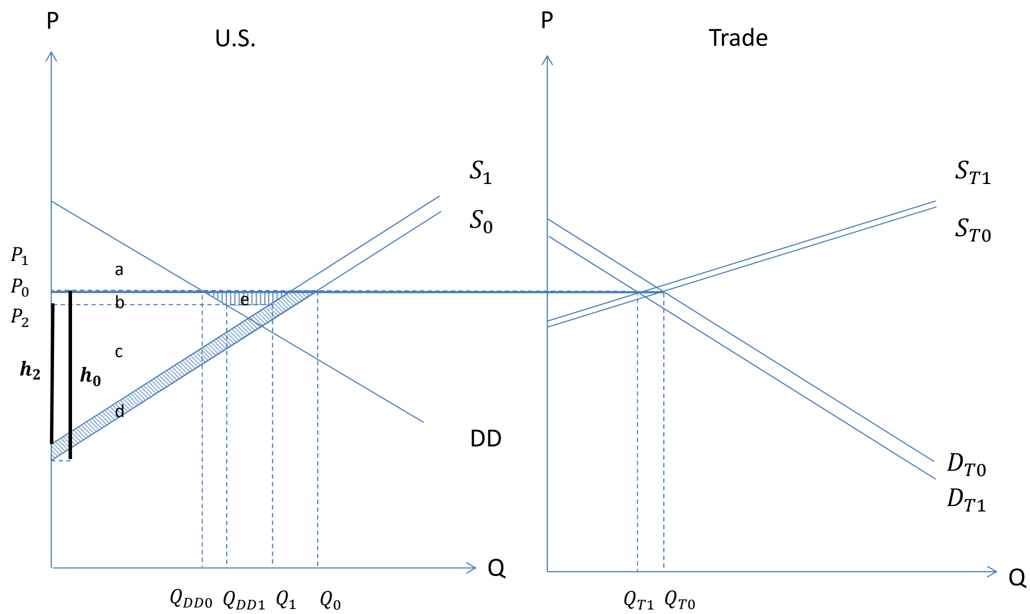


Figure 8.3: The U.S. Turkey Industry under AI Shock

1 percent of the baseline projection. By 2024 the decrease in turkey production is 0.2 percent of the baseline projection. The AI impact on turkey exports also vanishes over time: comparing the 285 million pounds drop in 2015, the decrease in 2016 turkey exports is only 80 million pounds (9.6 percent of the baseline projection) and by 2021 the amount of turkey exports is 1 percent lower than the baseline projection, and remains as close to the baseline projection thereafter. Starting from 2017, turkey retail price is higher than the baseline projection. The primary reason is that the decrease in turkey production is now greater than the decrease in turkey exports and thus price needs to rise to clear the market. The secondary reason is that the decrease in broiler retail price is now only 2 cents per pound lower than the baseline projection, and less increase in consumer demand for turkey is induced.

Figure 8.3 depicts the domestic market and the international trade for the U.S. turkey industry. The 2015 AI outbreak decreases the production of turkey from S_0

to S_1, DD is domestic disappearance of turkey, Q_0 is total quantity demanded for turkey (sum of exports and domestic consumption). The 2015 AI outbreak decreases the demand for turkey from the trade partners, reflected in Figure 8.3 by the shift of D_{T0} to D_{T1}. Decrease in turkey exports is at the similar level as the decrease in turkey production. As a result the equilibrium turkey wholesale price tends to remain around the pre-outbreak level P_0. However, the big decrease in broiler price (10 cents per pound for broiler retail price) and the significant turkey-broiler cross price elasticity of the demand for turkey products (0.21) drags the equilibrium price down to P_2. The change in welfare (ΔWelfare) induced by the AI outbreak is -$269.24 million, calculated by comparing the original consumer surplus (CS_0) and producer surplus (PS_0) and the new consumer surplus (CS_1) and producer surplus (PS_1)[4].

$$\begin{aligned} CS_0 &= a \\ PS_0 &= b + c + d + e \\ CS_1 &= a + b \\ PS_1 &= c \\ \Delta\text{Welfare} &= -(d + e) \end{aligned} \tag{8.7}$$

$$\begin{aligned} &\frac{Q_1}{h_2} \times \frac{P_2}{Q_1} = \epsilon_{TURKEY} = 0.457 \\ &\Rightarrow h_2 = \frac{1}{\epsilon_{TURKEY}} \times P_2 = \frac{1}{0.457} \times 65.02 = 142.3 \\ &\Rightarrow x_1 = \Delta Q + Q_0 - Q_1 = 478.11 + 8407 - 7902 = 965.44 \end{aligned} \tag{8.8}$$

