Economic analysis of Ghana's chicken industry

by

Frank Kyekyeku Nti

B.S., University of Ghana, 2008
M.S., Kansas State University, 2012

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agricultural Economics
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Abstract

Increasing feed price and the adverse effect of low cost poultry imports have put economic pressure on domestic poultry production in Ghana. With an increasing population and per capita income, poultry demand is expected to grow at a higher rate. There is, therefore, a need to improve domestic farm performance and/or competitiveness. This study estimates an input-oriented distance function to evaluate the technical efficiencies and cost efficiencies of chicken production in Ghana in a non-parametric framework using a dataset that includes all known chicken farms in Ghana. The choice of feed, that constitutes about 74% and 91% of the total variable cost in broiler and layer operations, respectively, may have direct effects on the financial position and performance of farms. As a result, the study also identifies determinants of producers' feed demand decision to inform policies to manage the availability, affordability and accessibility of feed. In identifying these determinants, the double hurdle model popular in the literature for modelling zero dependent variables is used to examine the decision mechanism underlying Ghanaian poultry farmers' feed demand decisions.

The results indicate that layer production is a more efficient enterprise than broiler production. However, noticeable differences in the production behavior and efficiency level among different farm classes, and among farms located in different geographic regions exist. In general, medium-sized farms combine their inputs and resources more optimally than large- and small-sized farms. The variables identified to influence efficiency levels differ substantially across the types of chicken enterprises and among estimated efficiency indicators. While the geographic location of farms, farm size, feed type, source of commercial feed and own feed preparation methods significantly influenced many of the performance indicators, farmers' educational level had little effect on producers' optimal inputs combination.

The decision on the type and quantity of feed used is critical to enhancing producers' profit margins. The study found that the decision to use own feed or commercial feed were largely influenced by similar factors but with opposite effects. For instance, the study finds that among other factors, the experience of farm operator, having a crop farm, farm location in a rural area, and farm size drive the decision to produce own feed but reduces the likelihood of purchasing commercial feed. On the other hand, age of farm operator and many regional dummies motivate the use of commercial feed but demotivates the using self-prepared feed. Differences also exist in the factors that influence the quantity of own feed produced and the quantity of commercial feed purchased among the three types of chicken enterprises.

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Dedication

To the memories of my Uncle, Kwaku Gyasi and my Grandfather, Kwame Amoako Ogyampa, for their words of wisdom and encouragement which still lives on in my heart and in my life, always challenging me to go for the ultimate in all I do but also being mindful of the potential externalities (positive or negative) associated with my actions in the quest to attain the quintessential.

Chapter 1 - General Introduction

1.1 Background

The chicken industry provides an effective way to improve incomes in low-resource agricultural economies because, whether produced as meat or eggs, it offers the shortest time to market among the major livestock species. As a result, many developing country governments have promoted the industry, contributing to some of these countries emerging as global players. For instance, Brazil transformed its domestic chicken meat production into an internationally competitive industry with significant involvement in the global market, exporting more than 3.6 million tons of chicken meat in 2014, up from about 168,813 tons in 1980, to overtake the United States as the leading exporter of chicken meat. Even so, many developing countries have failed to achieve the requisite performance levels to be competitive in their own markets, leading to significant importation of chicken products and debates about what public policies may be used to overcome their challenges[1].

Ghana has experienced rapid economic growth in recent years. Increasing incomes and urbanization have created a rise in demand for chicken products. For example, between 1990 and 2015, per capita income rose from $403 to $1,362 and chicken consumption increased from 1 kg to 6 kg per capita. This demand growth has been faster than domestic supply, with the deficit in supply being met by imports[2]. Imported chicken meat accounted for more than 67.48% of Ghana's total chicken consumption in 2014, an increase from 27.12 % in 1993[3]. This increase in chicken

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[1] Using OECD-FAO Agricultural Outlook Trade Data, poultry imports to Sub-Saharan Africa have risen exponentially since 1990 by about 1,315 percent from 92,910 metric tons to about 1.22 million metric tons in 2015, or 11.7% annually (http://stats.oecd.org/Index.aspx).

[2] The major exporters of chicken meat to Ghana are the United States, Brazil and the European Union (with an import market share of approximately 94.5%).

[3] According to OECD-FAO Agricultural Outlook Trade Data, Ghana is now the third largest importer of chicken products in Sub-Saharan Africa.

product imports seem to suggest that increasing domestic chicken production would create opportunities upstream in the grain and oilseed supply chains, generating economic benefits that could alleviate poverty and increase incomes of smallholder producers (FAO 2014). There are also downstream benefits. For example, there may be an expansion in primary and secondary chicken processing and enhancement of the packaging industry as well as improvement in cold chain systems. However, despite the potential upstream and downstream opportunities associated with expanding domestic chicken production in Ghana to meet the growing demand, the structure of Ghana's chicken industry has remained largely unchanged. And domestic supply continues to lag behind imports.

The foregoing raises both policy and managerial questions about the factors constraining the growth of Ghana's chicken industry. Domestic chicken producers' ability to raise production may be subject to both demand and supply conditions such as: (i) the substitutability of domestic products relative to imports; (ii) lack of processing capacity (FAO 2014; NDPC 2010); (iii) high feed cost, most importantly the availability (and cost) of domestically produce maize (FAO 2014); Etuah et al. 2013); (iv) lack of professionalism of the chicken industry; (v) limited access to improved technology (NDPC 2010; MOFA 2010) and (vi) weak institutional coordination of regulatory bodies (FAO 2014). These and other challenges facing the industry have long been highlighted in government policy documents but have received limited empirical attention. Addressing these constraints is critically important to the growth of Ghana's chicken industry and certainly deserve research attention. As a result, the primary goal of this study is to address two essential dimensions of the challenges facing Ghana's chicken industry – efficiency of the production system and producers' feed demand decisions in light of feed availability, accessibility and affordability constraints.

The objectives of the study are twofold: (i) to estimate and analyze the performance efficiencies in Ghana's chicken industry; and (ii) to estimate the determinants of chicken producers' demand for feed. Specifically, a unique data set from the 2015 census[4] of poultry producers in Ghana is used to first estimate the overall technical, pure technical, scale, allocative and cost efficiencies for Ghana's chicken industry. Subsequently, operational and socioeconomic factors driving efficiencies are examined to identify the potential source of inefficiency. The determinants of chicken producers' demand for self-prepared and commercial feed are then estimated. Lastly, information from the findings are synthesized to inform producers' strategic decisions and to contribute to the conceptualization and development of private and public policies geared towards improving the competitiveness of Ghana's chicken industry.

By assessing the technical and cost efficiencies of the poultry industry, this dissertation highlights the current deficiencies in the management of broiler, layer and dual chicken enterprises and explores the role farm size, feed type and off-farm income play on farm efficiency in Ghana. The study makes use of an input-oriented distance function (IDF) model to estimate efficiency for the three chicken enterprises in Ghana – layer, broiler and dual production. The input distance function describes producers' technological structure in terms of minimum input required to produce given levels of output (O'Donnell and Coelli 2005). This specification is appropriate for farm efficiency analysis because chicken producers' often have more short-term control over their input than output. Non-parametric methods based on linear programming techniques (Data Envelopment Analysis) are used to estimate the IDF model. This approach presents several attractive features compared to the stochastic frontier approach including no a priori assumptions

[4] The last count of poultry producers in Ghana prior to this survey was 1996. Given the dynamic changes that have occurred in the industry since then, new information about the industry is needed to guide the formulation of relevant and evidenced-based policies and also to help producers develop appropriate management strategies (Aning 2006).

about the structure of the frontier technology. It also conforms closely to economic theory because it ensures that curvature restrictions for the cost function are imposed in the estimation process. However, point estimates of efficiency obtained from this approach may be impacted by several sources of uncertainty including sampling variability that if not accounted for in the estimation of the frontier, may produce biased estimates. The Simar and Wilson (2007) bootstrap procedure was used to estimate biased-corrected efficiency scores and to construct bootstrap confidence intervals by taking into account at least some of the different sources of uncertainties.

Producers' feed demand is examined through a sequential two-step process: a feed acquisition decision[5] (first hurdle), followed by an intensity or quantity decision (second hurdle). Chicken feed may be obtained from two channels: (1) purchases from commercial sources; and (2) own feed formulation and production. Producers' preferences for feed from either source generate a number of zero observations that may be due to infrequency of use, corner solutions as well as abstention from use, as many producers use feed from only one source. To model the large numbers of zero responses, producers' choices about whether to purchase commercial feed or produce their own feed and their choice about the intensity of demand for each feed type is modelled separately using a Double-Hurdle (DH) specification. The DH specification allows for different processes to influence the acquisition and intensity decisions. It is also designed to explain the mechanism of demand when the source of zeroes is not identifiable in the data i.e. when data does not clearly show if zero observations are due to producers electing not to acquire a specific feed type, and/or producers choosing not to produce or purchase the selected feed type (Smith 2002). The DH model is estimated via a binary (or probit) sub-model, which captures factors influencing producers' acquisition decision, and a conditional truncated regression sub-

[5] A yes-no decision of whether to produce their own feed or not and/or whether to purchase commercial feed or not.

model, which captures factors influencing the intensity or quantity of each feed type used, while controlling for other factors that might influence producers' choice.

To the best of our knowledge this is the first study to use producer census data to estimate the overall technical, pure technical, scale, allocative and cost efficiencies for Ghana's chicken industry by farm size and geographic region all in one paper. It is also one of the first studies to empirically examine factors that explain the demand for self-prepared and commercial feed among chicken producers in Sub Saharan Africa.

1.2 Relevance of the Study

The outcome of the efficiency analysis has broad implications for both farm management and public policy design geared towards enhancing industry competitiveness and long-term farm viability. For individual farms, gains in efficiency are of particular importance to achieving producer income objectives. Insights from the relative performance scores will equip farms identified as producing off the frontier technologies to make appropriate change in their input mix decisions to enhance their relative performance levels without increasing their resource base. For policymakers, the estimated farm-level efficiency can serve as a benchmark against which to measure the impact of new public policies and intervention programs. As an essential input in policy formulation, information on farm-level efficiency could help policymakers understand sources of inefficiency and how to address them. The efficiency estimates will also provide insights into alternative approaches to enhancing the industry's contribution to national poverty reduction objectives. In addition, measuring the performance of poultry farms with more than one measure of efficiency provides a more comprehensive view of the industry's performance.

Furthermore, understanding producers' feed demand and its determinants improves the knowledge of economic and social impacts on chicken feed demand. A significant portion of production cost is feed. Therefore, identifying the factors that influence producer margins help policymakers and producers develop the appropriate policies and strategies to enhance farmers' ability to control feed costs more effectively. This would improve the financial performance of chicken farms, contribute to reduced poverty by enhancing smallholder farm incomes and therefore, enhance industry competitiveness. Thus, this study contributes directly to the ongoing discourse on how to address the multitude of challenges facing the poultry industry in Ghana by focusing on what has been identified by both farmers and their supporters as the industry's Achilles' heel: feed and feed cost (FAO 2014; Etuah et al. 2013). Available literature on the Ghana poultry industry is limited and has been described as unreliable (Sumberg et al. 2013). As a result, findings from this study not only serve as valuable contributions to the literature, but also provide better information to support better policies and management strategies to achieve a more competitive chicken industry in Ghana.

The reminder of the study proceeds as follows. After a brief overview of Ghana's poultry industry, a description of the empirical approaches of measuring efficiency, a review of past poultry production efficiency studies in Ghana and the empirical and conceptual framework underlining chicken feed demand are then presented. The next two chapters focus, respectively, on the data used for the study and the results of the study. Finally, a brief discussion of the conclusion and implications of the study findings for management strategies is presented.

Chapter 2 - The Ghana Poultry Industry

This Chapter presents a profile of the poultry industry in Ghana. The geographic and size distribution of chicken farms, chicken meat and egg supply as well as the performance situation of the chicken industry for the year 2015 are discussed in section 2.1. In section 2.2, a succinct overview of the domestic chicken market and consumption dynamics including Ghana's chicken import trend is presented. The poultry feed cost situation in Ghana as well as poultry policy design in developing countries are then presented in the last two sections.

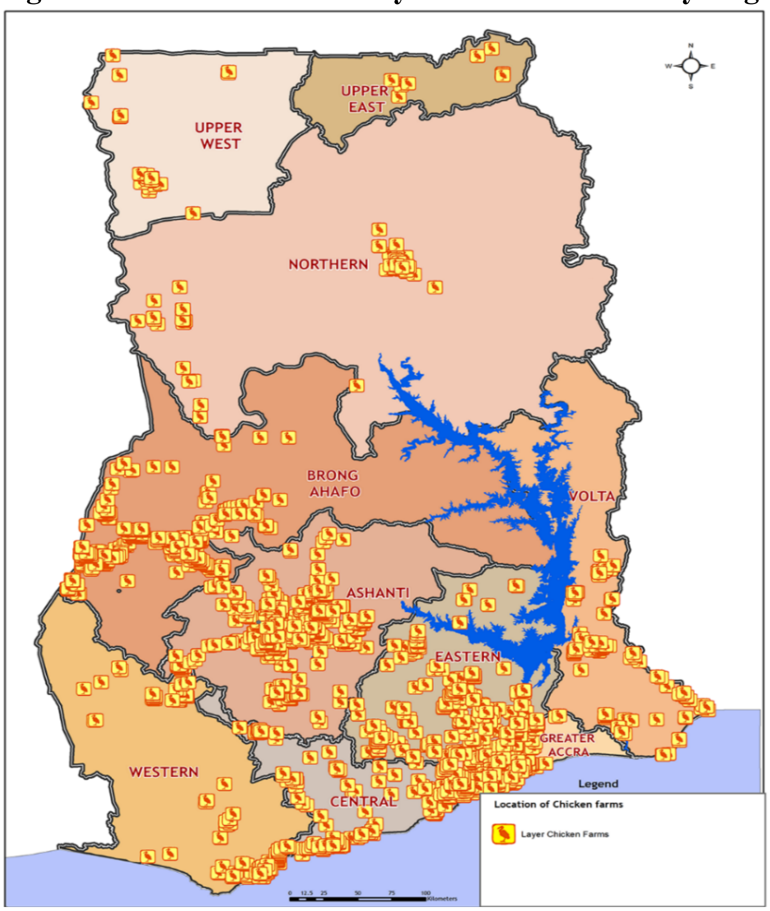
2.1 Domestic Production[6]

The poultry industry can be defined broadly to encompass all the major domesticated feather species. In Ghana this encompasses chicken, guinea fowl, turkey, duck, geese, quail and ostrich. Chicken is the dominant of all poultry species in Ghana with about 96.3% of poultry farms producing chicken-related products, comprising of two production segments: layer production, with table egg as the principal output and broiler production with live-birds as the principal output. Layer production is the dominant segment of Ghana's chicken industry. About 74.3% of chicken farms produced eggs in 2015 compared to only 38.8% that produced broilers. As shown in Figure 2:1 layer operations are located in all ten regions of Ghana, but are most concentrated in Ashanti Region (24.6% of all layer farms), Brong-Ahafo Region (22.5% of all layer farms), Eastern Region (12.7% of all layer farms) and Greater Accra Region (11.9% of all layer farms) (Amanor-Boadu et al. 2016). Most layer production takes place on a large number of small farms. According to the 2015 census of poultry producers report, layer farms with fewer than 5,000 birds (small-sized

[6] Supply figures presented in this section are for the year 2015 and based on production estimates from the 2015 Ghana Poultry Industry survey report. For a more detailed analysis on the structure and performance of Ghana's poultry industry in 2015, see Amanor-Boadu et al. (2016)

farms) accounted for 88% of total chicken farms with layers whereas layer farms with more than 10,000 birds (large-sized farms) accounted for 5.6% of chicken layer farms. In addition, farms with fewer than 10,000 birds but more than 5,000 birds accounted for 6.3% of total chicken farms with layers (Amanor-Boadu et al. 2016).

