A Frontier Analysis of U.S. Poultry Farms: Developing Performance Measures Using data generated from a Complex Survey Design

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Abstract
Using USDA's ARMS data for 2006 and 2011, we determine the extent and location of U.S. high and low-technology broiler farms and estimate net returns, scale efficiency, and technical efficiency associated with technology across different operation sizes. Larger-scale high-technology farms generally economically outperformed smaller-scale low-technology farms.

Key Words: ventilation system, technical efficiency, returns to scale, broiler

1. INTRODUCTION

The poultry industry plays a significant role in the economy of close to a dozen southern and southeastern states in the U.S. In 2007, there were close to 40,000 broiler operations in 17 major producing states accounting for more than 90 percent of production. The value of production was >$21 billion in 2007 (USDA-NASS, 2007). A tightly integrated operation, with chicken companies linked to broiler growers through production contracts was successful in profitably increasing production until recent years. Today, the business model of broiler production is adjusting to unprofitable broiler/feed price ratios and weak financial positions in some domestic chicken companies by linking up with global operations adept at riding out down markets, as well as being more financially able to take advantage of domestic and foreign market opportunities.

Broiler production is concentrated in a group of states (see Figure 1), primarily in the South, but also including significant production in Delaware and Pennsylvania. The top broiler states are Georgia, followed by Arkansas, Alabama, Mississippi, and North Carolina.

Most broiler production is under contract with a broiler processor integrator. The grower normally supplies the grow-out house, a significant investment of $300,000 or more. The house is equipped, by agreement with the integrator, with all necessary heating, cooling, feeding, and watering systems. The grower also supplies the labor needed in growing the birds and distributes the litter from the operation. The processor supplies the chicks, feed, and veterinarian and medicines. The processor schedules transportation of the birds from the farm to the processing plant. In many cases, the processor also supplies the crews who place broilers into cages for transportation to the slaughter plant.

A thorough analysis of the impact of broiler operation size and technology on competitiveness requires consideration of production systems, as broiler operations vary widely in technology—with those built since 1996 exploiting much greater control over the environment (climate controls).

An important reason for investigating the impact of technolgy on competitiveness is that significant economies of size have been shown in broiler production. MacDonald (2008) shows the cost advantages associated with large-scale broiler production.

Using ARMS data for 2006 and 2011, this study compares the performance measures (scale and technical efficiency and return on assets) of various sizes of broiler operations depending upon their classification as high tech or low tech—depending on the vintage of the broiler houses employed in the operation. Using these results, we then draw conclusions regarding competitiveness. We use the 2006 and 2011 ARMS surveys with explicit data on broiler operations, designed to cover close to 90 percent of the broiler operations in the United States.

Food Safety and Food Quality Issues Including the Use of Sub-therapeutic Antibiotics

Broiler producers use an array of strategies to prevent the emergence and spread of disease among grow out broilers (see MacDonald and Wang, 2011). The ARMS 2006 probed into emerging concerns about food safety and food quality issues by asking contractees: 1) whether their flock was tested for Avian Influenza; 2) whether their flock was tested for salmonella; 3) whether their flock was tested for any other pathogens that can cause human illness (e.g. Campylobacter, Listeria, E. coli 0157:h7, etc.; 4) whether a Hazard Analysis and Critical Control Point Program or the National Poultry Improvement Plan was followed; 5) whether feed provided by the contractor was tested for Salmonella; 6) whether specified animal welfare requirements, such as space per bird or the Humane Animal Certification were followed; 7) whether flocks were all in, all out; 8) whether houses were cleaned out, washed, sanitized, and dried after each flock was removed; 9) whether broilers were raised without antibiotics in their feed or water (unless the birds were ill); and 10) whether broilers were to be fed exclusively from vegetable feed sources. Appendix Tables 3 and 4 show that the use of food safety and quality items differed significantly by size and type of technology. In general, antibiotic use was highest on low-volume, low-technology operations and decreased over time. For example, sub-therapeutic use of antibiotics fell from close to 30 percent use in the Southeast and Delta in 2006 to 20 percent or less in 2011. MacDonald and Wang (2011), in previous work using the 2006 data, found that 42 percent of broiler operations did not use sub-therapeutic antibiotics in their operations.

Heat Stress

Figure 2 shows trends in broiler heat stress for broilers based on prism data (see St. Pierre et al., 2003 and Yalcin et al., 2001). Both of these studies suggest that management procedures to mitigate heat stress improved food conversion and lowered mortality without affecting body weight. The data suggest that heat stress is potentially an issue in most broiler producing states. New technologies to mitigate heat stress, including tunnel ventilation and evaporative cooling cells, have become common since the mid1990s.

Litter disposal

In production contracts, broiler growers do not own the chickens; rather they provide the broiler house, and the labor and utility expenses to raise the chicks. They also dispose of the litter produced by the broilers. The integrator supplies the chicks, the feed, veterinarian services, and transportation to the processing plant when the broilers are fully grown.

Literature Search

Nearly all growers operate under production contracts, where a grower's compensation is based, in part, on how the grower's performance compares with that of other growers (MacDonald 2008). There has not been an open cash market for broilers since the 1950s (Taylor 2004). In production contracts, broiler growers do not own the chickens; rather they provide the broiler house and the labor and utility expenses to raise the chicks.

Disease and animal growth issues are important in the broiler industry as discussed in the work by MacDonald (2008), MacDonald and McBride (2009), and MacDonald and Wang (2011). These authors note that broiler producers use antibiotics to promote growth and stave off disease, but that health officials, veterinarians and physicians are concerned that extensive use is reducing the efficacy of antibiotics in treating human and animal disease.