[4]Turkey supply elasticity, ϵ_{TURKEY}, is approximated by shocking turkey wholesale price by 20 percent and dividing the percentage change in turkey production by this 20 percent change in price.

$$
\begin{aligned}
&\frac{Q_0}{h_0} \times \frac{P_0}{Q_0} = \epsilon_{TURKEY} = 0.457 \\
&\Rightarrow h_0 = \frac{1}{\epsilon_{TURKEY}} \times P_0 = \frac{1}{0.457} \times 69.76 = 152.7
\end{aligned} \tag{8.9}
$$

$$
\begin{aligned}
\text{Area}_b &= \frac{1}{2}(Q_{DD0} + Q_{DD1}) \times (P_0 - P_2) \\
&= \frac{1}{2} \times (5112 + 5105) \times (69.76 - 65.02) = 24214.3 \\
\text{Area}_{d+e} &= \frac{1}{2} \times h_0 \times Q_0 - \frac{1}{2} \times h_2 \times Q_1 - \text{Area}_b \\
&= \frac{1}{2} \times 152.7 \times 5896 - \frac{1}{2} \times 142.3 \times 5606 - 24214.3 = 26924.2
\end{aligned} \tag{8.10}
$$

$$
\Rightarrow \Delta\text{Welfare} = -\text{Area}_{d+e} = -26,924.2 \text{ million cents}
$$

The effects of the 2015 AI outbreak on the U.S. pork industry are also simulated, and the results are listed in Table 8.6. Not much change is induced to the pork industry; the largest adjustment is the 0.4 percent decrease in pork retail price in 2015. The AI outbreak does not affect the pork industry directly, but because of the big decrease in broiler price and the significant pork-broiler cross price elasticity of the demand for pork products, per capita consumption for pork tends to decrease slightly and thus pork retail price has to decrease to clear the market; this spill-over effect from the broiler industry lasts till 2016 after which the decrease in broiler retail price is less significant. The 0.4 percent decrease in pork retail price in 2015 leads to the 0.1 percent decrease in pork production in 2016 due to the production lag caused by the long production period for the pork sector. The 2016 pork per capita consumption is 0.1 percent lower than the baseline projection led by the decrease in pork production. All projections for the pork industry return to their baseline levels after 2016.

Table 8.6: Effects of the 2015 AI Outbreak on the U.S. Pork Industry

	2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Pork Production (Million lbs.)										
Baseline	23,482	24,514	25,059	25,490	25,856	26,227	26,619	27,056	27,506	27,972
Scenario 1	23,476	24,497	25,049	25,484	25,854	26,227	26,621	27,058	27,509	27,975
Change	-6	-16	-11	-6	-2	0	2	2	3	3
% Change	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pork Exports (Million lbs.)										
Baseline	5,001	5,210	5,432	5,663	5,900	6,142	6,390	6,646	6,910	7,182
Scenario 1	5,001	5,209	5,431	5,662	5,898	6,140	6,389	6,645	6,909	7,181
Change	0	-1	-1	-2	-2	-1	-1	-1	-1	-1
% Change	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pork Retail Price (Cents/lb.)										
Baseline	397	376	371	372	377	383	392	399	405	411
Scenario 1	395	375	371	372	377	383	392	399	405	411
Change	-2	0	0	0	0	0	0	0	0	0
% Change	-0.4	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pork Per Capita Consumption (Lbs.)										
Baseline	47.0	48.6	49.0	49.0	48.9	48.8	48.8	48.8	48.9	49.0
Scenario 1	47.0	48.5	48.9	49.0	48.9	48.8	48.8	48.8	48.9	49.0
Change	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% Change	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pork Ending Stocks (Million lbs.)										
Baseline	580	625	646	661	671	681	689	699	710	722
Scenario 1	581	625	646	661	671	681	689	699	710	722
Change	1	0	0	0	0	0	0	0	0	0
% Change	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Two different levels of shocks have also been assumed for broiler production in the AI-outbreak regions, a 5 percent decrease in the number of broilers slaughtered in South Central Region and the Other Region (referred to as Scenario 2) and a 10 percent decrease in the number of broilers slaughtered in South Central Region and the Other Region (referred to as Scenario 3); although this has not happened in reality, the simulation results help industry stakeholders get prepared.