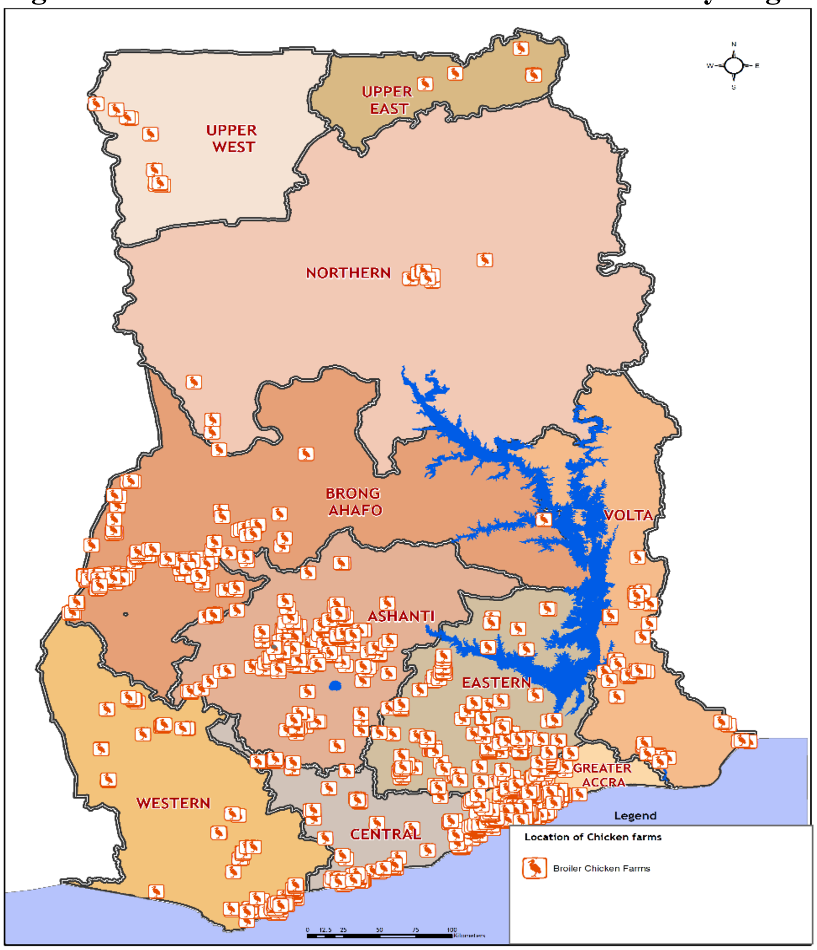
Figure 2:1 Distribution of Layer Chicken Farms by Region (2015)



Source: Adapted from Amanor-Boadu et al. (2016)

Broiler production is concentrated in Greater Accra (21.1% of all broiler farms), Eastern (18.4% of all broiler farms), and Central (14.7% of all broiler farms) Regions (Figure 2:2). Like layer production, most broiler production takes place on a large number of small farms. As shown by the 2015 poultry census report, approximately 86.7% of broiler farms fall within the small-sized category, about 8.6% fall within the medium-sized category and the remaining 4.8% are large-sized farms. However, most large-scale broiler operations take place in Brong-Ahafo Region (with about 15.6% of large broiler farms) and Ashanti Region (with about 7.5% of large broiler farms).

Figure 2:2 Distribution of Broiler Chicken Farms by Region (2015)



Source: Adapted from Amanor-Boadu et al. (2016)

Based on the 2015 Ghana Poultry Industry survey report, Table 2:1 summarizes the size distribution of chicken output in Ghana for 2015. Information regarding egg production revealed that in 2015 small-sized layer farms accounted for 32.0% of total egg output and produced an average of 6,091 crates of eggs per farm whereas medium-sized layer farms accounted for 13.2%, producing an average of 33,573 crates of eggs per farm (Table 2:1). Large-sized layer farms produced an average of 157,567 crates per farm while accounting for 54.8% of total egg output in 2015 (Table 2:1).

Table 2:1 Broiler and Egg Production for 2015 by Size of Operation

Size	Broiler Farms		Layer Farms	
	Average (Birds)	Production Share (%)	Average (Crates)	Production Share (%)
Small	530	32.6	6,091	32.0
Medium	2,807	17.0	33,573	13.2
Large	14,841	50.4	157,567	54.9
Total	1,410	100	16,694	100

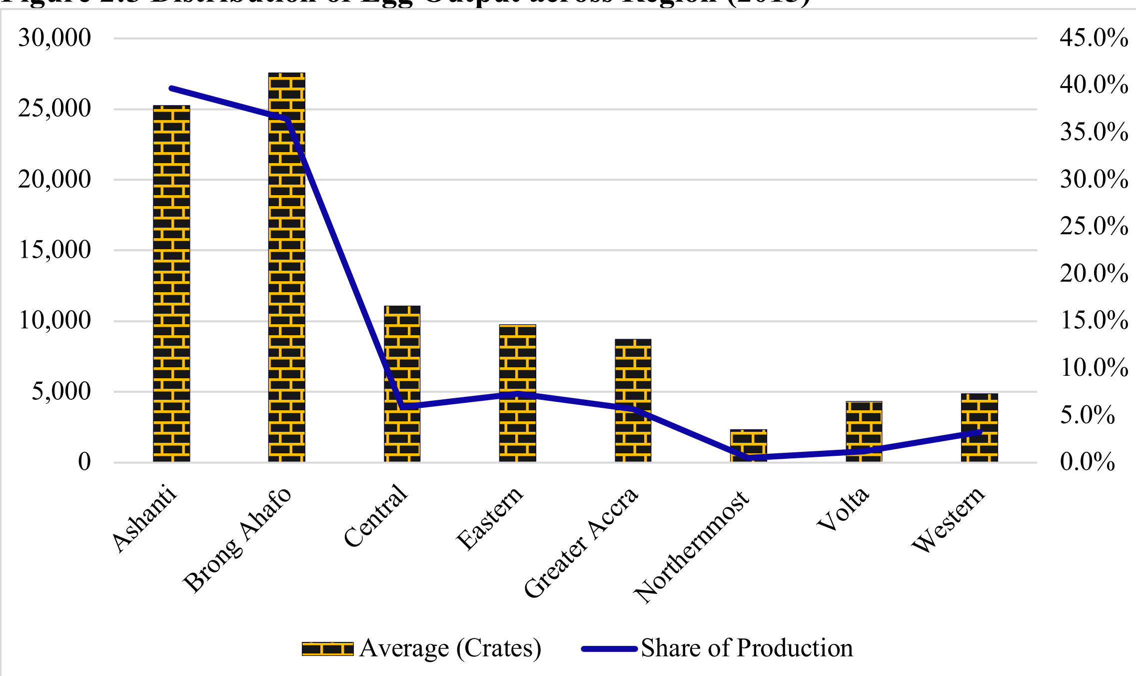
Source: Author's computation based on the 2015 Ghana Poultry Industry survey

The distribution of egg production by region shows that the average output per farm were 27,544 crates, 25,235 crates, and 11,061 crates in Brong-Ahafo, Ashanti and Central Regions in 2015. In the low egg producing areas of Volta, Western and the three northernmost regions the average egg output per farm were 4,342 crates, 4,855 crates and 2,357 crates, respectively (Figure 2:3). Small-sized broiler farms raised an average of 530 birds compared to 2,807 birds raised by medium farms and 15,000 birds by large farms (Table 2:1). At the same time, small farms accounted for 32.6% of total broiler output, medium-size farms' output share was 17.0% and large farms accounted for 50.4% of total broiler output (Table 2:1). The top three broiler producing regions – Brong-Ahafo, Ashanti, Greater Accra – produced on average 3,792 birds, 1,525 birds, and 1,006 birds per farm respectively in 2015 (Amanor-Boadu et al. 2016). In contrast, Volta and Western Regions had the lowest broiler flock size, averaging 549 birds and 895 birds per farm, respectively (Figure 2:4).

As noted in the 2015 poultry census report, chicken farms also differ in other economically important ways (production cost and gross margin) by farm size and geographic location. In general, larger chicken farms have lower average production cost and higher average gross margin.

According to Amanor-Boadu et al. (2016) estimated total average variable cost was around GHS 20.10 per bird for large-sized broiler farms and GHS 11.32 per crate for large-sized layer farms. This compares to the average variable cost of GHS 27.07 per bird and GHS 12.17 per crate for small-sized broiler and layer farms, respectively. Average gross margins of GHS 10.49 per bird and GHS 1.73 per crate were reported for large-sized broiler and layer farms, respectively; GHS 10.34 per bird and GHS 1.73 per crate for medium-sized broiler and layer farms, respectively; and GHS 8.64 per bird and GHS 1.24 per crate for small-sized broiler and layer farms, respectively.

Figure 2:3 Distribution of Egg Output across Region (2015)

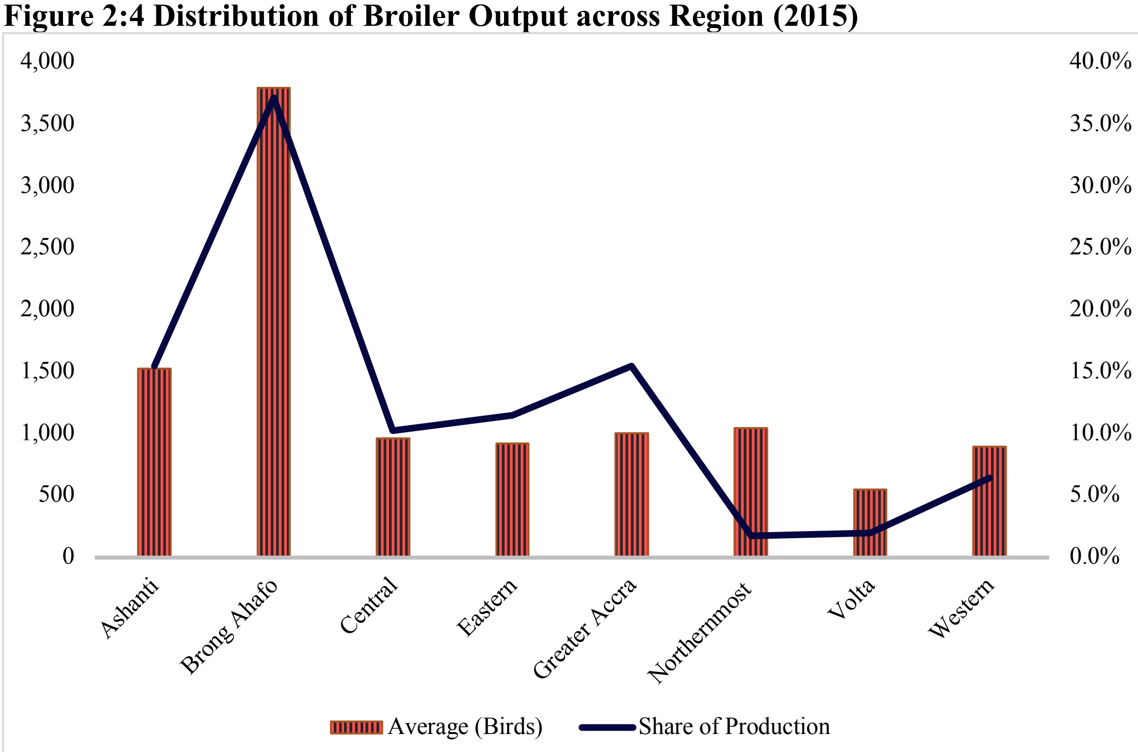


Source: Author's computation based on the 2015 Ghana Poultry Industry survey

Gross margins and cost structures also differ considerably by region. High egg output regions have lower average variable cost whereas low egg output regions have higher average gross margins. Ashanti and Brong-Ahafo Region are the lowest variable cost regions in chicken egg production averaging about GHS 11.83 and GHS 11.62 per crate of eggs, respectively, while

Central and Greater Accra are the highest variable cost regions averaging GHS 12.57 and GHS 12.43 per crate of eggs, respectively. Volta Region has the highest gross margin per crate of eggs, averaging about GHS 1.74. Western and the northernmost regions followed closely with an average gross margin of about GHS 1.60 per crate of eggs. The average gross margin for Ashanti and Brong-Ahafo Regions were GHS 1.14 and GHS 1.33 per crate of eggs, respectively. The variations in average cost, average gross margin and flock size, as presented in this section, underscore the potential for regional and size differences in allocative, cost and technical efficiency in domestic chicken production in Ghana.