As MacDonald (2008) points out, the industry is undergoing gradual structural change with production moving to larger operations. Broiler industry returns have bounced around dramatically in recent years, leading to production cutbacks and industry consolidation, but expansion is driven in large part by changes in feed costs (Feedstuffs November 12, 2012).

New Building Broiler Technology

New technologies, including tunnel ventilation and evaporative cooling cells, have become common since the mid-1990s (See the Economic Organization of U.S. Broiler Production EIB-38, ERS/USDA, 2006). Currently, more than 75 percent of broiler houses have cooling cells and tunnel ventilation according to the 2006 ARMS. In terms of vintage, houses constructed prior to 1995, about 40 percent of housing capacity, are less likely to have such technology, nor do they have modern technology such as computer warning systems. Two important types of climate control equipment are tunnel ventilation and evaporative cooling cells. Tunnel ventilation systems consist of large fans at one end of a broiler house and air inlets at the other end. The fans pull air through the house, removing heat from the building and creating a wind chill that provides further cooling. Evaporative cooling systems can be activated when tunnel ventilation alone fails to provide sufficient cooling. The systems are located on the outside of the house near air inlets. Cooling pads, moistened by fogging nozzles, lower the temperature of the air as it is pulled through the pads and the house.

Close to 75 percent of broiler houses had cooling cells and tunnel ventilation in 2006, and newer houses are likely to have them (MacDonald 2008). The majority of houses built after 1996 had these features. Older houses are sometimes retrofitted with cooling cells and ventilation, with the equipment installed after the houses were originally constructed.

Off Farm Labor trends

Off-farm employment remains important as a component of total income on broiler operations. ARMS data indicates that earned income for broiler farms averaged 12 percent of total income in 2011, down from 16 percent in 2006. A weak nonfarm economy may have reduced the share of off-farm income in total household income. A broiler farm household earned about $24,000 in real terms in 2011, down from about $28,000 in 2006, but annual off farm hours increased from 298 to 376 for operators and from 494 to 663 for spouses.

DATA AND METHODS

This study uses data from the 2006 and 2011 ARMS Cost of Production broiler versions, conducted by the USDA's National Agricultural Statistics Service and Economic Research Service. For 2006, this dataset provides 1,561 usable responses; for 2011, the dataset provides 1,444 usable responses. The ARMS collects information on farm size, type and structure; income and expenses; production practices; and farm and household characteristics, resulting in a rich database for economic analysis of the broiler sector. Because this design-based survey uses stratified sampling, weights or expansion factors are included for each observation to extend results to the broiler farm population of the largest U.S. broiler states, representing 90% of U.S. broiler production. A parametric input distance function approach is used to estimate performance measures, including returns to scale (RTS) and technical efficiency (TE). New technologies, including tunnel ventilation and evaporative cooling cells, have become common since the mid 1990s. (See the Economic Organization of U.S. Broiler Production EIB-38, ERS/USDA, 2006). A heat index is included as a driver in the frontier estimations for all broiler operations and by technology.

Stochastic Distance Frontier Approach

A Model to Assess Technical and Scale Efficiency

A parametric input distance function approach is used to estimate performance measures, including RTS and TE. Following Morrison-Paul et al. (2004a,b), the input distance function is denoted as $D^I(\boldsymbol{X},\boldsymbol{Y},\boldsymbol{R})$, where $\boldsymbol{X}$ refers to inputs, $\boldsymbol{Y}$ to outputs, and $\boldsymbol{R}$ to other farm efficiency determinants. For the analysis, three outputs developed from the

ARMS for broiler farms are: $Y_{NONPOULT}$ = value of crop and non-poultry animal production, Y_{POULT} = value of poultry production, and Y_{OFF} = off-farm income, which is total off-farm income less unearned income. Inputs are costs of: X_{LAB} = labor; X_{CAP} = capital; X_{MISC} = miscellaneous including feed, fertilizer, and fuel; and X_{OLND} = quality adjusted land. Thus, our analysis is whole-farm. This is a significant distinction considering the roles of off-farm income and other farm enterprises.

The input distance function represents farms' technological structure in terms of minimum inputs required to produce given output levels, as farmers typically have more short-term control over input than output decisions (Morrison-Paul et al. 2004a,b). Also, Morrison-Paul and Nehring (2005) found output-oriented models to have limitations—a less good fit—when output composition differences are important. See Morrison-Paul and Nehring (2005), and Dorfman and Koop (2005), for ARMS applications of distance functions.

To account for differences in land characteristics, state-level quality-adjusted values for the U.S. estimated in Ball et al. (2008) are used. See Nehring et al. (2006) for a fuller description. Ignoring land heterogeneity, including urbanization effects on productivity and agronomic (i.e., water holding capacity, organic matter, slope, etc., of land) and climatic information incorporating the differing cropping patterns used in broiler production, would result in biased efficiency estimates (Ball et al. 2008; Nehring et al. 2006).

Estimating $D^I(\boldsymbol{X},\boldsymbol{Y},\boldsymbol{R})$ requires imposing linear homogeneity in input levels (Färe and Primont 1995), which is accomplished through normalization (Lovell et al. 1994); $D^I(\boldsymbol{X},\boldsymbol{Y}, \boldsymbol{R})/X_1 = D^I(\boldsymbol{X}/X_1,\boldsymbol{Y}, \boldsymbol{R}) = D^I(\boldsymbol{X^*},\boldsymbol{Y}, \boldsymbol{R})$.[2] Approximating this function by a translog functional form to limit *a priori* restrictions on the relationships among its arguments results in:

(1a) $\ln D^I_{it}/X_{1,it} = \alpha_0 + \Sigma_m \alpha_m \ln X^*_{mit} + .5\, \Sigma_m \Sigma_n \alpha_{mn} \ln X^*_{mit} \ln X^*_{nit} + \Sigma_k \beta_k \ln Y_{kit}$