The 2015 AI outbreak resulted in the quantity of exports demanded decreasing by 15.5 percent. The decreased exports were due to a reduction in U.S. production of 0.6 percent and a decrease in the demand for U.S. exports. For Scenarios 2, it was assumed that production would decrease 3.2 percent and combining this with a decrease in export demand we calculated a 17.9 percent decrease in broiler meat exports. Similarly, the exports of broiler meat were reduced 20.3 percent for Scenario 3.

Simulation results are presented in Tables 8.9 to Table 8.12. For the broiler industry, a greater reduction in exports than in production was assumed under Scenario 2, which causes prices to decrease and domestic consumption to increase. Under Scenario 3, broiler production decreases more than broiler exports, and thus prices rises and domestic consumption drops. Broiler production recovers quickly from the AI outbreak. Starting from 2016, the reduction in broiler production is less than 1 percent of the baseline projection under both scenarios. The impact on broiler exports lasts longer. By 2018, effects are about 5 percent lower than the baseline projection under both scenarios; and the number decreases to 0.9 percent and 0.8 percent by 2024 in Scenarios 2 and 3, respectively. Broiler prices adjust accordingly. Starting from 2016 the reduction in broiler exports is greater than that in broiler production under both scenarios, and which causes the projected broiler retail price to be lower than the baseline projection in both cases. As a result, starting from 2016 broiler per capita consumption is higher than the baseline projection. Broiler retail price and per capita consumption return to their baseline levels in 5 years (with the differences fluctuating within 0.2 percent of the baseline).

The production shocks in the broiler industry interact with the egg industry; all changes in the egg industry due to the AI shock remain in the same direction as under Scenario 1. The 2015 reduction in egg production is 464 and 437 million dozens under Scenario 2 and Scenario 3, respectively. Under both scenarios, the impact on egg production recovers quickly. By 2024, egg production is only 12 million dozens lower than the baseline projection, which is 0.1 percent of the baseline. The impact on egg exports vanishes much more slowly than on egg production: by 2020, the amount of egg exports is more than 5 percent lower than the baseline projection; by 2024, the difference drops to 2.3 percent. The 2015 increase in egg wholesale price is 70.7 and 65 cents per dozen under Scenarios 2 and 3 respectively, which is more moderate than under Scenario 1. And it takes six years for the price to return to the baseline level (with the difference fluctuating within 1 percent of the baseline). The 2015 domestic consumption decreases by 12.4 and 11.6 eggs per person under Scenarios 2 and 3, respectively. This cut in consumption recovers quickly after the shock. By 2017 the difference in per capita consumption is less than 0.7 percent from the baseline and is low from then on.

The turkey industry also responds accordingly to the production shocks applied to the broiler production because of the significant turkey-broiler cross price elasticity of the demand for turkey products. Under Scenario 2, 2015 turkey retail price drops by 2 cents per pound which is much lower than the decrease of 9 cents per pound under Scenario 1; Under Scenario 3, the change in 2015 turkey retail price in the opposite direction since broiler retail price is now 7 cents per pound higher than the baseline. The impact on turkey production diminishes fast, starting from 2016 the difference in production from the baseline under both scenarios is less than 1 percent. Since the 2016 reduction in turkey production is less than that in turkey exports under both scenarios, also because of the decrease in 2016 broiler retail price (7 cents per pound under Scenario 2 and 9 cents per pound under Scenario 3), the 2016 turkey retail price decreases to 156 cents per pound under Scenario 2 and 154 cents per pound under Scenario 3. The drop in turkey price recovers after 2017 with the turkey price staying close to the baseline thereafter.