Figure 2:4 Distribution of Broiler Output across Region (2015)



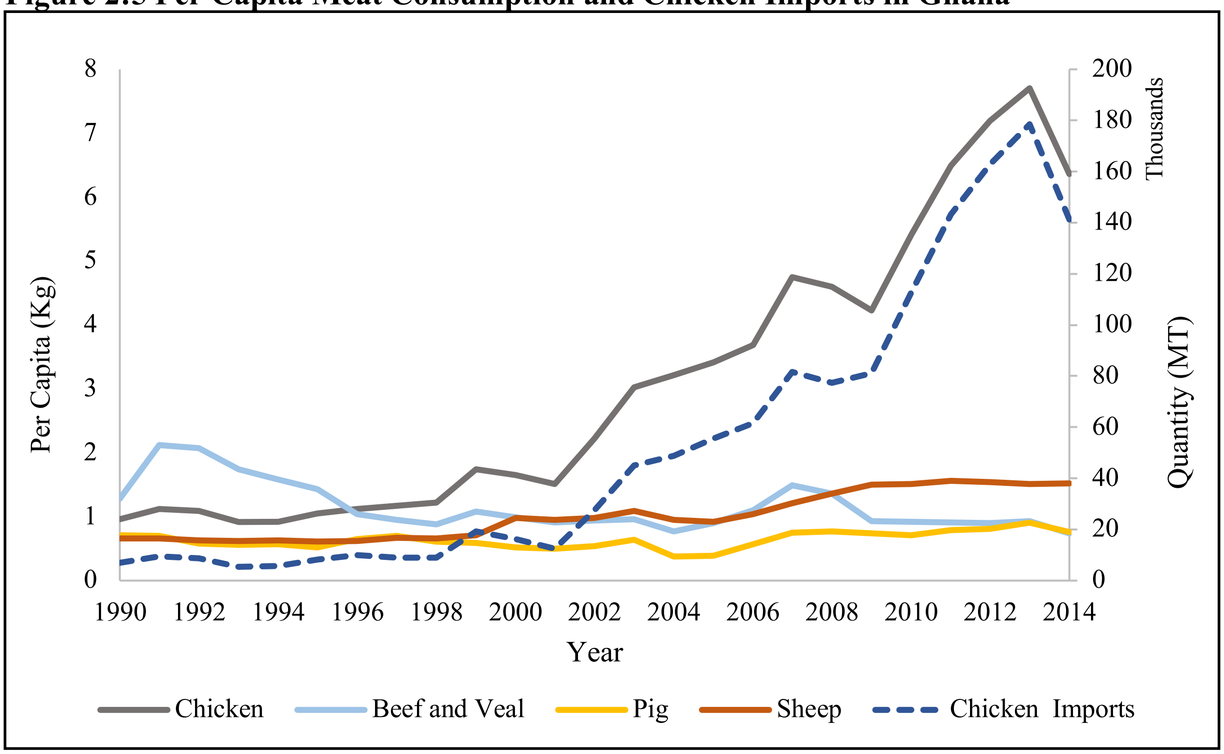
Source: Author's computation based on the 2015 Ghana Poultry Industry survey

2.2 Market and Consumption Dynamics

As previously indicated, Ghana's chicken market comprises of two segments. The layer market with table eggs as the main product sold and the broiler market with two differentiated products: live birds and ready-to-cook (RTC) fresh, frozen, chilled chicken meat. While domestic producers have a monopoly over the live birds and eggs market, the RTC market has been ceded to importers with little participation by domestic producers. In spite of the dominance of domestic production in the live birds' market, the share of live birds in total broiler meat supply keeps falling. According to the OECD-FAO agricultural statistics, the share of domestic broiler production in total broiler meat supply declined from about 67% in 1993 to 31% in 2015. A mixed bag of forces is driving this structural change in consumption toward RTCs. The rise in income caused the average consumer to substitute away from 'starchy staples' towards animal protein and fats and oils (see Bennett 1941). This phenomenon, known as Bennett's law, might be one of the causal factors of the changing consumption pattern towards protein-rich diet and ready-to-cook chicken meat products in Ghana. Also, as income rises, "time is reallocated to the disadvantage of time-consuming pursuits" (Baumol 1973), such as slaughtering and processing of live-bird (the dominant marketable form of domestically produced broilers) for home consumption. Thus, as the Ghanaian economy improves and modernizes, imported ready-to-cook chicken products become the product of routine choice for the increasingly time-constrained urban consumers with increasing disposable incomes.

The changing demand profile of Ghanaian consumers underscore the rapid growth in chicken meat imports and challenging environment in which the Ghanaian poultry industry finds itself. For example, using OECD-FAO Agricultural Outlook Trade Data, the quantity of fresh, chilled and frozen edible poultry meat and offal imports into Ghana was estimated to have increased from about 7,064 metric tons in 1990 to 178,509 metric tons in 2013, before declining to nearly 141,237 metric tons in 2014 (Figure 2:5). The effect of this trend is a decline in the market share of domestic production in the chicken broiler market space, creating policy concerns about the future, performance, and sustainability of domestic chicken operations. As a result, the development of the sector has been considered a major public policy priority. This occurred because of the wide-ranging implications for food security, poverty reduction and improvement in protein and micronutrient deficiencies due to its low investment, rapid turnover rate, wider acceptability across religion and cultures, and comparatively low-cost for consumers.

Figure 2:5 Per Capita Meat Consumption and Chicken Imports in Ghana



Source: OECD-FAO Agricultural Outlook Trade Data, complied by author

Per capita income in Ghana is rising, and as suggested by Bennett's law, consumption of animal protein, particularly chicken products, has been following a similar growth trend. Between

1990 and 1999, total chicken meat consumption grew at 6.8% per annum against a less than one percent annual growth in gross domestic product (GDP) per capita. The growth rate in total chicken meat consumption doubled between 2000 and 2015 whereas GDP per capita has been growing at 13.7% per annum. However, according to OECD-FAO Agricultural Outlook Trade Data, the average per capita consumption of chicken eggs and meat – 18 eggs (1.21 kg) per capita in 2013 and 6.36 kg retail weight (rwt) of chicken meat per capita in 2014 – are below the recommended consumption levels of 131 eggs (9.19 kg) per capita and 13.2 kg rwt chicken meat per capita, respectively. As clearly shown in Figure 2.5, per capita chicken consumption in Ghana moves in a similar direction as supply. A decline in consumption reflects a decline in supply. Therefore, the relatively low per capita chicken meat and egg consumption in Ghana may have its foundation in the inability of supply to meet potential demand, ceteris paribus. The combination of relatively low per chicken consumption, the growing demand for poultry products and increasing incomes coupled with projected rapid growth in high-value agricultural products such as poultry products in developing countries (Alexandratos and Bruinsma 2012) represents significant market opportunities for poultry producers in Ghana, where most demand is met by domestic production. Addressing potential production and cost efficiency gaps associated with domestic poultry production in Ghana, undertaking in this study, will contribute to improvements in the performance and competitiveness of Ghana's poultry industry.

2.3 Poultry Feed Situation in Ghana

As with most poultry production systems across the world, feed cost is consistently identified as a constraint to production expansion and profitability in Ghana. For example, Etuah et al. (2013) show that broiler farmers in Ghana's Ashanti Region rank high feed costs as the severest constraint to their production ahead of "competition from cheap imports" and "lack of government support". Thus, among chicken producers in Ghana, there is increasing interest in lowering production cost via reducing feed cost, yet, much of the focus of national poultry policies in Ghana remain linked to the imposition of higher tariffs on poultry imports[7] (Sumberg et al. 2013). The issue of feed-food competition also heightens the severity of the feed constraint situation. Maize, which constitutes about 60% of chicken feed, is the second most important staple crop in Ghana. The yield per hectare of maize is low and shortfalls in domestic production for human consumption exist. The net result is a continuing shortage of maize for feed use that translates into high feed price.

A study by Amanor-Boadu et al. (2016) estimated feed cost at 74.2% of total variable cost in broiler operations and 92.3% in egg or layer operations. Regional and scale variations in feed cost were also identified in the same study. For instance, in broiler operations, feed cost as a proportion of total variable cost ranged between 92.9% for the three northernmost regions (Upper East, Upper West, and Northern Regions) and 77.5% in Ashanti Region. In the same study, feed cost share of total variable cost averaged 74.8% for small-scale farms compared to 73.2% for medium-scale and 72.6% for large-scale operations. Also, feed cost and gross margin were shown to exhibit a direct positive relationship. High feed cost regions were estimated to contribute less to total gross margin, so were small-scale operations having the least gross margins. Thus, a high share of variable cost attributable to feed prompts understanding producers' feed demand decisions and their determinants.

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[7] For example, in 1999 a 20 percent import tariff was assessed on all poultry meat imports, which was later dropped to 10 percent and completely removed in 2002 (FAO 2014). The implementation of an Economic Community of West African States (ECOWAS) Common External Tariff (CET) established a new poultry import tariff of 20 percent in 2005. In 2016, a fifth band of the CET for products considered most sensitive came into force, increasing the tariff on all imported poultry products to 35 percent. In addition to the 35 percent tariff, a livestock import policy that requires importers of poultry products to purchase 40 percent of chicken meat from local sources, was adopted in the latter part of 2014.
(see https://www.rvo.nl/sites/default/files/2015/05/Analysis%20Poultry%20Sector%20Ghana_april%202015.pdf).

2.4 Poultry Policy Design in Developing Countries

A review of policies and programs of developing countries – Brazil, Thailand, Vietnam, and India – that have successfully transformed their poultry sector into a domestically and internationally competitive industry reveals lessons applicable to the Ghanaian context. For example, the harmonious integration and coordination of a set of vertical activities – production, processing, and distribution – along the production path through institutional innovations and internalized coordination mechanisms served as a driver for the transformation of the Brazilian poultry industry into an internationally competitive industry with increased performance and productivity (Farrelly 1996).

In the late 1960s, Brazilian policymakers realized that the strategy to increase performance in the poultry sector through protectionist and restrictive initiatives did not achieve the objective of increasing competitiveness of domestic production. A set of new initiatives that focused on developing the internal structures of the industry to increase performance and competitiveness were instituted. Institutional and policy innovations played a pivotal role in developing the internal structures of the poultry sector (Farrelly 1996). For example, through the promotion of effective integration contracts with incentive structures, farmers' technical performance was improved. Also, significant investment in research and development (R&D) resulted to the development of improved strains of birds adaptable to local conditions with lower mortality, and high feed conversion efficiency.

These policies together with government involvement in all activities along the production path, served to make inputs available, affordable and accessible to decrease transaction costs, manage risk, and achieve economies of scale and scope. Moreover, the development of the Brazilian poultry industry also arose from the progressive integration of the vertical production system that led to a qualitative change in the level of production, with low production and transaction cost due to economies of scale as defining characteristics. As a result, the sector became increasingly efficient, contributing to the current global dominance of Brazilian chicken exports[8].

In the case of Ghana, public policies have not been successful at addressing the issues of high transaction and production cost, low performance and productivity, and low competitiveness of domestic production. Much of the focus in relation to domestic or national poultry policy systems remain linked to the imposition of higher tariffs on poultry imports. Considering the transformation of the poultry industry in Brazil, a viable pathway towards a low cost, high performance and internationally competitive domestic poultry industry in Ghana is contingent, more importantly, on understanding the internal structures influencing performance prior to embarking on public policy interventions. As such, understanding the performance characteristics, constraints to production and cost efficiency, and input choice behavior among producers is essential to understanding the internal structures of Ghana's chicken industry.

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[8] According to OECD-FAO Agricultural Outlook Trade Data, Brazil increased its poultry meat exports from 168,813 tons in 1980 to over 4.2 million tons in 2015 while overtaking the United States as the leading exporter of poultry meat.

Chapter 3 - Research Methods

The first part of this chapter discusses the limitations, advantages and assumptions underlining the two main approaches of measuring efficiency: parametric and non-parametric. The second part consists of the description of input-oriented DEA models used in addressing objective one of this study, by providing the framework for measuring farm-specific relative technical, allocative, scale and cost efficiencies. The third part consists of a description of the bootstrap and truncated regression models employed to assess the influence of farm and farmer specific factors on estimated farm efficiency scores. Lastly, the conceptual and empirical frameworks underscoring the Cragg Double hurdle model used to estimate producers' feed demand are discussed in section 3.4.

3.1 Theoretical Approaches of Measuring Efficiency

Researchers working in efficiency analysis typically use one of two fundamental approaches: the parametric approach, after Aigner, Lovell, and Schmidt (1977) and Meeusen and van Den Broeck (1977); and the nonparametric approach, after (Charnes, Cooper, and Rhodes 1978; Banker, Charnes, and Cooper 1984)) and Färe et al. (1985). The specific advantages and limitations of the two approaches are presented in the remainder of this section.

3.1.1 The Parametric Approach

The parametric approach is based on the econometric estimation of a frontier function which begins by fitting a functional form to observed data to determine a priori input-output relationships (Coelli et al. 2005). The level of inefficiency is the measured distance between the observations and the estimated frontier function. The stochastic frontier (SF) approach dominates the application literature in econometric efficiency estimation (Greene 2007). This approach allows for the departure of observed choices from optimal ones to be due to both unforeseen or uncontrollable factors and inefficiency via a convoluted error term. Formally, the model can be expressed as $y_i = f(x_i;\beta) + \mu_i - \nu_i$, where y_i is observed outcome, x_i is a vector of K inputs and β is a vector of $K+1$ technology parameters. The deterministic portion of the frontier is $f(x_i;\beta)$ and $f(x_i;\beta)+\mu_i$ is the optimal outcome. The model uses two distinct error terms μ_i and ν_i, where μ_i captures random shocks, statistical noise, or measurement errors and ν_i represents the inefficiency term. By definition ν_i is assumed to be greater than or equal to zero. In practice, it is general assumed that μ_i and ν_i can take on a range of distributional specifications - half-normal, truncated normal, gamma, exponential (Aigner et al. 1977); Meeusen and van Den Broeck 1977; Stevenson 1980; Greene 1980). However, the choice of distribution is sometimes arbitrary and ambiguous, but μ_i is generally accepted to be normally distributed with zero mean and variance σ_μ.