$+ .5\ \Sigma_k\ \Sigma_l\ \beta_{kl} \ln Y_{kit} \ln Y_{lit} + \Sigma_q\ \phi_q\ R_{qit} + .5\ \Sigma_q\ \Sigma_r\ \phi_{qr}\ R_{qit}\ R_{rit} + \Sigma_k\ \Sigma_m\ \gamma_{km} \ln Y_{kit} \ln X^*_{mit}$

$+ \Sigma_q\ \Sigma_m\ \gamma_{qm} \ln R_{qit} \ln X^*_{mit} + \Sigma_k\ \Sigma_q\ \gamma_{kq} \ln Y_{kit} \ln R_{qit} + v_{it} = TL(\boldsymbol{X^*}, \boldsymbol{Y}, \boldsymbol{R}) + v_{it}$, or

(1b) $-\ln X_{1,it} = TL(\boldsymbol{X^*}, \boldsymbol{Y}, \boldsymbol{R}) + v_{it} - \ln D^I_{it} = TL(\boldsymbol{X^*}, \boldsymbol{Y}, \boldsymbol{R}) + v_{it} - u_{it}$,

where i denotes farm; t the time period; k,l the outputs; m,n the inputs; and q,r the $\boldsymbol{R}$ variables. We specify $X_1 = X_{OEVOTH}$ as the numeraire so the function is specified –primarily-- relative to purchased feed and purchased chicks supplied by the integrator (but reported in the survery using state averages supplied by the integrator); not consistent with the literature on farm production in terms of yields but arguably appropriate for the broiler operation where feed and chick purchases comprise the bulk of costs to the operation. .

Distance from the frontier, $-\ln D^I_{it}$, is characterized as the technical inefficiency error $-u_{it}$. Equation (1b) was estimated as an error components model using maximum likelihood methods. The one-sided error term u_{it}, distributed as exponential, is a nonnegative random variable independently distributed with truncation at zero of the $N(m_{it},\sigma_u^2)$ distribution, where $m_{it}=\boldsymbol{R}_{it}\delta$, $\boldsymbol{R}_{it}$ is a vector of farm efficiency determinants (assumed to be the factors in the $\boldsymbol{R}$ vector), and δ is a vector of estimable parameters. The random (white noise) error component v_{it} is assumed to be independently and identically distributed, $N(0,\sigma_v^2)$. Estimated using SPF techniques, TE is characterized assuming a radial contraction of inputs to the frontier (constant input composition).

Productivity impacts (marginal productive contributions, MPC) of outputs or inputs can be estimated by the first order elasticities, $MPC_m = -\varepsilon_{DI,Ym} = -\partial \ln D^I(\boldsymbol{X},\boldsymbol{Y},\boldsymbol{R})/\partial \ln Y_m = \varepsilon_{X1,Ym}$ and $MPC_k = -\varepsilon_{DI,X^*m} = -\partial \ln D^I(\boldsymbol{X},\boldsymbol{Y},\boldsymbol{R})/\partial \ln X^*_k = \varepsilon_{X1,X^*k}$. MPC_m indicates the increase in overall input use when output expands (should be positive, like a marginal cost or output elasticity measure), and MPC_k indicates the shadow value (Färe and Primont 1995) of the k^{th}

input relative to X_1 (should be negative, like the slope of an isoquant). Similarly, MPCs of structural factors, including soil texture (TEXT) and water holding capacity (WATER) can be measured through the elasticities, $MPC_{Rq} = -\varepsilon_{DI,Rq} = -\partial \ln D^I(\boldsymbol{X},\boldsymbol{Y},\boldsymbol{R})/\partial R_q = \varepsilon_{X1,Rq}$. If $\varepsilon_{X1,Rq} < 0$, increased R_q implies less input is required to produce a given output, and vice versa.

Scale economies are calculated as the combined contribution of the M outputs Y_m, or the scale elasticity $SE = -\varepsilon_{DI,Y} = -\Sigma_m \partial \ln D^I(\boldsymbol{X},\boldsymbol{Y},\boldsymbol{R})/\partial \ln Y_m = \varepsilon_{X1,Y}$. That is, the sum of the input elasticities, $\Sigma_m\, \partial \ln X_1/\partial \ln Y_m$, indicates the overall input-output relationship, and thus RTS. The extent of scale economies is thus implied by the shortfall of SE from 1; if SE<1, inputs do not increase proportionately with output levels, implying increasing RTS. Finally, TE "scores" are estimated as $TE = \exp(-u_{it})$. Impacts of changes in R_q on TE can also be measured by the corresponding δ coefficient in the inefficiency specification for $-u_{it}$. We specify the drivers of the inefficiency effects as population accessibility (POPACC), operator and spouse off farm labor (OPHOURS and SPHOURS, respectively), operator age (AGE), use of antibiotics (ANTIBIOTICS), and a temperature humidity index (THI), and a time dummy (YEAR). It is assumed that the inefficiency effects are independently distributed and u_{it} arise by truncation (at zero) of the exponential distribution with mean μ_{it}, and variance σ^2.

Input endogeneity has been a concern in the estimation of input distance functions; if found, biased estimates result. Some studies have used instrumental variables to correct the problem, while others have argued either that (1) it was not problematic in their studies because random disturbances in production processes resulted in proportional changes in the use of all inputs (Coelli and Perelman 2000, Rodriguez-Alvarez 2007) or (2) no good instrumental variables existed, thus endogeneity was not accounted for (Fleming and Lien 2010). We estimated instruments for each of the inputs. The Hausman test was used to test for endogeneity. Since endogeneity was found, the predicted values are used as instruments in the SPF.