There is still not much change induced to the pork industry under Scenarios 2 and 3 (Table 8.12). Pork retail price adjusts according to the change in broiler price because of the significant pork-broiler cross price elasticity of the demand for pork products. 2015 pork retail price decreases by 0.1 percent under Scenario 2, and increases by 0.4 percent under Scenario 3. The changes lead to a 6 million pound decrease and a 7 million pound increase in 2016 pork production under Scenarios 2 and 3, respectively. Because of the decrease in 2016 broiler retail price (7 cents per pound under Scenario 2 and 9 cents per pound under Scenario 3), pork retail price also decreases in 2016 by 1 cent per pound under Scenario 2, and 2 cents per pound under Scenario 3. The 2016 reduction in pork price decreases the 2017 pork production and the 2017 pork per capita consumption is 0.1 percent lower than the baseline. All projections for the pork industry return to their baseline levels after 2017.

To sum up, this chapter evaluates the effects of the 2015 AI outbreak and two hypothetical AI outbreaks on the U.S. poultry and egg industries. The lasting effects of the AI outbreak are examined by comparing the 10-year projection results for production, exports, prices, and per capita consumption for broiler, turkey, egg, and the related pork industry with their baseline scenario projections. In all cases, the effects of the shock on production started to fade out after the second year while the effects of the shock on exports lasted longer. Shocks on the broiler industry have larger effects on the other two poultry sectors than on the pork sector since the three poultry industries are closely correlated either from the supply side (broiler and egg) or from the demand side (broiler and turkey) compared to the pork sector. If the crop sectors modeled by Rhew(2014), beef and dairy sectors modeled by Maisashvili (2014) are also included in the system, more response from the pork industry could be expected since more interactions among the livestock sectors will be induced through the feed demand for grains and the feed costs for livestock sectors.

Table 8.7: Effects of the Hypothetical AI Outbreaks on the U.S. Broiler Industry

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Broiler Production, Ready-to-cook (Million lbs.)										
Baseline	38,846	39,763	40,581	41,315	42,009	42,686	43,373	44,075	44,783	45,508
Scenario 2	37,615	39,567	40,358	41,089	41,797	42,498	43,212	43,939	44,670	45,415
Change	-1,232	-195	-222	-226	-212	-188	-161	-136	-113	-93
% Change	-3.2	-0.5	-0.5	-0.5	-0.5	-0.4	-0.4	-0.3	-0.3	-0.2
Scenario 3	36,581	39,676	40,442	41,150	41,839	42,527	43,232	43,955	44,683	45,425
Change	-2,265	-87	-139	-165	-170	-159	-141	-120	-100	-83
% Change	-5.8	-0.2	-0.3	-0.4	-0.4	-0.4	-0.3	-0.3	-0.2	-0.2
Broiler Exports (Million lbs.)										
Baseline	7,336	7,487	7,673	7,861	8,031	8,183	8,311	8,428	8,541	8,653
Scenario 2	6,026	6,644	7,114	7,475	7,753	7,976	8,153	8,305	8,444	8,576
Change	-1,311	-842	-559	-386	-278	-207	-158	-123	-97	-77
% Change	-17.9	-11.3	-7.3	-4.9	-3.5	-2.5	-1.9	-1.5	-1.1	-0.9
Scenario 3	5,844	6,545	7,070	7,460	7,752	7,981	8,160	8,313	8,451	8,582
Change	-1,492	-941	-603	-401	-279	-202	-151	-116	-90	-71
% Change	-20.3	-12.6	-7.9	-5.1	-3.5	-2.5	-1.8	-1.4	-1.1	-0.8
Broiler Retail Price (Cents/lb.)										
Baseline	202	200	201	203	206	210	214	218	222	226
Scenario 2	200	193	197	201	206	210	214	218	222	226
Change	-1	-7	-4	-2	-1	0	0	0	0	0
% Change	-0.6	-3.5	-1.9	-0.9	-0.3	-0.1	0.0	0.1	0.1	0.1
Scenario 3	210	192	196	201	205	209	214	218	222	226
Change	9	-9	-5	-3	-1	0	0	0	0	0
% Change	4.4	-4.4	-2.7	-1.3	-0.6	-0.2	0.0	0.0	0.1	0.1