The SF model as described only allows for the estimation of average level of technical inefficiency in a sample. However, observation-specific efficiency information may be extracted by using the Jondrow et al. (1982) conditional expectation formula or the efficiency estimator developed by (Battese and Coelli 1988). If estimation of observation-specific efficiency is the end goal, the distributional assumption imposed on ν_i becomes crucially important. This is because evidence of differences in firm-level efficiency estimates and inferences across different distributional specifications for ν_i exist in the empirical literature (Chirikos 1998; Folland and Hofler 2001; Baccouche and Kouki 2003). The truncated normal distribution, for example, is a generalization of the half normal distribution. However, in economic terms the half normal assumes that the probability of being inefficient is small whereas the truncated normal affords more flexibility regarding the extent of inefficiency.

Several distribution selection test-procedures such as the Likelihood ratio (LR) test, Lagrange multiplier (LM) test, Kolmogorov–Smirnov test, Pearson χ^2 test, and Wald test have been proposed to test the adequacy of distributions for the inefficiency term in a sample. Yet, determining the true distribution for the inefficiency term is a generally challenging problem since these tests usually provide ambiguous outcomes (Broek et al. 1980; Forsund, Lovell, and Schmidt 1980). For instance, the non-rejection of a particular distributional assumption against plausible alternative distributions does not make it the true underlying distribution for the inefficiency term in a sample. On the other hand, the rejection of a specific distributional assumption could be subjected to several interpretations. It could mean that the assumed normal distribution of μ_i may be incorrect, and/or imposed restrictions on the technology could be affecting the distribution of the inefficiency term (Bauer 1990).

In addition to the distribution of the inefficiency term, the adequacy of the functional form used to fit the observed data is another challenge. Different functional specifications impose different restrictions on certain features (e.g. elasticities, factor substitution, shape of isoquant) of the production, or cost function (or profit, etc.), that can distort the efficiency measures (Greene 2007). However, flexible functional forms that can relax these restrictions may also fail to enforce the monotonicity or global convexity properties of the underlying production, or cost function (Greene 2007). As such, the efficiency measures in this setting may also be misleading. All told, as appropriately observed by Varian (1984), the parametric form "must be taken on faith" since the true functional form could never be directly tested.

3.1.2 The Nonparametric Approach

Developed by Charnes et al. (1978), the nonparametric data envelopment analysis (DEA) approach is a piecewise linear representation of the underlying technology and it is constructed by using linear programming techniques to *envelope* observed data. Although it is easy to implement, the applicability of the linear programming techniques is premised on the assumption that observed decision-making units (DMU) are implicitly homogenous in their input and output traits. As observed by (Farrell 1957), it is sometimes the case that quality differences exist in the factors of production due to the time and value dimensions of capital. Thus, the homogeneity assumption may be too restrictive and efficiency measures may be reflecting these quality differences.

In DEA, the efficiency level of a DMU is measured relative to the entire set of DMUs being evaluated and it is estimated as the distance between each observation and the "best practice" frontier. The frontier is a linear/convex combination of observed best/optimal methods of production among the DMUs in a specific enterprise. The linear/convex combination property of the nonparametric frontier can have several implications. First, it implies that by construction it is technically feasible for the DMUs to produce any weighted average combinations of the input-output bundles because of the implicit infinite divisibility of inputs and outputs assumption. This assumption is generally restrictive or unrealistic, because in reality inputs may not exist in a continuous quantity. Second, reference DMUs' the performance or "best practice" may be suboptimal compared to the theoretical best out of sample best results. This construct of the nonparametric frontier (formed by observed "best practice" in a sample) may impose some structural limitations on the nonparametric approach. First, the potential sensitivity of the nonparametric efficiency scores to the number of observations, the number of outputs and inputs, and the dimensionality of the frontier (Thiam et al. 2001); (Ramanathan 2003). Second, the effect of extreme observations that could make up the frontier (Bravo-Ureta et al. 2007). The efficient frontier obtained in such environments may not reflect the "true" frontier.

Nonparametric frontiers have one-sided distribution or error by construction with no *a priori* assumptions on the distributional structure underlying the data, and are not a construct of a particular functional form (Chavas and Aliber 1993); Färe et al. (1985)). However, nonparametric estimators are inherently deterministic in nature, which indicates that they do not accommodate stochastic phenomena such as measurement errors or random noise in the data that can potentially bias efficiency estimates (Hallam 1992). All errors or deviations from the frontier are ascribed to managerial inefficiencies, which can be misleading in decision-making. If data are contaminated with statistical noise, the efficient frontier obtained may be warped and not a reflection of the "true" or optimal frontier for DEA. Also, not accounting for observational errors due to shock or statistical noise makes it challenging to draw statistical inferences from the analysis.

An attempt to contain managerial and observational errors in DEA estimation can be found in the literature through an integration of DEA with artificial neural network (ANN) (Wang 2003). Wang (2003) demonstrates that neural network based non-parametric models can be used to create data envelopes that are based on the entire original data set, rather than some outlier data points from which uncertainty has been lost. These models assist in finding a non-linear regression function for the data set from which a distribution with a unique shape called extreme-unbalanced-two-tailed distribution can be obtained (Wang 2003). This distribution accounts for potential managerial or observational deviations. In terms of drawing statistical inferences, recent innovations in efficiency analysis have indicated that bootstrapping techniques could improve the statistical efficiency of regression estimates as well as correct biases in the efficiency estimates. For example, Simar and Wilson (2007) developed the bias-correcting single and double bootstrap techniques capable of describing the underlying data-generating process (DGP) with the simulation of a sampling distribution for the nonparametric model. It provides consistent inference within data envelopment analysis model estimations and corrects the biased efficiency estimates that are produced from the traditional DEA approach.

3.1.3 Empirical Studies on Poultry Production Efficiency in Ghana

There are not many studies on efficiency in Ghana's poultry industry. The few that has been done estimate efficiency using the stochastic frontier analysis (SFA) approach and focus attention on chicken farms in the three largest chicken-producing regions – Ashanti, Brong-Ahafo, and Greater Accra. Dziwornu et al. (2014) and Etuah (2014) use the stochastic cost frontier model to examine farm-level cost efficiency for small scale commercial broiler farms. Profit efficiency is examined in both broiler production (Dziwornu and Sarpong 2014; Tuffour and Oppong 2014) and layer production (Yevu 2013) using the stochastic profit frontier model. Results from these studies suggest significant profit inefficiencies of the order of 32% to 46% in broiler operations and 35% in layer operations from harnessing existing resources in a less efficient manner. Likewise, cost inefficiencies ranged between 10% and 14% in broiler operations. By reallocating resources, these studies suggest that an average broiler farm can reduce input costs by at least 10% or increase profit by at least 32% whereas an average layer farm can increase profit by at least 45% when producing on the efficient frontier. These outcomes underscore the potential for improvement in both profit and cost efficiencies within Ghana's chicken industry.

A common feature of these studies is the in use of the Cobb-Douglas functional form and a normal-truncated normal error distribution. The functional form and error distribution are imposed to approximate the underlying technology. However, the adequacy of their approximation is rarely tested in the above studies. It is important to note that efficiency measurements are sensitive to a priori assumptions about the functional forms and error distributions (Baccouche and Kouki 2003). Hence, the results from these studies may be biased if the Cobb-Douglas functional form and the normal-truncated normal error distribution do not appropriately approximate the true underlying technology and distribution of error term. The implication of this bias can be severe if policies are implemented on the results of such models.

This study differs from related efficiency studies of the Ghana poultry industry in many important ways. The most important point of departure is its use a census of chicken farms in all regions across the country. It also differs in its estimation of technical and cost efficiencies via the non-parametric data envelopment analysis (DEA) procedure. Amanor-Boadu et al. (2016) showed that Ghana's chicken operations display regional differences in all dimensions – size, cost, prices, profits, etc. For example, the average variable cost of layer production is significantly lower for farms in the Ashanti and Brong-Ahafo Regions (Amanor-Boadu et al. 2016). Such differences have the probability to result in variability in regional allocative and cost efficiency. Because farm census data for all regions are used, this study provides region specific production and cost efficiency ratings for chicken farms across the country. The next section provides the mathematical formulation of the DEA approach to address the study's objectives.

3.2 Data Envelopment Analysis

In this dissertation, the nonparametric data envelopment analysis approached developed by Charnes et al. (1978) is used to estimate farm specific relative technical, scale, allocative and cost efficiency. DEA is a mathematical programming technique applied to frontier analysis that can handle large numbers of input and output variables. This technique is usually introduced as a nonparametric, deterministic procedure that rests on the assumptions of linearity and proportionality to assess the relatively efficient production frontier based on observed input-output data. From the set of similar DMUs, DEA identifies the reference set (those exhibiting best practice) to define the efficient frontier. The level of efficiency of DMUs operating off the frontier can then be evaluated as a radial projection to the efficient frontier.

Two general approaches to derive the properties of a production technology are found in the literature. These may be characterized as primal (input/output) and dual (cost or profit) approaches depending on the behavioral assumption made. The primal approach uses only input/output data to construct a series of nonparametric frontier technologies (Färe and Grosskopf 1985). Technical and scale efficiency are subsequently estimated under the assumption that input/output multipliers or prices are unknown. These multipliers or weights are empirically determined from the observed data. The dual approach employs cost or profit rather than input data to construct a series of nonparametric cost frontiers. Thus, input and/or output prices are known or observed. The cost efficiency for each observation is estimated relative to the efficient cost frontiers. Information on the estimated observation-specific technical efficiency together with the observed cost data can be used to estimate observation-specific allocative and scale efficiency. Although, the dual cost approach corresponds more closely to the theoretical concept of economic behavior (cost minimization), relative price variability is a necessary requirement for unbiased parametric estimation of the cost efficiency indexes with cross-sectional data (Lusk et al. 2002). This limitation is overcome by the use of nonparametric estimation procedures. In what follows, the DEA procedure for the different efficiency measures mentioned above is presented in detail.

3.2.1 The Technical Efficiency Measures

The theoretical basis for the DEA technical efficiency estimation procedure is provided by the conventional benefit/cost theory via the ratio of weighted outputs to weighted inputs. The output and input weights are generally unknown but estimated empirically from the observed input-output data. Let's assume that there are n DMUs to be evaluated, with each DMU_j $(j = 1,....,n)$, using m inputs, $x_{ij}(i = 1,....,m)$ and generating s outputs, $y_{rj}(r = 1,....,s)$. Each DMU_j is denoted by (x_j, y_j) with $x_j \in \mathbf{R}^m$ and $y_j \in \mathbf{R}^s$. And the matrix of observed inputs and outputs are denoted by $X = (x_{ij}) \in \mathbf{R}^{m\times n}$ and $Y = (y_{rj}) \in \mathbf{R}^{s\times n}$, respectively. X and Y are assumed semi-positive (all inputs are non-negative and at least one input and one output have a positive value). The overall input measure of technical efficiency (CCR efficiency) by Charnes et al. (1978) is calculated by solving the following fractional programming problem which compares weighted multiple inputs with weighted multiple outputs data (multiplier form):

$$
\begin{aligned}
e_j = \ & Max \ \ \mu y_j / \upsilon x_j \\
& s.t \\
& -\upsilon X + \mu Y \le 0 \\
& \mu \ge 0 \\
& \upsilon \ge 0
\end{aligned}
\tag{3.1}
$$

where e_j is the efficiency score of DMU_j, the DMU to be evaluated, $\mu, v \ \ge 0$ are nonnegative scalars or multipliers determined by the solution to the nonlinear fractional programming (FP_j) problem. Following Charnes and Cooper (1962), the above nonconvex nonlinear formulation can be transformed to a linear programing, LP_j, formulation to make it easily solvable by applying the theory of linear fractional programming using the following transformation: $\mu = tu^T$; $\upsilon = tv^T$ and $t = (v^T x_j)^{-1}$. The linear programming problem, LP_j, is then given as:

$$
\begin{aligned}
Max \quad & u^T y_j \\
s.t \quad & \\
v^T x_j &= 1 \\
-v^T X + u^T Y &\leq 0 \\
u^T &\geq 0 \\
v^T &\geq 0.
\end{aligned} \tag{3.2}
$$

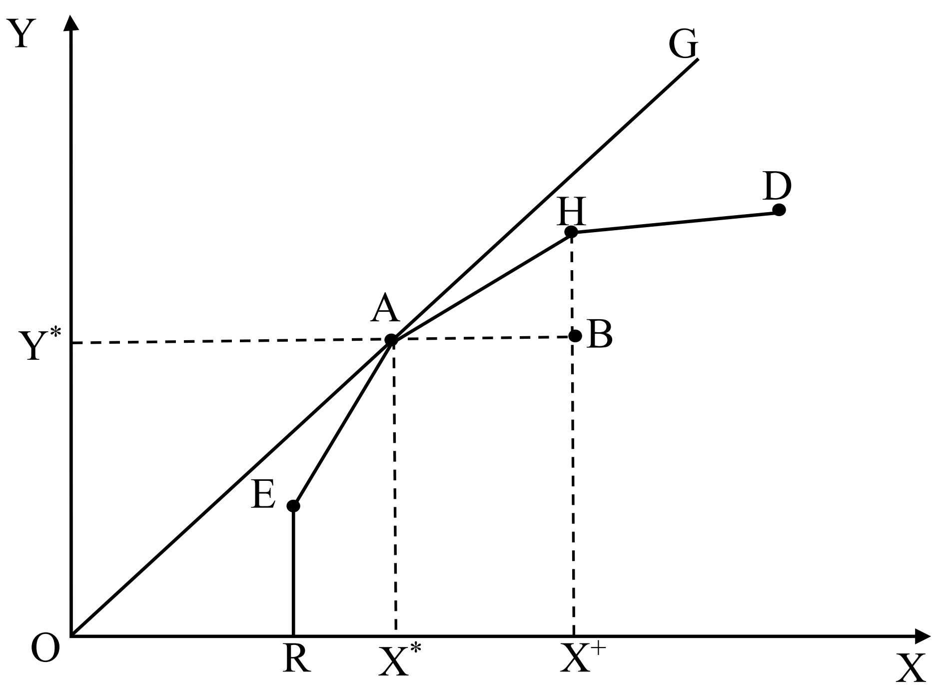
Measuring overall input technical efficiency via the LP_j model can pose some estimation problems as well. In particular, the computational effort grows as the number of DMUs, n, increases. Also, the economic interpretations of LP_j are less direct or straightforward in terms of the output and input weights (Charnes and Cooper 1962). The dual, DLP_j, to the linear programming problem, called the envelopment problem, is easier to implement with fewer computational challenges. All coefficients or optimized parameters have direct economic interpretations, hence, the preference for the DLP_j formulation in DEA efficiency analysis. The DLP_j for DMU_j can be mathematically formulated as follows:

$$
\begin{aligned}
Min \quad & \theta_j \\
s.t \quad & \\
\theta_j x_j - X\lambda &\leq 0 \\
Y\lambda &\geq y_j \\
\lambda &\geq 0
\end{aligned} \tag{3.3}
$$

where $\lambda \in \sim^n_+$ is a vector of optimal weights assigned by the linear program, and θ_j is the estimated efficiency. If the optimal solution (θ_j^*, λ^*) of the DLP_j above satisfies the Pareto-Koopmans efficiency condition $(\theta_j^* = 1)$, then DMU_j is overall technical or CCR-efficient. Otherwise, DMU_j is CCR-inefficient when $\theta_j^* < 1$ (Charnes and Cooper 1962).