Using ARMS Data to Estimate an SPF

Since complex stratified sampling is used with ARMS, inferences regarding variable means for regions are conducted using weighted observations. As discussed by Banerjee et al. (2010), the ARMS is a multiphase, non-random survey, so classical statistical methods may yield naïve standard errors, causing them to be invalid. Each observation represents a number of similar farms based upon farm size and land use, which allows for a survey expansion factor or survey weight, effectively the inverse of the probability that the surveyed farm would be selected for the survey. As such, USDA-NASS has an in-house jackknifing procedure that it recommends when analyzing ARMS data (Cohen et al. 1988; Dubman 2000; Kott 2005), which allows for valid inferences to the population. Thus, econometric estimation of SPF models presents unique challenges when using ARMS data. The SAS QLIM procedure was used to estimate SPF models. We use the jackknife replicate weights in SAS to obtain adjusted standard errors. A property of the delete-a-group jackknife procedure is that it is robust to unspecified heteroscedasticity.

The USDA version of the delete-a-group jackknife divides the sample into 15 nearly equal and mutually exclusive parts. Fifteen estimates of the statistic (replicates) are created. One of the 15 parts is eliminated in turn for each replicate estimate with replacement. The replicate and the full sample estimates are placed into the jackknife formula:

$$\text{(2)} \quad \text{Standard Error } (\beta) = \{14/15\sum_{k=1}^{15}(\beta_k - \beta)^2\}^{1/2}$$

where β is the full sample vector of coefficients from the Frontier 4.1 program results using the replicated data for the "base" run. β_k is one of the 15 vectors of regression coefficients for each of the jackknife samples. The t-statistics for each coefficient are computed by dividing the “base” run vector of coefficients by the vector of standard errors of the coefficients**.**

Using ARMS Data to Estimate a Tobit model of Off-farm Labor

Appendix Tables 1 and 2 and Figure 3 develop information on the drivers of this important component of the broiler contractee operation using a tobit model.

RESULTS

Farm Categories for Comparison

Six combinations of size and technology status are compared in this study. Farms are first divided into low tech and high tech categories based upon whether the majority of buildings on the operation were built before or after 1996. Given the wide range in the size distribution of intensive high tech oprations, this category is further broken into the following size categories for low tech: ≤250,000 chicks sold and >250,000 chicks sold; and for high-tech: ≤250,000 chicks sold, 251,000-500,000 chicks sold, 501,000-750,000 chicks sold, 751,000-1,000,000 chicks sold, and >1,000,000 chicks sold. These size categories allow for comparisons of productivity, financial, and environmental measures by size and technology status. The resulting categories can be compared on the basis of not only TE and SE, but also on other economic and productivity measures. Appendix Tables 1 and 2 present tobit regression analyses used to estimate instrumental variables for operator and spousal off-farm employment hours. These instruments were, in turn, used in the stochastic frontier estimation.

Stochastic Frontier Results

Table 1 shows stochastic frontier estimates. Close to half of the coefficients are significant. The productive impact of population pressure ($\gamma_{YPOULT,POPACC}$ = 0.0085) is significant, though positive in sign, indicating that increased urbanization decreases the productive contribution of (increases the inputs required for) broiler production.

We also find a positive and significant coefficient for $\beta_{YPOULT,YPOULT}$, suggesting increasing RTS in the pooled model. This result shows not only the importance of scale efficiency, but also provides support for the model. From Table 2, note that MPCs of outputs and inputs have the correct signs, positive for outputs and negative for inputs, though few are significant.

Off-farm Employment

Appendix Tables 1 and 2 and Figure 3 develop information on the drivers of this important component of the broiler contractee operation using a tobit model. The results indicate that the wage rate, acres, non farm assets, household net worth, and the operator's education are important drivers of off-farm employment by operator and spouse. They show that spouse hours increased significantly over time.

Comparisons by Category

Appendix Table 3 presents farm characteristics and economic measures by technology status and size. The category representing the largest number of farms is the low tech category with >250,000 chicks sold; the smallest category is that of high tech broiler operations with >1,000,000 chicks sold. The low-tech broiler operations with >250,000 chicks sold produced the most broiler meat, while high tech broiler operations with ≤250,000 chicks sold produced the least. Off-farm operator labor use tended to decrease for both low tech and high tech broiler operations as size increased; the highest usage was 499 hours on the high tech small operations with <250,000 chicks sold; the reverse is true for off-farm spousal hours, which tended to increase with size of operations up to about 750,000 chicks sold, with the largest total for high-tech operations with 500,000 to 750,000 chicks sold. Manure sold tended to increase with size for both technologies.

Urbanization scores tended to decrease with farm size. Hence, this score is inversely related to the technical efficiency of the operation. Technical efficiency increased with size for both technologies as did returns to scale, showing evidence of economies of size in U.S. broiler production.