Table 8.7: Continued

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Broiler Per Capita Consumption (Lbs.)										
Baseline	84.4	85.8	86.9	87.6	88.3	89.0	89.8	90.6	91.4	92.3
Scenario 2	84.7	87.4	87.8	88.1	88.5	89.0	89.8	90.5	91.4	92.2
Change	0.3	1.6	0.9	0.4	0.2	0.0	0.0	0.0	0.0	0.0
% Change	0.3	1.9	1.0	0.5	0.2	0.1	0.0	0.0	0.0	0.0
Scenario 3	82.6	87.8	88.1	88.3	88.6	89.1	89.8	90.6	91.4	92.2
Change	-1.9	2.0	1.2	0.6	0.3	0.1	0.0	0.0	0.0	0.0
% Change	-2.2	2.3	1.4	0.7	0.3	0.1	0.0	0.0	0.0	0.0
Broiler Ending Stocks (Million lbs.)										
Baseline	723	756	779	796	809	820	830	841	852	865
Scenario 2	702	775	786	797	807	817	826	837	849	862
Change	-22	19	8	1	-2	-3	-4	-3	-3	-3
% Change	-3.0	2.5	1.0	0.1	-0.3	-0.4	-0.4	-0.4	-0.3	-0.3
Scenario 3	648	782	793	801	809	818	827	838	850	862
Change	-76	27	14	5	0	-2	-3	-3	-2	-2
% Change	-10.5	3.5	1.8	0.6	0.0	-0.2	-0.3	-0.3	-0.3	-0.3

Table 8.8: Effects of the Hypothetical AI Outbreaks on the U.S. Egg Industry

	2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Egg Production (Million dozens)										
Baseline	8,407	8,514	8,615	8,713	8,813	8,913	9,015	9,121	9,228	9,337
Scenario 2	7,944	8,397	8,530	8,653	8,769	8,881	8,990	9,101	9,212	9,325
Change	-464	-117	-86	-60	-44	-32	-25	-19	-16	-12
% Change	-5.5	-1.4	-1.0	-0.7	-0.5	-0.4	-0.3	-0.2	-0.2	-0.1
Scenario 3	7,971	8,405	8,531	8,652	8,768	8,880	8,991	9,101	9,213	9,325
Change	-437	-109	-85	-61	-45	-33	-25	-20	-15	-12
% Change	-5.2	-1.3	-1.0	-0.7	-0.5	-0.4	-0.3	-0.2	-0.2	-0.1
Egg Exports (Million dozens)										
Baseline	375	361	351	344	339	335	332	330	329	329
Scenario 2	336	323	317	315	315	316	317	318	320	321
Change	-39	-38	-34	-29	-24	-19	-15	-12	-9	-8
% Change	-10.4	-10.6	-9.7	-8.4	-7.0	-5.7	-4.5	-3.6	-2.8	-2.3
Scenario 3	336	323	317	315	315	315	317	318	320	321
Change	-39	-38	-34	-29	-24	-19	-15	-12	-10	-8
% Change	-10.4	-10.4	-9.6	-8.4	-7.1	-5.8	-4.6	-3.6	-2.9	-2.3
Egg Wholesale Price (Cents/dozen)										
Baseline	107	104	104	105	106	107	108	109	110	111
Scenario 2	182	119	113	110	109	109	109	110	111	112
Change	75	15	9	5	3	2	1	1	0	1
% Change	70.7	14.5	8.3	5.1	2.6	1.5	0.7	0.7	0.1	0.9
Scenario 3	176	118	113	110	109	109	109	110	111	111
Change	69	14	9	6	3	2	1	0	1	1
% Change	65.0	13.6	8.6	5.6	2.9	1.7	0.8	0.2	0.5	0.5

Table 8.8: Continued

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Egg Per Capita Consumption (Eggs)										
Baseline	264.2	266.3	267.9	269.6	271.0	272.5	274.0	275.6	277.2	278.9
Scenario 2	251.8	263.3	266.2	268.5	270.4	272.1	273.9	275.4	277.1	278.7
Change	-12.4	-3.0	-1.7	-1.1	-0.6	-0.3	-0.1	-0.1	0.0	-0.2
% Change	-4.7	-1.1	-0.6	-0.4	-0.2	-0.1	-0.1	-0.1	0.0	-0.1
Scenario 3	252.6	263.5	266.1	268.4	270.3	272.1	273.8	275.5	277.1	278.8
Change	-11.6	-2.8	-1.8	-1.2	-0.6	-0.4	-0.2	-0.1	-0.1	-0.1
% Change	-4.4	-1.0	-0.7	-0.4	-0.2	-0.1	-0.1	0.0	0.0	0.0
Egg Ending Stocks (Million dozens)										
Baseline	24	25	25	26	27	28	28	29	30	31
Scenario 2	19	23	25	26	27	27	28	29	30	31
Change	-5	-1	-1	-1	0	0	0	0	0	0
% Change	-21.7	-4.9	-3.2	-2.1	-1.4	-1.0	-0.7	-0.5	-0.4	-0.3
Scenario 3	19	24	25	26	26	27	28	29	30	31
Change	-5	-1	-1	-1	0	0	0	0	0	0
% Change	-20.3	-4.5	-3.2	-2.2	-1.5	-1.0	-0.7	-0.5	-0.4	-0.3