A graphical illustration of the frontier technology formed by the constraints in DLP_j for a single output single input case is provided in Figure 3:1. The ray OAG forms the efficient frontier or reference technology. It can be seen that the output quantity, Y^*, for observations A and B corresponds to different bundle of resources, X^* and X^+ respectively. The figure shows that B requires X^* / X^+ times as much input as A to produce the same output quantity, Y^*. Thus, it is possible to rescale *B's* input use from X^+ to X^* to generate a resource mix that is overall technical or CCR-efficient.

Figure 3:1 Illustration of Production Efficiency Frontiers



Technical efficiency measures may be derived in terms of inputs (*input-conserving orientation)* or in terms of output (*output-augmenting orientation).* The choice of either an *input-oriented* or an *output-oriented* model depends on DMUs' control over their input or output variables. The version described in Figure 3:1 is the *input-oriented* model, which minimizes all inputs by the same proportionality factor, θ_j^*, while satisfying at least the observed output level. The *output-oriented* model, on the other hand, maximizes outputs with given inputs. Mathematically, the optimal solution, η_j^*, of an *output-oriented* CCR model can be derived from an optimal solution of the *input-oriented* CCR model via: $\eta_j^* = 1/\theta_j^*$. Intuitively, η_j^*, represents an equal expansion rate for all outputs with higher values (*i.e.* $\eta_j^* > 1$) corresponding to low efficiency.

The underlying production frontier in the *input-oriented* CCR model is linearly homogenous and assumes a constant returns-to-scale frontier technology. This means that increasing the input level of an efficient DMU results in the output level increasing by the same factor. In the absence of any bounds on inputs, the assumption of constant returns-to-scale is rather restrictive or unrealistic. Microeconomic theory suggests that the degree of homogeneity can be greater than, equal to, or less than one, creating 'economies' or 'diseconomies' of scale. However, the CCR model is unable to effect a separation of potential scale variations. Responding to this limitation of the CCR model, Banker, Charnes, and Cooper (1984) (BCC) proposed an extension to the CCR model by appending a convexity condition, $\sum \lambda_j = 1$, that put no restriction on the allowable returns to scale. In this case, the frontier technology is characterized by variable returns-to-scale (VRS) and can exhibit increasing or decreasing returns-to-scale in different regions of the feasible space. This situation is illustrated in Figure 3:2, where point *E* up to, but not including point A, exhibit increasing returns-to-scale; point A exhibits constant returns-to-scale and points H to *D* exhibit decreasing returns-to-scale. The points E, A, D, H and the x-axis, form the reference technology of the BCC model. It is characterized by a piecewise linear representation of the underlying technology with a convex hull of existing DMUs spanning the frontier.

The *input-oriented*[9] BCC model evaluates the efficiency of DMU_j by solving the following linear program (Banker et al. 1984):

$$\begin{aligned} Max \quad & u^T y_j - u_j \\ s.t \quad & \\ & v^T x_j = 1 \\ & -v^T X + u^T Y - u_j e^T \leq 0 \\ & u^T \geq 0 \\ & v^T \geq 0 \\ & u_j \text{ unrestricted} \end{aligned} \tag{3.4}$$

whose LP dual problem is expressed as:

$$\begin{aligned} Min \quad & \theta_j^B \\ s.t \quad & \\ & \theta_j^B x_j - X\lambda \leq 0 \\ & Y\lambda \geq y_j \\ & e\lambda = 1 \\ & e^T \lambda \geq 0 \end{aligned} \tag{3.5}$$

where e^T is a row vector with all elements unity. As with the CCR model, the optimal solution $(\theta_j^{B*}, \lambda^*)$ of BCC_j, should satisfies the Pareto-Koopmans efficiency condition $(\theta_j^{B*} = 1)$ to become BCC-efficient or pure technical efficient. Note that any CCR-efficient unit is BCC-efficient, but BCC-efficiency is generally higher than CCR-efficiency. Alternatively, DMU_j can be BCC-efficient without being CCR-efficient due to the difference in its scale efficiency level.

[9] The inverse relationship between output-oriented and input-oriented CCR models is not available for the BCC model.

3.2.2 The Cost Efficiency Measures

The concept of technical efficiency relates to the ability of a DMU to proportionally rescale inputs or outputs to the efficient production frontier. As an alternative, allocative efficiency uses revenue or cost data to measure the ability of a DMU to choose its outputs in a revenue-maximizing way or choose its inputs in a cost-minimizing way or choose both outputs and inputs simultaneously in a profit maximizing way. Allocative efficiency is reached when technical efficiency is attained, the right output mix in light of prevailing output prices is produced, and/or the right input mix in light of prevailing input prices is used. Thus, allocative efficiency can be evaluated in terms of outputs (using a revenue function), in terms of inputs (using a cost function) and in terms of both inputs and outputs (using a profit function). A DMU that is technical and allocative efficient in input use is cost efficient and one that is technical and allocative efficient in outputs is revenue efficient. Profit efficient DMU's are defined as those that are overall technical efficient, and also exhibit allocative efficiency (Chavas and Cox 1999).

To estimate the cost-based allocative efficiency for each DMU, first, the linear programming technique by (Färe and Grosskopf 1985) is used to construct a series of nonparametric cost frontiers by solving the minimization problem:

$$
\begin{aligned}
C_j(y, w) = \; & Min \;\; w_j x_j \\
& s.t \\
& x_j - X\lambda \geq 0 \\
& Y\lambda \geq y_j \\
& \sum \lambda = 1 \\
& \lambda \in \sim^{+}
\end{aligned}
\qquad (3.6)
$$

where w_j is the price vector for the input x_j assumed to be strictly positive $(w_j > 0)$. $\lambda \in \sim^{+}$ is a nonnegative vector of the intensity level for each observation and serves to construct a convex hull to envelop the data. The intensity vector restricted to sum to one $(\lambda = 1)$ imposes variable returns-to-scale on the frontier technology and satisfies strong disposability of outputs and cost (Afriat 1972). Removing this convexity condition or constraint on the intensity vector allows constant returns to scale (CRS) frontier technology. Solving the linear program in Equation 3.6 generates the vectors $C_j^v(y,w)$ and $C_j^c(y,w)$ that show the minimum possible cost of producing all outputs under VRS and CRS technology, respectively, by choosing the optimal input bundles (x_j^v, x_j^c).

After obtaining the minimum cost under VRS and CRS, the level of cost-based allocative efficiency index (AE_j^i) is computed as:

$$AE_j^i = \frac{C_j^i(y,w)}{\theta_j^i * C_j(y,w)} \tag{3.7}$$

where the superscript i, correspond to the frontier technology assumed (CRS or VRS). The index is a ratio of the minimum possible cost under CRS or VRS and the product of actual cost $(C_j(y,w))$ incurred and technical efficiency under CRS or VRS. AE_j^i is bound between zero and one and reflects the degree to which a DMU minimizes cost along the technically efficient frontier. $AE_j^i < 1$ implies the DMU is allocative inefficient in producing outputs at the minimum possible cost while $AE_j^i = 1$ represents allocative efficient DMU. It follows that a DMU is allocative inefficient in input use if the marginal value product of its inputs is less than its normalized observed price. If an inefficient DMU operates in a cost minimizing way, it can reduce production cost by $(1 - AE_j^i)$.

To derive a measure of the cost efficiency index CE_j^i, the assumption of technically efficient production in Equation 3.7 is relaxed to assess only the deviation of observed cost from the estimated efficient frontier cost under CRS and VRS. Formally:

$$CE_j^i = \frac{C_j^i(y,w)}{C_j(y,w)} \tag{3.8}$$

The index CE_j^i is bounded between zero and one where $CE_j^i = 1$ indicates that the DMU is cost efficient or operates on the cost frontier. Alternatively, $CE_j^i < 1$ indicates that the DMU is not cost efficient and operates above the cost frontier. $1 - CE_j^i$ measures the proportion by which cost can be reduced due to cost inefficiency. It is apparent from Equations (3.7 and 3.8) that a technical efficient DMU that is allocative efficient is cost efficient. That is, the cost efficiency index can be decomposed into measures of technical efficiency and allocative efficiency[10].

The input- and output-based indexes of technical and allocative efficiency discussed are short-run measures conditional on observed outputs and inputs, respectively. Conditions for short-run equilibrium may not hold in a long-run case. For example, in the absence of barriers to entry and exist, zero profit is a necessary condition for long-run equilibrium. Satisfying this condition requires firms to produce at an "optimal scale" output and/or input that corresponds to the maximum average revenue or the minimum average cost or the lowest possible cost-to-revenue ratio (Chavas and Cox 1999). More precisely, a perfectly competitive firm must produce at the smallest cost per unit of outputs or the largest revenue per unit of inputs to achieve long-run equilibrium. Whether a firm is producing at the most efficient scale attainable at the minimum

[10] Mathematically, $CE_j^j = AE_j^i * \theta_j^i$. However, CE under CRS can be estimated as the product of technical efficiency under VRS, allocative efficiency under VRS and scale efficiency. As a result, it is often referred to as overall efficiency in the efficiency literature (Thanassoulis 1993).

average cost or maximum average revenue can be determined through the measurement of its scale efficiency.

The cost-based scale efficiency index, SE_j^c, for each DMU can be obtained by comparing the DMU's operational scale under VRS frontier technology with the most efficient scale attainable at the minimum average cost[11]. Mathematically:

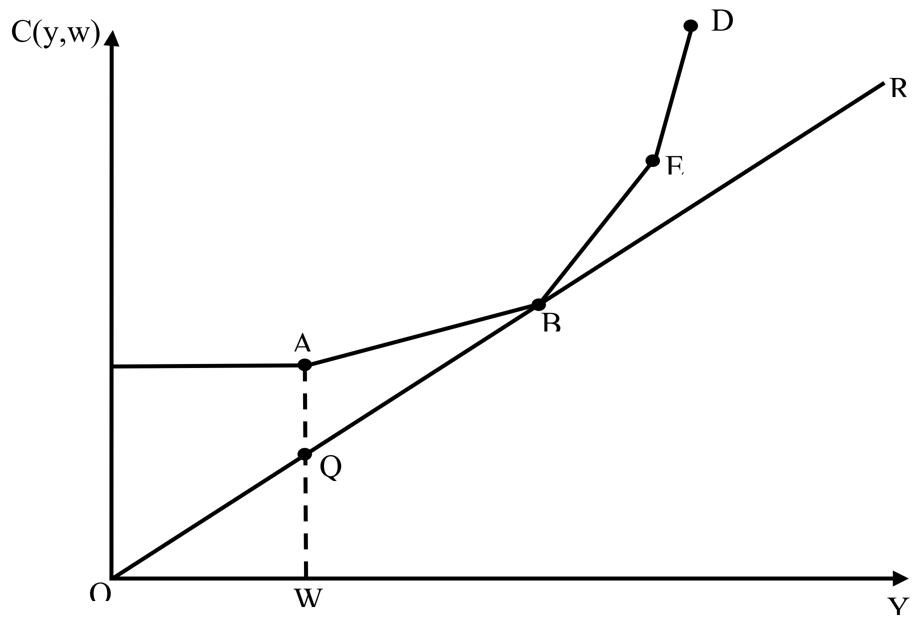
$$SE_j^c = \frac{C_j^c(y,w)}{C_j^v(y,w)} \tag{3.9}$$

where SE_j^c is calculated as the ratio of minimum possible cost under constant returns to scale to the minimum cost feasible under variable returns to scale. The value of SE_j^c is smaller than unity for inefficient scale of operation and equals unity for efficient scale of operation. If $SE_j^c = 1$ then production corresponds to the minimum average cost possible and the frontier technology exhibit constant return to scale. Otherwise, DMU may belong to decreasing return to scale or increasing return to scale technology. To determine the type of return to scale for each scale inefficient DMU, the $C_j(y,w)$ measurement in Equation 3.6 is restricted to be non-increasing return to scale (NIRS).