Table 1. Input Distance Function Parameter Estimates, 2006-2011 Frontier

Variable	Parameter	(t-test)
α_{0}	5.4083	(1.92)*
α_{XLAB}	-0.2327	(-0.60)
α_{XLAND}	-0.6019	(-1.75)*
α_{XCAP}	0.0089	(0.02)
$\beta_{YNONPOULT}$	0.1520	(2.98)**
β_{YPOULT}	-0.0696	(-0.18)
β_{YOFF}	-0.0155	(-0.29)
$\beta_{YNOPOULT,YNONPOULT}$	0.0091	(8.03)***
$\beta_{YPOULT,YPOULT}$	0.0363	(2.45)*
$\beta_{YOFF,YOFF}$	0.0008	(0.65)
$\beta_{YNONPOULT,YPOULT}$	-0.0181	(-4.57)***
$\beta_{YNONPOULT,YOFF}$	-0.0004	(-0.82)
$\beta_{YPOULT,YOFF}$	0.0005	(0.13)
$\gamma_{YPOULT,TEXT}$	-0.0047	(-2.10)*
$\gamma_{YPOULT,WATER}$	-0.0008	(-0.83)
$\gamma_{YNONPOULT,POPACC}$	0.0102	(0.05)
$\gamma_{YPOULT,POPACC}$	0.0085	(4.11)***
$\alpha_{XLAB,XLAB}$	0.0194	(1.44)
$\alpha_{XLAND,XLAND}$	-0.0171	(-1.59)
$\alpha_{XCAP,XCAP}$	0.0903	(3.71)***
$\alpha_{XLAB,XLAND}$	-0.0745	(-0.92)
$\alpha_{XLAB,XCAP}$	0.0268	(0.37)
$\alpha_{XLAND,XCAP}$	-0.0860	(-1.03)
$\alpha_{DUMCHICK}$	0.0602	(3.49)***
$\alpha_{YEAR2011}$	-0.0161	(-0.36)
δ_{0}	-5.6507	(-2.15)*
δ_{POPACC}	0.5078	(2.62)*
$\delta_{OPHOURS}$	0.4731	(2.71)*
$\delta_{SPHOURS}$	-0.0380	(-0.66)
δ_{AGE}	0.6122	(0.31)
$\delta_{ANTIBIOTICS}$	0.0083	(0.31)
δ_{THI}	-0.0019	(-2.02)*
δ_{YEAR}	-0.2564	(-1.08)

Sigma	0.2197	(14.76)***

Notes: *** Significance at the 1% level (t=2.977), ** Significance at the 5% level (t=2.145), and * Significance at the 10% level (t=1.761).
Source: USDA Agricultural Resource Management Study. USDA (2006, 2011).

Table 2: MPC's for Outputs and Inputs and Return to Scale (t-statistics in Parentheses)

MPC_{YNPLT}	***0.065***	*(1.79)***	MPC_{XLAB}	***-0.079***	*(-0.03)*
MPC_{YPOULT}	***0.781***	*(2.41)***	MPC_{XLAND}	***-0.032***	*(-1.01)*
MPC_{YOFF}	***0.001***	*(0.11)*	MPC_{XCAP}	***-0.133***	*(-1.44)*
RTS	***0.846***	*(2.99)****	$MPC_{XOEVOTH}$	***-0.755***	*(-0.08)*

Conclusions

The ARMS design allowed us to sort broiler farms into high tech and low tech systems and expand the observations to the U.S. broiler farm population to examine relative competitiveness. Our frontier estimates are robust **in correcting for** endogeneity and survey design. Hence, we can legitimately make statistically valid inferences to the population of broiler farms surveyed in 2006 and 2011. The general conclusion is that, in terms of economic viability, size of operation matters. Large broiler operations with more than 250,000 chicks sold increased their share of total production from 43 percent of the total in 2006 to close to 57 percent in 2011. Larger broiler operations economically outperformed smaller operations for both systems, evidenced by RTS and profitability measures. Larger operations also sold a much larger proportion of the litter produced—close to 40 percent for the very largest. The market for litter improved in 2011 compared to 2006 with all operations able to sell 32 percent in 2011 compared to 23 percent in 2006. Most of the gain, however, occurred on larger operations in the Southeast. Antibiotic use decreased significantly over time in the face of industry criticism, dropping from 27 percent of all operations using to only 19 percent—but most of the drop occurred in the Southeast. Retrofitting to install new technology—as measured by new technology since 1996—increased dramatically. Overall, new technology represented close to 60 percent of production in 2011 compared to only 36 percent in 2006, led by sharp gains in the Southeast.

In contrast to other livestock sectors in the United States, for example swine and dairy, off-farm labor employment remains an important component of the broiler operation, even on the larger operations. In fact, off-farm employment increased in 2011 compared to 2006, up nearly 100 hours a year for operators and 200 hours a year for spouses. The off-farm employment results indicate that the wage rate, acres, non farm assets, household net worth, and the operator's education are important drivers of off-farm employment by operator and spouse. They show that spouse hours increased significantly over time.

Finally, regarding the temperature humidity index (THI) employed in this study, we find that the index increased over time, mostly due to an increase in the index in the Delta and Southern Plains. Since retrofitting is dominated by larger operations in regions with high scores, a high THI score is consistent with an increase in economic performance.

Future research will further examine differences in 2006 and 2011 broiler operations, recognizing that the economic environment in which broiler operations were operating in 2011 was different from that in 2006. We will also look further into differences by system, i.e., high tech versus low tech, identifying technology differences as they impact frontier estimation in a statistical sense using Limdep.

Preliminary results show significant differences in net return on assets, technical efficiency, and scale efficiency measures by new technology buildings and by region. However, size continues to be the dominant determinant of profitability and efficiency.

Given the dynamic nature of both demand and supply of broiler production, it is of importance to determine the relative profitability of broiler producers by production system. Expanding to two years of data, those years being five years apart, improves the analysis such that decision makers have greater information on which to base their decisions. Today, the business model of U.S. broiler production is adjusting to unprofitable broiler/feed price ratios in some domestic chicken companies by linking up with global operations adept at riding out down markets, as well as being more financially able to take advantage of domestic and foreign market opportunities.

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Endnotes

1. By definition, linear homogeneity implies that $D^I(\omega X,Y,R) = \omega D^I(X,Y, R)$ for any $\omega>0$; so if ω is set arbitrarily at $1/X_1$, $D^I(X,Y, R)/X_1 = D^I(X/X_1,Y, R)$.

2. We used Tim Coelli's FRONTIER package for the SPF estimation, and computed the measures and t-statistics for measures using PC-TSP.