Table 8.9: Effects of the Hypothetical AI Outbreaks on the U.S. Turkey Industry

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Turkey Production, Ready-to-cook (Million lbs.)										
Baseline	5,896	5,985	6,074	6,169	6,270	6,380	6,501	6,636	6,782	6,942
Scenario 2	5,606	5,938	6,024	6,122	6,229	6,345	6,473	6,613	6,765	6,927
Change	-291	-47	-51	-47	-41	-35	-28	-23	-18	-14
% Change	-4.9	-0.8	-0.8	-0.8	-0.7	-0.5	-0.4	-0.3	-0.3	-0.2
Scenario 3	5,606	5,969	6,045	6,136	6,238	6,351	6,476	6,616	6,766	6,929
Change	-291	-16	-30	-34	-33	-29	-25	-20	-16	-13
% Change	-4.9	-0.3	-0.5	-0.5	-0.5	-0.5	-0.4	-0.3	-0.2	-0.2
Turkey Exports (Million lbs.)										
Baseline	814	841	862	883	907	931	958	989	1,023	1,062
Scenario 2	529	769	834	867	894	921	950	982	1,018	1,057
Change	-285	-72	-27	-16	-13	-10	-9	-7	-6	-4
% Change	-35.0	-8.6	-3.1	-1.9	-1.4	-1.1	-0.9	-0.7	-0.6	-0.4
Scenario 3	529	778	844	874	898	924	951	983	1,018	1,058
Change	-285	-63	-17	-10	-8	-8	-7	-6	-5	-4
% Change	-35.0	-7.5	-2.0	-1.1	-0.9	-0.8	-0.7	-0.6	-0.5	-0.4
Turkey Retail Price (Cents/lb.)										
Baseline	165	164	167	170	172	175	178	180	181	183
Scenario 2	164	156	167	170	173	175	178	180	182	183
Change	-2	-8	-1	1	1	1	1	1	0	0
% Change	-1.0	-4.9	-0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.2
Scenario 3	172	154	164	169	172	175	178	180	182	183
Change	7	-10	-3	0	0	0	0	0	0	0
% Change	4.2	-6.2	-1.7	-0.2	0.1	0.2	0.2	0.2	0.2	0.2

Table 8.9: Continued

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Turkey Per Capita Consumption (Lbs.)										
Baseline	15.9	16.1	16.2	16.3	16.4	16.5	16.7	16.9	17.1	17.3
Scenario 2	15.9	16.1	16.2	16.2	16.3	16.5	16.6	16.8	17.0	17.3
Change	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.0
% Change	0.0	0.2	-0.3	-0.5	-0.5	-0.4	-0.4	-0.3	-0.2	-0.2
Scenario 3	16.0	16.2	16.2	16.2	16.3	16.5	16.6	16.8	17.0	17.3
Change	0.0	0.1	0.0	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.0
% Change	0.3	0.4	-0.1	-0.4	-0.4	-0.4	-0.3	-0.3	-0.2	-0.1
Turkey Ending Stocks (Million lbs.)										
Baseline	253	260	262	265	268	272	276	281	286	292
Scenario 2	245	266	261	263	267	270	274	279	285	292
Change	-8	6	-1	-2	-2	-2	-1	-1	-1	-1
% Change	-3.2	2.2	-0.4	-0.8	-0.7	-0.6	-0.5	-0.4	-0.3	-0.2
Scenario 3	237	269	263	264	267	271	275	279	285	292
Change	-16	9	2	-1	-1	-1	-1	-1	-1	-1
% Change	-6.3	3.3	0.6	-0.3	-0.4	-0.4	-0.4	-0.4	-0.3	-0.2