---

[11] DMU's operating in the region of decreasing returns to scale (DRS), increasing returns to scale (IRS) or constant returns to scale (CRS) can be evaluated using this condition: $SE_j^c \neq 1$ and $C_j^n = C_j^c$ reflects decreasing returns to scale and $SE_j^c \neq 1$ and $C_j^n \neq C_j^c$ reflects increasing returns to scale (Coelli et al. 2005) . C_j^n is estimated by imposing the constraint, $\sum \lambda \leq 1$, on Equation 3.6

Figure 3:2 Illustration of Cost Efficiency Frontiers



Let $C_j^{nrs}(y,w)$ be the optimal cost efficiency score under the non-increasing returns-to-scale. If $C_j^{nrs}(y,w) = C_j^{v}(y,w)$ then scale inefficiency is due to IRS, otherwise, scale inefficiency is due to DRS. In other words, a DMU exhibits increasing returns to scale (IRS) if it exhibits neither CRS nor DRS and decreasing returns to scale (DRS) if it exhibits NIRS but not CRS. Figure 3:2 depicts measures of CRS, VRS, and NIRS in cost and output space. The NIRS cost frontier is bounded by OBED and the C-axis whiles OQBR forms the CRS frontier cost. The curve passing through points A, B, E, D and the C-axis is the reference cost frontier formed by constraints in (3.6). On this curve, DRS prevail to the left of B, and IRS prevails to the right of B. Point A is efficient relative to the VRS cost frontier but inefficient relative to the CRS cost frontier. In the same way, point Q is NIRS and CRS cost efficient but not VRS cost efficient. Only point B is efficient relative to all frontier technology.

3.3 The Bootstrap Procedure and Efficiency Effects Model

Recall that the primary objective of this research was to determine the efficiency of chicken production in Ghana with the view to analyze the influence of various operational and socioeconomic factors on performance in a two-stage estimation process. In the first stage, the DEA method described above was used to estimate the efficiency of DMUs relative to the frontier. In the second stage, the estimated farm-specific efficiency scores are regressed on potential covariates to identify key performance drivers. The nature of the DEA procedure, however, presents problems for stable classification of DMUs into efficient and inefficient performers and it also presents challenges related to testing the statistical significance of efficiency estimates. Other challenges include the serial correlation among estimated DEA efficiency scores and the correlation between environmental variables and the unobserved error term in both estimation stages (Xue and Harker 1999; Cooper et al. 2001; Léopold Simar and Wilson 2007).

The DEA is unable to evaluate the efficiency of a DMU relative to the true population frontier or "theoretical optimum." Hence, DEA efficiency estimates are uncertain and sensitive to sampling variation, extreme observations, number of observations as well as the dimensionality of the input and output variables (Nunamaker 1985; Wilson and Simar 1995). The omission of the most efficient DMUs from the dataset may, therefore, bias estimated efficiency scores upwards. Also, as an extreme point technique for generating point estimates of efficiency measures, the slightest perturbation of observations can cause significant changes in DEA estimated efficiencies whereas testing of statistical significance of DEA point estimates is difficult to derive analytically. Consequently, "you cannot tell whether particular units are inefficient in a statistical significant sense" (Wilson and Simar 1995). Aside the sensitivity of efficiency measures to sampling variation, the problems of serial correlation and correlation between environmental variables and the error term naturally occur in the second stage estimation. The second stage regression is premised on the assumption of dependence of firms' choice of inputs and outputs on environmental or contextual factors. Unfortunately, if this assumption holds, then the problem of correlation between environmental variables and the error term arises. The dependence of covariates and the error term have been shown to violate a basic regression assumption of explanatory variable/error term independence, resulting to biased parameter coefficients. By construction, the DEA efficiency score for a DMU is a relative index not an absolute index, computed conditional on all other DMUs in the sample. This means that errors associated with DMUs' measurements may be serially correlated with each other in an unknown way, given rise to parameter estimates in the second stage estimation that are not consistent.

Concerns about these limitations of the DEA procedure: instability of DEA efficiency estimates, serial correlation among DEA efficiency estimates, correlation between environmental variables and error term have been discussed in several studies (Ferrier and Hirschberg 1997; Wilson and Simar 1995; Xue and Harker 1999; Cooper et al. 2001). As a way of mitigating these inherent problems of the DEA, bootstrapping procedures have been applied to both the first and second stage estimations. The bootstrap procedure is a nonparametric statistical technique based on the idea of randomly and repeatedly resampling with replacement the empirical distribution of interest by simulating or mimicking the original data-generating process (DGP) or the true population distribution (Efron 1979; Efron and Tibshirani 1994; Simar and Wilson 2000). The bootstrap estimator has an asymptotic property that causes the instability of DEA efficiency estimates, serial correlation among DEA efficiency estimates, and correlation between environmental variables and error term to become negligible asymptotically by providing a reasonable estimator for the true unknown data generating process (DGP).

The double bootstrap procedures in Algorithm 2 of Simar and Wilson (2007) are used to address the limitation of the DEA approach above. They are capable of describing the true underlying data-generating process (DGP) of the observed data is followed, to first bias correct estimated DEA efficiency measures and evaluate the effect of environmental variables on inefficiency whiles correcting for any serial correlation issues that may arise. The implementation of the Simar and Wilson (2007) double bootstrap application was carried out in the following steps:

Step 1: Estimate $\hat{\lambda}_i = \hat{\lambda}_i(x_i, y_i)\ \forall\ i = 1,.....,n$ by using Equations (3.3), (3.5) and (3.6) under the assumption of variable or constant returns to scale.

Step 2: Estimate $\hat{\lambda}_i = r_i\beta + \varepsilon_i$ using a truncated regression procedure where $\hat{\lambda}_i$ is a vector of DEA point estimates of farm efficiency (technical, scale, allocative and cost efficiencies) from step one for the ith farm, r_i is the matrix of explanatory variables assumed to impact the choice and use of inputs (x_i) and outputs (y_i). These explanatory variables include demographic information of the farm operator (Age, Experience, Education, etc.), farm specific characteristics (location, farm size, proportion of hired labor, etc.) and institutional factors (membership in producer organization, etc.). β is a vector of parameters to be estimated, and ε_i is a continuous *iid* random error term. Since $\hat{\lambda}_i^* \leq 1$ by definition, ε_i is assumed to be distributed $\mathrm{N}(0, \sigma^2)$ with right-truncation at 1, and independent of r_i.

Step 3: Implement the bootstrap technique to develop the bootstrap estimates $B_i = \left\{\hat{\beta}_{ib}^*\right\}_{b=1}^{K_1}$ by repeating the following four steps K_1 times:

a) For each farm $i = 1,.......,n$, ε_i is drawn from the $\mathrm{N}(0, \hat{\sigma}_\varepsilon)$ distribution.

b) For each farm $i = 1,.......,n$, compute $\lambda_i^* = r_i\hat{\beta} + \varepsilon_i$.

c) For $i=1,.......,n$, a pseudo data set of (x_i^*, y_i^*) is constructed, where $x_i^* = x_i(\hat{\lambda}_i / \lambda^*_i)$ and $y_i^* = y_i$

d) A new DEA efficiency score, $\hat{\lambda}_i^*$, is estimated for all $i=1,.......,n$ using the pseudo data set and Equations (3.3), (3.5) and (3.6).

Step 4: For each farm $i=1,.......,n$, the bias-corrected estimator is computed as $\hat{\hat{\lambda}}_i = \hat{\lambda} - Bias(\hat{\lambda}_i)$ where the bias term is estimated as follows: $(1/K_1 \sum_{b=1}^{K_1} \hat{\lambda}_{ib}^*) - \hat{\lambda}_i$

Step 5: Then $\hat{\hat{\beta}}_i$ and $\hat{\hat{\sigma}}_\varepsilon$ are estimated by regressing $\hat{\hat{\lambda}}_i$ on r_i using the ordinary least square.

Step 6: Repeat the following three steps K_2 time yielding a set of bootstrap estimates

$$\zeta = \left\{ (\hat{\hat{\beta}}^*, \hat{\hat{\sigma}}_\varepsilon^*)_b \right\}_{b=1}^{K_2}$$

a) For each farm $i=1,.......,n$, ε_i is drawn from the $\mathrm{N}\left(0, \hat{\hat{\sigma}}_\varepsilon\right)$ distribution.

b) For each farm $i=1,.......,n$, compute $\lambda_i^{**} = r_i \hat{\hat{\beta}} + \varepsilon_i$.

c) Employing ordinary least squares, λ_i^{**} is regressed on r_i to yield estimates $\hat{\hat{\beta}}^*$ and $\hat{\hat{\sigma}}_\varepsilon^*$

Step 7: The bootstrap estimates ζ and the estimates $\hat{\hat{\beta}}$ and $\hat{\hat{\sigma}}_\varepsilon$ generated in Step 5 are used to construct confidence intervals for each element of β and σ_ε. The $(1-\alpha)$ percent confidence interval of the jth element of vector β, where α is some small value (*i.e.*, α=0.05) and $0<\alpha<1$ is constructed at the $\Pr(-b_{\alpha/2} \le \hat{\hat{\beta}}_j^* - \hat{\hat{\beta}}_j \le -a_{\alpha/2}) \approx 1-\alpha$ such that the estimated confidence interval is $[\hat{\hat{\beta}}_j + a_{\alpha/2}^*, \hat{\hat{\beta}}_j + b_{\alpha/2}^*]$.

In summary, the double bootstrap procedure provides a framework for addressing some of the limitations associated with the traditional two-stage DEA estimation procedure even though estimates from the two methods might not be significantly different if a population data is used. Estimation of producers' feed demand also follow a two-stage estimation process where the first stage involves estimating the decision of whether or not to use a specific feed type. The second stage concerns the quantity of the specific feed type to use. The conceptual and empirical frameworks underscoring this estimation procedure are discussed in the next section.

3.4 Estimation of Chicken Producers' Feed Demand

3.4.1 Conceptual Framework

Chicken producers in Ghana are assumed to use three principal factors of production: labor, day-old-chicks (DOCs), and feed to produce eggs and/or broiler meat. Their objective is assumed to be maximizing their expected profits for the production situation. Broiler production is typically a batch process averaging a 7-week growth cycle and an average of two cycles in a year. Layer production cycle, on the other hand, last for an average of 77 weeks. During a production process, the level and cost of DOC's and labor are usually fixed and cannot be easily adjusted. Thus, producers are constrained to employ parametric quantities of labor and DOCs. However, the cost and quantity of feed per bird fluctuates by growth stages or age of birds (starter, grower, finisher), the number of birds in each growth stage (which may vary with mortality loss), and more importantly the type of feed (self-prepared or commercially purchased) used in production.

Producers can select the feed quantity required to produce the parametric output by first selecting the feed type(s) – i.e., whether to prepare own feed, purchase commercially prepared feed or both[12] – and then choose the quantity of each selected feed type. Each feed type may be characterized by different quality of feed ingredients, which may affect the cost of feed and the quantity needed to achieve the expected parametric output. Also, supply fluctuations associated with each feed type – influenced by external factors as well as market variations – may translate into different prices for the different feed types. Therefore, if fixed cost (short-run cost of DOCs and labor)[13] does not change with the production level, then with an optimal choice of feed (type and quantity) among a set of possible alternatives, production cost could decline, thus increasing enterprise profitability, ceteris paribus.

In this case, a profit-maximizing commercial poultry producer in Ghana has three strategic options in managing the highest cost item in her production cost structure: purchase commercially prepared feed, produce own feed on-farm or use both own and commercial feed at varying proportions. While on-farm feed is self-prepared by the producer for his own use, commercial feed is produced by feed companies for sale to farmers. Producers may elect to use either one type of feed or a combination of both in varying proportions subject to a number of producer socio-demographic characteristics, market conditions, institutional considerations as well as other observable and unobservable motivating factors. The decision choice over the type of feed and the feasible quantity to purchase or produce is driven by the ability to achieve the desired input quality and quantity at a price deemed supportive of producers' profit maximizing objective. Thus, given the production technology, fixed inputs and input prices, the producer input choice model assumes that among a set of technologically feasible feed bundles, producers will choose the

[12] The total quantity of feed used by a representative producer is the sum of self-prepared feed and that purchased commercially.
[13] The level of the fixed cost is assumed to be optimal.

lowest cost bundle that maximizes expected profit and allows the production of the target output level, ceteris paribus.

We specify the conceptual feed demand model for poultry producers in Ghana as:

$$S = f(F, D, P_c, Z) \tag{3.10}$$

where S is the quantity of feed that a producer self-prepares or purchase commercially, F is a matrix of farm characteristics and D is a vector of variables referring to farm operator's socioeconomic characteristics. The farm characteristics include location, number of farms, whether the farm is the producers' primary income source and farm size, while farm operator characteristics include education, age, and experience. The quantity of feed purchased or self-prepared is affected by market conditions including the market price of the major ingredients – maize – used to produce own feed, and the market price of commercially purchased feed, P_c. Z represents a vector of other motivating factors that dictate producers' preference for commercial or self-prepared feed such as consistent quality of commercial feed, lower relative cost of commercial feed compared to own feed, control over the quality of own feed compared to commercial feed and flexibility in the formulation of own feed to meet specific bird needs.

3.4.2 Model Estimation

In this study, the decision mechanism underlying poultry producers' feed demand generates a large proportion of zero observations. For example, just over 63.9% and 55.1% of layer farms use self-prepared[14] and commercial feeds, respectively. However, the sources of zero feed-use observations are not separably identifiable in our data and can therefore, take on properties of

[14] A large number of zeros on own feed production was recorded for the broiler industry where only 33.5 percent of producers self-prepare their own feed.

corner solutions (no purchase of a specific feed type at current prices and resource levels) and/or abstentions (unwillingness of producers to produce their own feed or purchase commercial feed) from use. This raises empirical question on how to explain the structural feed demand decision mechanism that *a prior* information suggests being at work. While many decision mechanisms can explain the appearance of zeros, producers' feed demand is modelled as a two-step sequential decision – i.e., whether or not to purchase commercial feed (acquisition decision) and the quantity of commercial feed[15] actually purchased (intensity decision) – process via Cragg's (1971) double hurdle specification.[16] This specification not only allows for separate processes to influence the non-use of feed (commercial or self-prepared) and the quantity of feed actually purchased or self-prepared, but also allows for both corner solution and abstention to explain the decision mechanism that leads to the appearance of zero feed-use observations.