3. Note that a standard "productivity" or "technical change" measure, usually defined as the elasticity with respect to time, or the time trend of the input-output relationship, is not targeted here. Elasticities with respect to the time dummies provide indications of production frontier shifts for each time period, but for short time series other external factors such as weather often confound estimation of a real technical change trend.

4. States and their designated regions included in this dataset include: NORTHEAST: DE, MD, and PA; APPALACHIA: KY, NC, TN, and VA; CORN BELT: MO; DELTA: AR, LA, and MS; SOUTHEAST: AL, GA, and SC; SOUTHERN PLAINS: OK and TX; and PACIFIC: CA.

Appendix Table 1. Tobit Regression Analysis for Ophour Drivers; Instrumental Variable Op, Other Inputs.[1]

Variable	Estimate		Standard Error
Constant	34.161		0.11
Wage Rate on Farm	11.448		0.49
Operator Education	2.710	***	3.73
Texture	-12.566		-0.68
Water Holding Capacity	2.777		0.86
Acres Operated	0.028		0.42
Urban	-1.610		-0.06
Assets	-0.000		-0.38
Household Well-being	9.990		0.60
Adjusted Wages Off-Farm	0.008	***	6.63
Harvested Acres	-0.156	***	-4.21
Nonfarm Net Worth	-0.00005		-0.06
Nonfarm Assets	0.002	*	2.08
Household Net Worth	-0.00004		-0.96
Year2011	4.184		0.08
Sigma	629.614	***	22.06
Observations	2,961		

1. Urban is a dummy variable. All others are continuous.

Appendix Table 2. Tobit Regression Analysis for Sphour drivers; instrumental Variable Sp, Other Inputs.[1]

Variable	Estimate		Standard Error
Constant	849.536	*	2.11
Wage Rate on Farm	-66.032	*	-2.12
Operator Education	1.484		1.29
Texture	-16.978		-0.57
Water Holding Capacity	-6.039		-1.40
Acres Operated	-0.028		-0.23
Urban	-36.257		-0.75
Assets	0.000001		1.49
Household Well-being	90.423	***	5.16
Adjusted Wages Off-Farm	0.008	***	4.10
Harvested Acres	-0.043		-0.37
Nonfarm Net Worth	-0.00007		-0.40
Nonfarm Assets	0.002		0.50
Household Net Worth	-0.001	*	-1.93
Year2011	191.415	*	2.11
Sigma	778.116	***	42.78
Observations	2,961		