Table 8.10: Effects of the Hypothetical AI Outbreaks on the U.S. Pork Industry

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Pork Production (Million lbs.)										
Baseline	23,482	24,514	25,059	25,490	25,856	26,227	26,619	27,056	27,506	27,972
Scenario 2	23,481	24,508	25,048	25,482	25,852	26,225	26,619	27,057	27,508	27,974
Change	-1	-6	-11	-8	-4	-1	0	1	2	2
% Change	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scenario 3	23,487	24,520	25,047	25,480	25,849	26,223	26,618	27,056	27,507	27,974
Change	5	7	-12	-9	-7	-3	-1	0	1	1
% Change	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pork Exports (Million lbs.)										
Baseline	5,001	5,210	5,432	5,663	5,900	6,142	6,390	6,646	6,910	7,182
Scenario 2	5,001	5,210	5,431	5,662	5,899	6,141	6,389	6,645	6,909	7,181
Change	0	0	-1	-1	-1	-1	-1	-1	-1	-1
% Change	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scenario 3	5,002	5,210	5,432	5,663	5,899	6,141	6,389	6,645	6,909	7,181
Change	0	0	0	0	-1	-1	-1	-1	-1	-1
% Change	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pork Retail Price (Cents/lb.)										
Baseline	397	376	371	372	377	383	392	399	405	411
Scenario 2	397	375	371	372	377	383	392	399	405	411
Change	0	-1	0	0	0	0	0	0	0	0
% Change	-0.1	-0.3	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scenario 3	399	374	371	372	377	383	392	399	405	411
Change	1	-2	-1	0	0	0	0	0	0	0
% Change	0.4	-0.5	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 8.10: Continued

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Pork Per Capita Consumption (Lbs.)										
Baseline	47.0	48.6	49.0	49.0	48.9	48.8	48.8	48.8	48.9	49.0
Scenario 2	47.0	48.6	48.9	49.0	48.9	48.8	48.8	48.8	48.9	49.0
Change	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% Change	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scenario 3	47.1	48.6	48.9	49.0	48.9	48.8	48.8	48.8	48.9	49.0
Change	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% Change	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pork Ending Stocks (Million lbs.)										
Baseline	580	625	646	661	671	681	689	699	710	722
Scenario 2	580	626	646	661	671	681	689	699	710	722
Change	0	1	0	0	0	0	0	0	0	0
% Change	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scenario 3	579	627	647	661	671	681	689	699	710	722
Change	-1	1	0	0	0	0	0	0	0	0
% Change	-0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

9. SUMMARY AND CONCLUSION

The U.S. hog industry experienced significant industry consolidation and concentration during the past couple of decades. Major structural changes exploiting scale economies have occurred during the last twenty years, including an increase in use of production contracts, increases in market share of specialized operations, and increases in size of operations, and have led to increased productivity in hog industry. The structural changes in the U.S. hog industry have also been intensified in recent years due to higher feed cost. Starting from 2007, corn and soybean meal prices have risen unprecedentedly and reached a record high after the worst U.S. drought in more than half a century in 2012.

Major structural change occurred for the U.S. poultry industry in the more distant 1950s and 1960s. The increase in feed grain prices also affected the poultry sector notably as feed is the largest single cost item. The 2015 outbreak of the highly pathogenic avian influenza (AI) H5 incidents is another ongoing shock for the U.S. poultry and egg industries. In the effort to control the spread of HPAI, a large number of infected flocks were destroyed and international trade was restricted. Production and exports were thus negatively affected.

In the presence of the structural changes in the pork industry and complications of disease outbreaks facing todays poultry industry, a more up-to-date partial equilibrium, sector-specific modelling system is developed to facilitate analyzing these agriculture sectors, understand their interactions with other sectors, and making more accurate projections.

For each of the four industries, pork, broiler, turkey, and egg, a complete representation of the demand for meat from the consumer sector, the supply for meat from the livestock producers sector, as well as trade and ending stocks has been developed; and a vector of primary prices, one from each industry, is used to clear the markets such that the sum of squared excess supply from each of the individual markets is minimized.

Consumer demand in each livestock sector is modeled by a double-log functional form for its straightforward interpretation of the coefficients as elasticities. The primary explanatory variables are: own price, price for closely related meat products, non-meat food price index, food expenditures, and a trend term or lagged quantity demanded representing the effect of living patterns as needed.