In the presence of substantial concentration of zero feed-use observations, a linear regression on either the overall sample or just the non-zero sample[17] may generate biased and inconsistent parameter estimates – i.e., may underestimate the intercept and overestimate the slope (Cragg 1971; Amemiya 1984; Long 1997). If the decision outcome is a corner solution of a resource-constrained problem of a profit maximization, then, the Tobit specification will be appropriate in modelling producer feed demand decision, given its actual economic conditions. An important limitation of this specification is that it imposes the assumption that the stochastic process which influences the non-use of feed is the same as that which determines the quantity of

[15] Similarly, producers make sequential choices in their demand for self-prepared feed: they first decide whether or not to produce their own feed (acquisition decision), then, conditional on acquisition, they decide on the quantity of own feed to actually produce.

[16] The model has also been used in demand analysis for tobacco (Jones 1989), fertilizer demand in Zambia (Xu et al. 2009), fertilizer demand in Malawi (Ricker-Gilbert et al. 2011), and improved fish feed demand in Kenya (Amankwah et al. 2016).

[17] This is a common practice in the literature where an ordinary least square model is used to explain the relationship between discretely censored or zero-inflated dependent variables and some observed covariates.

feed used in production. While such assumption may hold, it is quite reasonable to assume that factors affecting the two processes can be significantly different.

Furthermore, the structural characteristics of the Tobit model assume zero optimal feed-use at current prices. Thus, all zero observations represent a corner solution such that a change in relative feed prices or a change in the expenditure for either commercial or self-prepared feed will effect positive use of the feed i.e. non-use of feed from a particular source is attributable to economic factors alone (Cragg 1971; Blaylock and Blisard 1992). This assumption might be rather restrictive when different processes can influence acquisition and intensity decisions or when zero observations arises due to non-economic considerations (see Cragg 1971). For example, as mentioned earlier, easy access to and the consistency of commercial feed quality influence its use by some poultry producers. In the same sense, producers choose to produce their own feed for reasons such as the ability to control the quality more effectively and exploit flexibility in feed formulation to meet specific bird needs. This suggests that the zeros in our data can reflect producers' decision to not produce their own feed or purchase commercial feed (i.e., when desired demand is non-positive), as well as, some motivating or limiting factors constraining their decision even when desired demand is actually positive. In such situations, the application of the Tobit specification to poultry producers' feed demand can lead to biased and inconsistent parameter estimates.

3.4.2.1 Double Hurdle Models for Feed Demand

The body of work on hurdle models originated by Cragg (1971) is a generalization of the Tobit model, built around the concept of decomposing a demand decision into two separate decisions: an acquisition decision and an intensity decision. The conceptual basis for decomposing demand into separate stochastic process rests on the notion that producers must overcome two hurdle decisions before recording positive feed use. The first stage decision involves the choice of a feed type $(i.e.\ \kappa_i = 1)$ and the second stage decision involves the choice of feed intensity (or actual quantity). It is assumed that the two hurdle decisions are tackled as a sequence where the sequential decision mechanism can be defined by the following mathematical representations:

$$\kappa_i = 1\{\kappa_i^* > 0\} \tag{3.11}$$

and

$$a_i = 1\{a_i^* > 0 \mid \kappa_i = 1\} a_i^* \mid (\kappa_i = 1) \tag{3.12}$$

where (3.11) is the first hurdle decision (whether or not to produce own feed; and whether or not to purchase commercial feed), which is represented by a probit model based on the latent variable relations:

$$\kappa_i = 1 \text{ if } \kappa_i^* > 0 \text{ and } 0 \text{ if } \kappa_i^* \leq 0$$

and

$$\kappa_i^* = h_i \gamma + \upsilon \tag{3.13}$$

where κ_i^* is a latent acquisition variable taking the value 1 if $a_i > 0$, (i.e. the producer produce his/her own feed or the producer purchase commercial feed) and 0 otherwise; γ is the vector of parameter estimates for the probit model; h_i represents the vector of covariates hypothesized to influence the decision to use own feed or produce commercial feed (farm and producer characteristics); and υ is a vector of independently and normally distributed random noise with mean zero and variance σ^2 i.e. $\upsilon \sim N(0, \sigma^2)$. The acquisition or non-acquisition of a feed type is modelled as a probability choice where acquisition occurs with probability:

$$P(\kappa_i = 1) = P(a_i^* > 0) = \Phi(-h_i \gamma) \tag{3.14}$$

and non-acquisition occurs with a probability:

$$P(\kappa_i = 0) = P(a_i^* \le 0) = 1 - \Phi(-h_i\gamma) \tag{3.15}$$

The second hurdle or intensity decision explains the outcome of a continuous decision of the quantity of feed to self-produce or purchase. Its statistical specification is based on the existence of a latent utility random variable a_i^* that represents the quantity of feed needed to produce the desired quantity of output to maximize expected profit. The latent utility random variable is continuous, real-valued and linked directly to the observed feed quantity a_i via the transformation:

$$a_i = \begin{cases} 0 & \text{if } a_i^* \le 0 \\ a_i^* & \text{if } a_i^* > 0 \end{cases} \tag{3.16}$$

The observed feed quantity variable is subject to a ceiling effect with several of its value censored at 0. If a producer decides to produce or purchase feed, then we have $\mathrm{a_i} > 0$; if a producer decide not to produce or purchase feed, then $\mathrm{a_i} = 0$. Formally, the utility-quantity relationship takes the form of

$$a_i = 1\{a_i^* > 0\}\, a_i^* \tag{3.17}$$

where $1\{Q\}$ represents an indicator function. If event Q holds, $1\{Q\} = 1$, then the observation is uncensored i.e. we observe a positive quantity of commercial feed for producer i; if not, $1\{Q\} = 0$, then the observation is censored i.e. producer i does not produce or purchase feed. In order to model producers' intensity decision, the second hurdle is defined by a lognormal regression framework as follows:

$$\ln \mathrm{a}_i^* = z_i\theta + \varepsilon_i \tag{3.18}$$

where z_i is a vector of economic and non-economic covariates hypothesized to influence quantity of commercial or self-prepared feed used, θ is the vector of parameter estimates for the lognormal regression model, ε_i is a vector of independently and normally distributed random noise with mean zero and variance one i.e. $\varepsilon_i \sim N(0,1)$. The parameters of equations (3.13) and (3.18) are estimated separately under the assumption of independency between the disturbances υ_i and ε_i. Their interpretation lends itself to the assumption that producers decide first whether or not to acquire a given feed type (self-prepared or commercial), then conditional on acquisition only do they determine the use intensity or quantity. In this case, the disturbances, υ_i and ε_i are assumed to be distributed according to a bivariate normal distribution specified as

$$\begin{bmatrix} \upsilon \\ \varepsilon_i \end{bmatrix} \sim N\left(\begin{bmatrix} h_i\gamma \\ z_i\theta \end{bmatrix}, \begin{bmatrix} 1 & \rho\sigma \\ \rho\sigma & \sigma^2 \end{bmatrix} \right) \tag{3.19}$$

where ρ which represents the correlation coefficient between the error terms of the acquisition and intensity equations has a value of zero. This assumption $(\rho = 0)$ allows the model to be decomposed into a probit for κ_i^* and a truncated for $\ln a_i^*$. Thus, the probability density function of the observed censored variable a_i of the hurdle models is a discrete-continuous mixture that assigns a probability mass $P(a_i = 0)$ to the discrete component ($a_i = 0$) and a density function $f_+(a_i)$ to the continuous component $(a_i > 0)$. Assuming independence $(\rho = 0)$ between the error terms of acquisition and intensity, the joint lognormal density or log likelihood function for the double hurdle model can be expressed as:

$$\ln L_{Hurdle} = \sum_0 \ln\left[1 - \Phi(h_i\gamma)\Phi\left(\frac{z_i\beta}{\sigma}\right)\right] + \sum_+ \ln\left[\Phi(h_i\gamma)\frac{1}{\sigma}\phi\left(\frac{a_i - z_i\beta}{\sigma}\right)\right] \tag{3.20}$$

where $\sum_{0}$ is a sum over all zero observations and $\sum_{+}$ is the sum overall positive observations; $\Phi(\bullet)$ and $\phi(\bullet)$ respectively, denote the standard normal $N(0,1)$ cumulative distribution function and probability density function of a random variable. The first term represents the log-likelihood of the probit model for acquisition and the second term represents the likelihood for the truncated regression of the positive values of feed quantity.

Integrating the probit and truncated regression models, the unconditional expectation of a_i for the double hurdle model can be expressed as:

$$E(a_i \mid z_i, h_i) = \Phi(h_i\gamma)\left[z_i\beta + \sigma^*\lambda(z_i\beta/\sigma)\right] \qquad (3.21)$$

where $\lambda(z_i\beta/\sigma)$ is the Inverse Mills Ratio (IMR) expressed as $\phi(z_i\beta/\sigma)/\Phi(z_i\beta/\sigma)$; $\Phi(h_i\gamma)$ is the probability of using own feed or the probability of purchasing commercial feed and $\left[z_i\beta + \sigma^*\lambda(z_i\beta/\sigma)\right]$ is the conditional expected quantity of feed, $E(a_i \mid a_i > 0, z_i)$. For a given observation, the partial effect of a continuous independent variable on the unconditional expected value of a_i can be written as (Burke 2009):

$$\begin{aligned}\frac{\partial E(a_i \mid z_i, h_i)}{\partial z_j} = {} & \gamma_i\phi(h_i\gamma)^*(z_i\beta + \sigma_i\lambda(z_i\beta/\sigma_i) \quad + \\ & \Phi(h_i\gamma)^*\beta_j\left[1-\lambda(z_i\beta/\sigma_i)(z_i\beta/\sigma_i + \lambda(z_i\beta/\sigma_i))\right]\end{aligned} \qquad (3.22)$$

Similarly, the partial effect of discrete independent variable on the unconditional expected value of a_i can be written as:

$$\frac{\partial E(a_i \mid z_i, h_i)}{\partial z_j} = \Phi(h_i\gamma)\left\{(z_i\beta + \sigma_i\lambda(z_i\beta/\sigma_i)\right\}_{z_{j=1}} + \Phi(h_i\gamma)\left\{(z_i\beta + \sigma_i\lambda(z_i\beta/\sigma_i)\right\}_{z_{j=0}} \qquad (3.23)$$

In the probit model, the marginal effect of an independent variable, h_i, around the probability that $a_i > 0$ is:

$$\frac{\partial P(a_i > 0 \mid h_i)}{\partial h_j} = \gamma_i \phi(h_i \gamma) \tag{3.24}$$

In the truncated regression model, the marginal effect of an independent variable, z_i, on the expected value of a_i, given that $a_i > 0$ (conditional average partial effect) is:

$$\frac{\partial E(a_i \mid a_i > 0, z_i)}{\partial z_j} = \beta_j \left[1 - \lambda(z_i\beta / \sigma)\left\{(z_i\beta / \sigma + \lambda(z_i\beta / \sigma)\right\}\right] \tag{3.25}$$

Chapter 4 - Data

4.1 Data and Summary Statistics

The data used for this study are from the 2015 Ghana Poultry Industry (GPI) survey (a USAID supported survey to track poultry production activities in Ghana) conducted between December 2015 and January 2016 (Amanor-Boadu et al. 2016). The GPI survey is a national census of commercial poultry producers in Ghana, covering all ten regions of the country, with detailed information on individual farm's production systems, housing systems, inputs, production levels and capacity, stocking practices, feed and feed ingredients, sales and marketing channels, human resources, health management practices, farm financial characteristics and demographic information on farm operators.[18] Commercial farms were defined by producers' primary production intent and by the minimum number of birds on the farm. Unlike non-commercial farms that may have other objectives, such as hobby, prestige, store of wealth, etc., commercial farms' production objective is solely to generate income through the sale of the farms' output. This implies following specific husbandry protocols – providing housing, feed and medication – and selling the output from production in ways that minimize costs in order to generate the highest net income.[19] Because of these investments (housing, medication, feed and sales), a minimum of 50 broilers and 15 layers i.e. produce a minimum of 60 eggs per week, was set as the threshold for qualifying as a commercial farm for the purpose of analysis.

The survey design used to identify and interview all know commercial poultry farms was the snowball approach. However, initial listing of poultry farms was obtained from national and

[18] For a more detailed description of the survey see Amanor-Boadu et al. (2016).
[19] Non-commercial poultry farms, also described as "village" or "backyard" poultry, often are neither housed or fed on any systematic basis and are kept not for profit but as a store of wealth and for managing household financial risks in many agrarian economies. See Aning (2006) for further description.