2. Urban is a dummy variable. All others are continuous.

Figure 1: Broiler Production by State

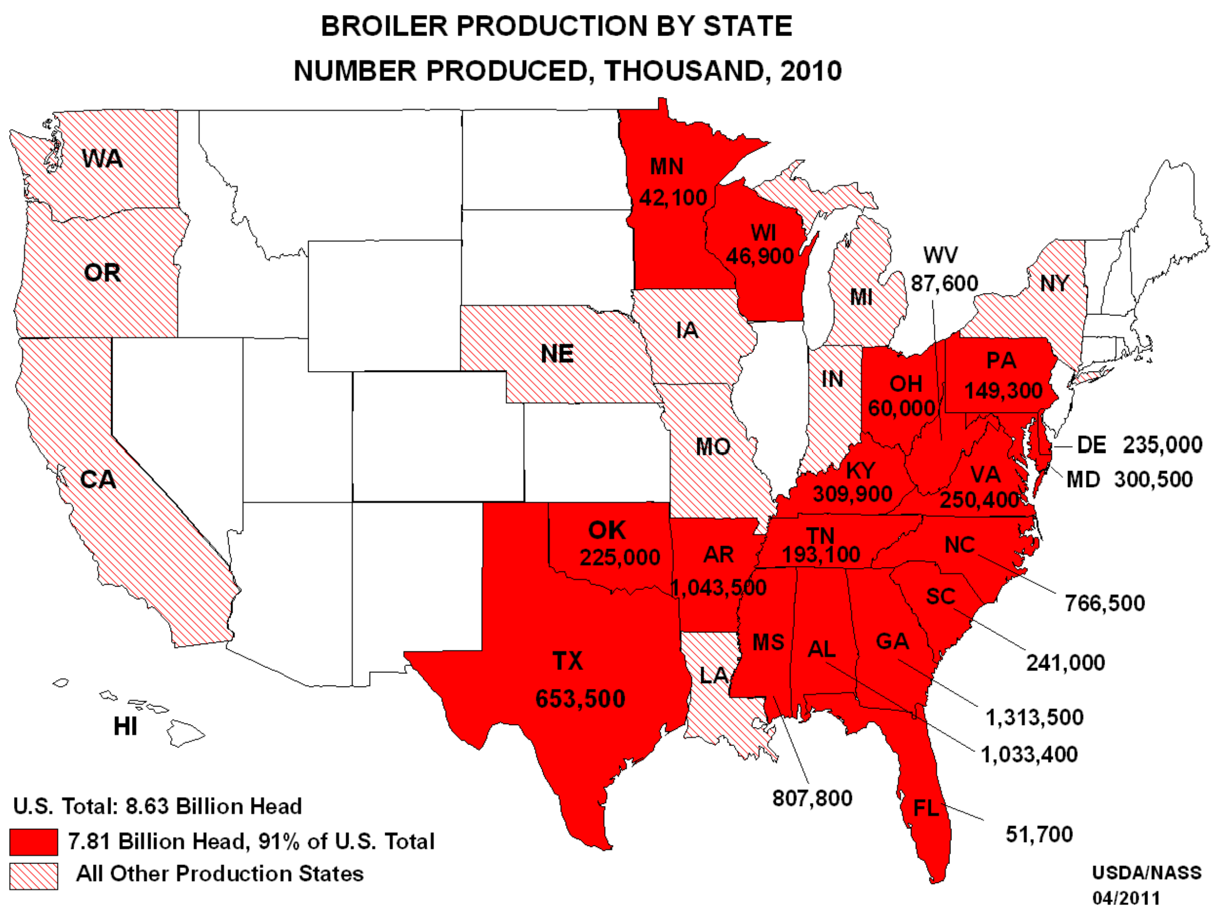

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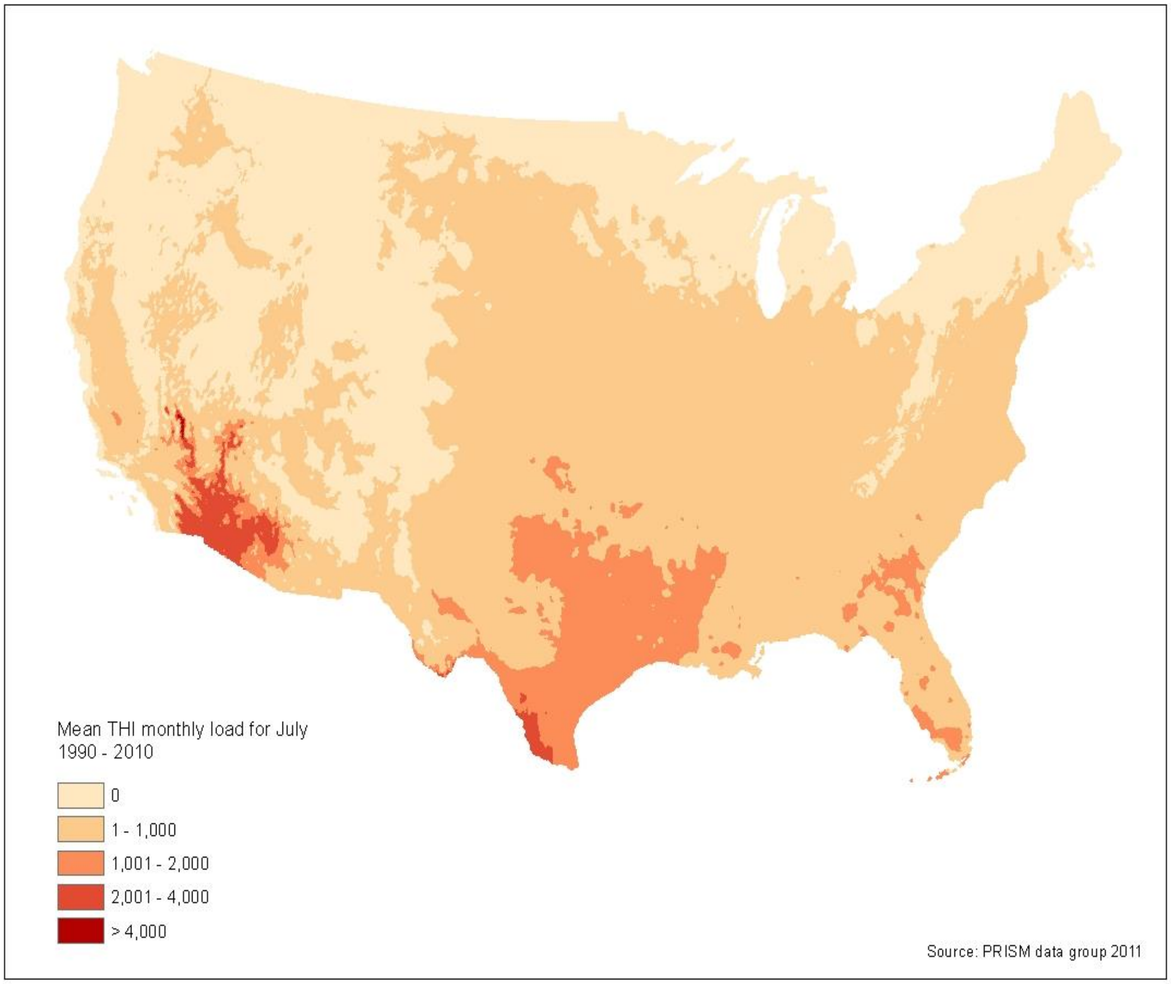
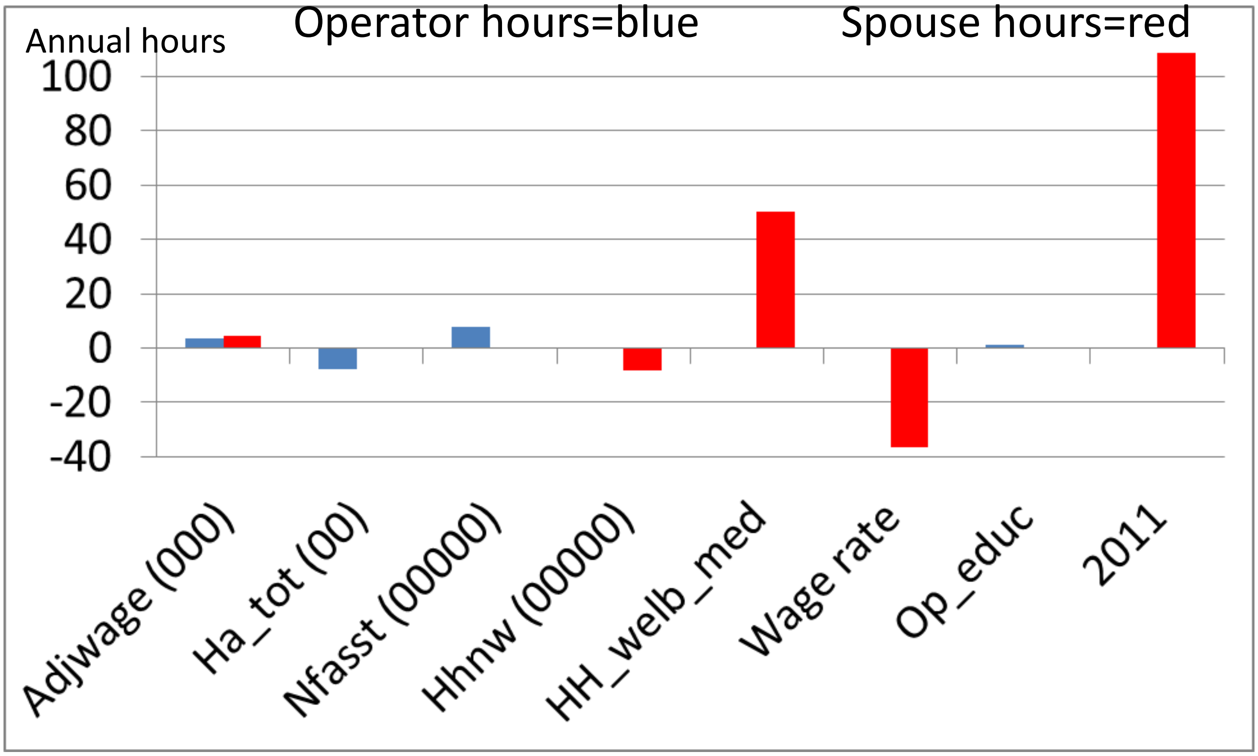
Figure 2: Heat Index for Broilers