Livestock production is modeled in a way that all of the important decision points in the production process are included, each with an econometric function, to reflect the sequential nature of production decisions and to incorporate the biological constraints in livestock production.

Critical decision points in pork production included in the model are breeding herd investment (gilts added to the breeding herd) and disinvestment (slaughter of breeding herd), the number of sows farrowed and pig crop, and the slaughter of hogs. Contribution margin calculated from the gross revenue less variable costs is the direct factor affecting hog breeding herd investment and disinvestment. Unlike previous studies, both farrow-to-finish and farrow-to-feed hog farms contribution margin are considered in the current model as traditional farrow-to-finish hog producers have given way to more specialized hog operations during the recent structural changes which occurred in the U.S. pork industry.

Critical decision points in broiler production include hatching egg production, broiler-type hatching eggs being set in incubators, broiler-type chicks being hatched, placed on feed, and the number of broilers slaughtered. Contribution margin data are not available for the broiler industry; the price ratio of broiler wholesale price/broiler-type chick price to feed price is used to represent the profitability of broiler feeding in different production stages and affect the final broiler production. Separate production regions of the broiler industry have been included in this study to assist studying events that effect one region but not another. The poultry industry is divided into four regions: the South Central (SC), the South Atlantic (SA), the North Atlantic (NA), and Other Regions (OTH), according to Hatchery Production Annual Summary (USDA NASS), with adjustments made due to data availability.

Egg production is comprised of hatching egg production and table egg production, where regional hatching egg production is specified in the broiler model and U.S. total hatching egg production is simply the summation of the regional production. Critical decision points in table egg production include egg-type hatching egg production, egg-type hatching eggs being set in incubators, egg-type chicks being hatched, placed on feed and lay eggs. Egg wholesale price/egg-type chick price and egg layers feed cost are used to represent the profitability and cost in different production stages for egg layer feeding and the final table egg production.

Major decision points in the turkey production model start with turkey eggs being set in incubators since no data is available for earlier production stages. Also because of data availability, the next step to be modeled is turkey poults being placed on feed. And the final step is the number of turkey slaughtered. Turkey wholesale price and feed cost are used to represent the profitability and cost for turkey feeding respectively.

The study period is 1985 to 2014. Annual data is used for all variables. Single equation ordinary least squares method is used to estimate the production equations since the large size of the model precludes the use of econometric methods designed for systems of equations [Sands and Westcott (2011)]. And two stage least squares (2SLS) method is applied to estimate the per capita consumption equations in the system. Based on the assumption that the structural errors are pairwise uncorrelated, the recursive system used to describe livestock productions is consistently estimated by OLS.

Adjusted R-squared is used to infer the goodness of fit of the model specification. P-value and t-statistics show the statistical significance of an explanatory variable. Breusch-Godfrey test is applied to test for the presence of serial correlation whenever lagged dependent variable is included in the explanatory variables. Mean Absolute Percentage Error (MAPE) and Theils U2 (U2) are used to measure the accuracy of fitted values. All equations were deemed reasonable because the coefficients had the correct signs, significant t-statistics, and large R-squares. Estimated elasticities were compared with literature. Midterm (2015 to 2024) projections of livestock productions, prices, and consumptions were also compared with FAPRI and USDA projections to validate the model specification.

The estimated partial equilibrium system was applied to evaluate the effects of the 2015 highly pathogenic avian influenza (HPAI) outbreak on the U.S. poultry and egg industries. The actual changes in 2015 poultry and egg production and trade published by USDA were used to shock the model; the lasting effects of the AI outbreak were examined by comparing the 10-year projection results for production, exports, prices, and per capita consumption for broiler, turkey, egg, and the related pork industry with their baseline scenario projections. The effects of the shock on productions started to fade out after the second year while the effects of the shock on exports lasted longer. Shocks on the broiler industry had larger effects on the other two poultry sectors than on the pork sector since the three poultry industries are closely correlated either from the supply side (broiler and egg) or from the demand side (broiler and turkey) compared to the pork industry. If the crop sectors modeled by Rhew(2014), beef and dairy sectors modeled by Maisashvili (2014) were also included in the system, more response from the pork industry could be expected because more interactions among the livestock sectors would be induced through the feed demand for grains and the feed costs for livestock sectors.

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