Source: Prism and GIS/ERS calculations

Figure 3 Significant marginal effects for operators and spouses conditional on working off-the-farm, 2006-11



Note: Statistically significant marginal effects from operator and spouse equations, E(y|x, y>0).

Appendix Table 3. Characteristics of Broiler Operations Including Technical Efficiency and Returns to Scale, by Technology and Size, 2006 and 2011 ARMS Broiler Surveys.

Item	Low Tech ≤250,000 Chicks Sold	Low Tech >250,000 Chicks Sold	High Tech ≤250,000 Chicks Sold	High Tech 251,000-500,000 Chicks Sold	High Tech 501,000-750,000 Chicks Sold	High Tech 501,000-1,000,000 Chicks Sold	High Tech >1,000,000 Chicks Sold
No. Observations	368	1,174	98	429	439	285	212
No. Farms	6,391	12,399	1,746	5,048	4,198	2.092	1,338
% Value of Production	6.2	40.3	2.1	12.2	15.0	10.7	12.2
Chicks sold per Farm	155,773	566,834	172,821	385,082	608,379	863,787	1,450,753
Antibiotics %	26.07	24.25	15.90	23.30	21.29	20.54	22.72
Acres operated	134	218	394	191	194	299	424
Manure Acres	41	82	60	73	78	121	164
Manure sold %	14.05	27.88	17.96	32.03	38.42	31.68	42.12
Manure Rev $	226	1,711	550	1,445	2,565	2,675	4,750
Urban Score	126	108	139	113	92	92	101
Net Return on Assets	0.029	0.035	0.012	0.035	0.037	0.041	0.061
Household returns	0.061	0.053	0.035	0.056	0.054	0.057	0.070
Temp Humidity Index							
Debt-Asset Ratio	0.09	0.16	0.16	0.28	0.34	0.38	0.36
Op Hrs Off Year	431	300	499	374	266	260	190
Sp Hrs Off Year	471	584	522	566	746	570	552
Off farm % In	28.00	14.48	18.00	15.55	11.79	9.93	5.22
Technical Efficiency	0.73	0.77	0.74	0.78	0.79	0.80	0.79
Returns to Scale	0.79	0.86	0.79	0.85	0.87	0.89	0.92

Appendix Table 4. Characteristics of Broiler Operations Including by Technology and Size by Region , 2006 and 2011 ARMS Broiler Surveys by Region.

Item						
	NE and AP 2006	NE and AP 2011	Southeast 2006	Southeast 6 2011	Delta and SP 2006	Delta and SP 2011
No. Observations	415	376	480	421	611	603
No. Farms	5,413	5,338	4,909	4,754	6,514	5.029
% Value of Production	45.0	55.0*	43.71	56.3*	44.7	55.3*
Chicks Sold per Farm	401,826	411,309	541,853	551,607	491,566	557,772
Antibiotics %	22.31	21.64	29.56	14.71*	28.31	21.40*
Acres Operated	173	195	186	229	194	299
Manure Acres	18	20	79	75	95	90
Manure Sold %	17.90	20.24*	24.37	40.72*	24.61	34.88*
Manure Rev $	226	1,230	955	3,028*	769	2,869*
Excess N per acre	63.43	46.27*	77.58	26.63*	59.50	5.47*
Urban Score	126	108	121	121	54	60*
Land Price $/acre	7,677	4,245*	4,553	3,588*	1,874	2,343*
Net Ret on Assets	0.035	0.046	0.043	0.040	0.031	0.034
Household Returns	0.054	0.062	0.059	0.056	0.057	0.058
Temp Humidity Index	103	168*	308	402*	461	815*
Debt-Asset Ratio	0.10	0.24*	0.16	0.32*	0.27	0.38*
New Tech %	31.68	49.36*	35.72	57.52*	39.54	51.43*
Op Hrs Off Year	256	392*	319	348	323	409
Sp Hrs Off Year	424	559*	491	767*	558	714*
Off-farm % In	17.88	12.58*	13.67	12.54	17.79	14.89
Poult/Vprodtot %	77.52	61.93*	79.96	66.87*	80.22	67.54*
Fert/Har acre $	71.99	51.07*	110.75	61.50*	34.36	31.13

*Significant at the 1, 5 or 10 percent level for 2011 compared to 2006