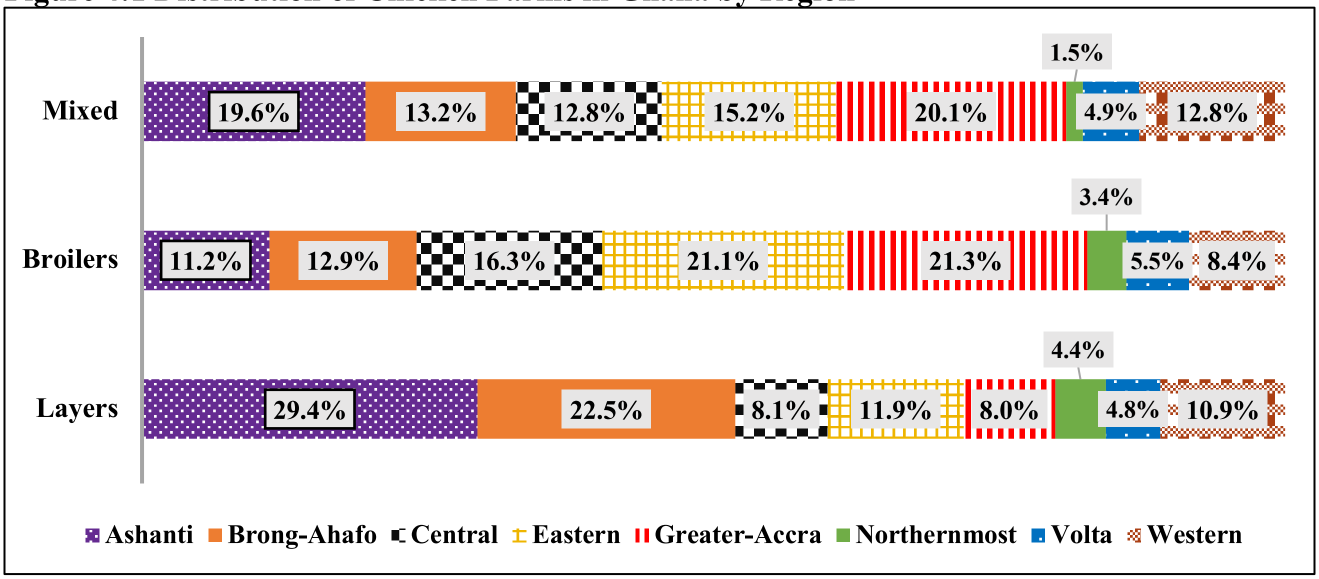
regional poultry producers associations and from regional and district Ministry of Food and Agriculture (MoFA) staffs. After been interviewed, listed producers were then asked about known poultry farms in their localities. Those not already listed were added to the list and interviewed. Thus, the dataset is considerably larger than those used by previous studies on the economics of poultry farms in Ghana by including all known commercial poultry farms in Ghana, a source of the study's originality. The primary dataset contains observations on a total of 4,040 commercial poultry farms producing all domesticated poultry species in Ghana: 3,661 chicken farms, 210 guinea fowl farms, 182 turkey farms and 73 duck farms. From this distribution, it is clear that chicken is the dominant poultry specie in Ghana with approximately 96.3% of poultry producers producing chicken-related products – broilers, layers, growers/pullets and cockerels (Amanor-Boadu et al. 2016). This compares with only 11.5% producing non-chicken species. As a result, this dissertation focuses on the performance of chicken production in Ghana and in those factors that determine performance differences and feed demand among chicken farms.

4.2 Type of Farm Enterprise, Location and Size

Three chicken farm enterprises are analyzed: broiler, layer and mixed operations (i.e. produce broilers and layers simultaneously). To secure a homogenous technology for the non-parametric efficiency analysis, separate frontiers for layer, broiler, and dual farms were estimated. Also, separate feed demand functions were assumed and estimated for each feed type by chicken enterprise. Out of the 3,661 chicken farms, 2,890 (78.9%) produced layers, 1,508 (41.2%) produced broilers and 837 (20.7%) had a dual enterprise production system in 2015. Farms with incomplete information on all variables used in the study or had zero output for the year 2015 were eliminated. This reduced the actual number of observations to 2,830 chicken farms (about 77.3%

of total chicken farms): 1,536 layer farms (53.1% of total chicken layer farms), 762 broiler farms (50.5% of total chicken broiler farms), and 532 dual enterprises (63.5% of total mixed chicken farms).

Figure 4:1 Distribution of Chicken Farms in Ghana by Region

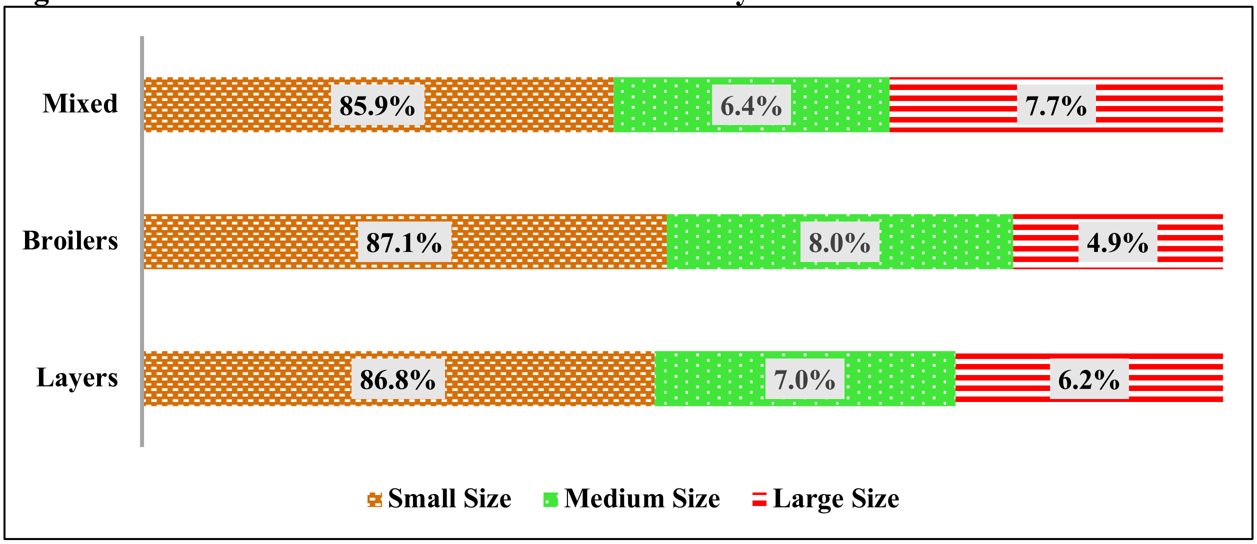


Regional and size distribution of farms by the three types of chicken enterprises are presented in Figure 4:1 and Figure 4:2. Geographic differences in the number of chicken farms are evident, with the three Northernmost[20] (Upper East, Upper West and Northern) Regions recording the lowest number of commercial layer (4.4%), broiler (3.4%) and mixed (1.5%) chicken farms. Ashanti (29.4%) and Brong Ahafo (22.5%) account for more than half of all layer chicken farms while Eastern (21.1%) and Greater Accra (21.3%) have the highest number of commercial broiler farms. Greater Accra Region also have the highest number mixed chicken farms, accounting for

[20] The three northernmost regions (Northern, Upper East and Upper West), each presenting fewer than 30 broiler or layer chicken farms, have been aggregated into a single group (Northernmost) to preserve anonymity of the producers and also enhance statistical validity of the estimates.

20.1% of all chicken farms that produce both layers and broilers. While Ashanti Region accounts for 11.2% of chicken broiler farms, its share of mixed farms is the second-highest (19.6%).

Figure 4:2 Distribution of Chicken Farms in Ghana by Size



Chicken farms were classified into three different classes according to the number of birds raised: small, medium-sized and large. However, there is no fixed definition as to what number of birds constitutes a 'small', 'medium' or 'large' farm. Aning's (2006) chicken farm size definition, in which small-size farms have less than 5,000 birds, medium-size between 5,000 and 10,000 birds and large-size more than 10,000 birds were used to classify layer and mixed farms into the three farm classes. Based on this classification, 86.8% of layer chicken farms fall into the small category, compared to 7.0% and 6.2% that are in the medium- and large-size category (Figure 4:2). Likewise, 85.9% of mixed farms are small while 6.4% are medium and the remaining 7.7% are large. With respect to broiler production, farms with fewer than 2,000 birds were classified as small. Those with between 2,000 and 5,000 birds, classified as medium while those with more than 5,000 birds classified as large farms (Amanor-Boadu et al. 2016). Based on this classification by Amanor-Boadu et al. (2016), small broiler farms accounts for 87.1% of all broiler farms used for our analysis while medium and large broiler farms account for 8.0% and 4.9% of all broiler farms, respectively.

4.3 Construction and Description of Variables

The dataset comprises observations on prices and quantities of two outputs: live-birds (broilers) and eggs, and four inputs: feed; labor; veterinary service; and day-old chicks. These formed the frame for the DEA efficiency analysis. Output quantities are measures of the total number of broiler birds and crate of eggs sold. Input quantities are measures of total kilogram of feed, labor hours, cost of veterinary service and medication, and cost of day-old chicks (DOCs). The feed variable was defined as the sum of the amount of feed purchased and/or produced over the life of the flock of birds. Producers purchase/produce feed in multiple sizes – 45 kg, 50 kg, and 1000 kg. The number of bags in each size group was multiplied by its appropriate weight and summed across the different size groups to obtain the total feed in kilograms. The labor input variable was calculated as the total duration of hours worked by summing full time, part-time and seasonal work hours. With regards to day-old-chicks, four sources were identified: own production; self-imported day-old chicks; importer or distributor day-old-chicks; and local day-old-chicks' suppliers. The price of own DOCs is imputed to be equal to the average of local suppliers' price. The sum of the cost of DOCs from all four sources served as the total cost of day-old-chicks. Veterinary cost was calculated as the sum of the total cost of veterinary service and medication over the life of the flock of birds.

Solving the cost-minimizing DEA models (Equation 3.6) requires information on input prices. Feed price was derived as the total feed cost divided by total feed quantity. The feed price varies by specialization as farms may use different feed ingredients with different quality, different feed ration and different combinations of purchased and self-prepared feed. Labor includes paid and unpaid operational labor. The price of labor is calculated as the ratio of labor costs divided by the sum of paid and unpaid hours. Paid labor price was used as a proxy for unpaid labor wage in each labor category – full, part-time and seasonal. Besides input, output and price data, a number of variables linked to the economic performance of chicken farm enterprises were hypothesized to influence efficiency measures as well as producers' feed demand decisions. Detailed definition, and measurement of these variables categorized by farm operator characteristics, farm structure and farm location are presented in Table 4:1.

Farm and farmer characteristics included as explanatory variables in the efficiency effect model, r_i, as well as the feed demand models – x_i, h_i, z_i – are experience and education level of farm operator (none, elementary, secondary, post-secondary), whether the farm is the primary income source of farm operator, membership in a producer organization, whether producer operates a crop farm, farm size (small, medium, large), whether the farm is operated by the owner and regional location of farm. Efficiency is expected to be positively related to the number of years the farmer has been operating a chicken farm. Thus, experience is hypothesized to increase efficiency. Educated farm operators are expected to have better management skills, and the ability to access and process information more readily. This means that educated farm operators have the potential to allocate resources more efficiently. Membership of a producer organization is an additional potential source of relevant production and marketing information. It is therefore expected that membership in a producer organization will ease input supply constraints and correlate positively with efficiency.

Table 4:1 Description of Explanatory Variables Included in the Efficiency Effect (EE) Models and the Feed Demand Models

Variable	Description
Farm Operator Characteristics	
Age	Age of farm operator in years
Experience	Farm operator's years of poultry farming experience
Education	No Education =1 if farm operator has no education, 0 otherwise
	Primary Education =1 if highest level of education completed is primary education, 0 otherwise
	Secondary Education = 1 if highest level of education completed is secondary education, 0 otherwise
	Post-secondary Education = 1 if highest level of education completed is post-secondary education, 0 otherwise (Base category)
Primary income source	1 if farm is the primary income source of owner, 0 otherwise
Producer organization	1 if producer belongs to a producer organization, 0 if otherwise
Operate crop farm	1 if producer operates a crop farm, 0 otherwise
Farm Structure	
Farm size	Small-size = 1 if farm produce under 2,000 or 5,000 for broiler and layer operations, respectively, 0 otherwise (Base category)
	Medium-size = 1 if farm produce 2000 to 4,999 or 5000 to 9,999 birds for broiler and layer operations, respectively, 0 otherwise
	Large-size = 1 if farm produce 5,000 or more birds for broiler operation and 10,000 or more birds for layer operation, 0 otherwise
Owner operated farm	1 if farm is operated by owner and 0 if farm is operated by a farm manager
Farm Location	
Rural	1if farm is located in a rural area, 0 if farm is located in an urban area
Region	Ashanti = 1 if farm is located in Ashanti Region, 0 otherwise
	Brong Ahafo = 1 if farm is located in Brong Ahafo Region, 0 otherwise (Base category)
	Central = 1 if farm is located in Central Region, 0 otherwise
	Eastern = 1 if farm is located in Eastern Region, 0 otherwise
	Greater Accra = 1 if farm is located in Greater Accra Region, 0 otherwise
	Northernmost = 1 if farm is located in Northern, Upper East and Upper West Regions, 0 otherwise
	Volta = 1 if farm is located in Volta Region, 0 otherwise
	Western = 1 if farm is located in Western Region, 0 otherwise

Farms that are not producers' primary income source, particularly, owner-operated farms, may command less of their time and effort and hinder the timeliness of chicken production activities. As a results farms that are not producers' primary income source are expected to be less efficient. Incentives for preparing own feed as well as determining the quantity of own feed to produce are expected to be higher when a chicken producer also operates a crop farm. This is because maize, which is the main ingredient in chicken feed is the dominant crop grown by producers operating a crop farm. Thus, chicken farms that operate a crop farm would be more likely users of self-compounded feed. However, the crop farm may compete with the chicken enterprise for labor. This may impede the timeliness of the chicken production activities. As a result, the *a priori* relationship between farm performance and operating a crop farm is hypothesized to be negative. The dummy variables for farm size are of particular importance. Large farms are expected to be on a higher frontier than small and medium farms because of economies resulting when labor cost are spread over relatively large number of birds. Additionally, it is assumed that large farms are more likely users of self-compounded feed as most operate their own feed mills.

Chicken production in Ghana does not lend itself to standard operating processes, making it costly to supervise, measure and reward efforts of hired managers. As such, owner-operated enterprises are expected to be have a higher economic efficiency than farms operated by hired managers. The regional and rural variables were constructed as discrete variables, used as controls for unobserved location-specific effects such as the availability of commercial or self-compounded feed ingredients on farm performance and producers' feed demand. It is important to note that the effects of education, experience, whether the farm is the primary income source of farm operator, and membership in a producer organization on feed demand are indeterminate due to the lack of supporting theory and evidence in the literature.

Table 4:2 Description of Explanatory Variables Included in the Efficiency Effect (EE) Models

Farm Management Characteristics	Description
Feed type	Own feed =1 if producer use only self-prepared feed, 0 otherwise (Base category) Commercial feed = 1 if producer use only commercial feed, 0 otherwise Mixed feed = 1 if producer use both own and commercial feed, 0 otherwise
Source of day old chicks (DOC)	Own DOC = 1 if producer produce her own DOCs, 0 otherwise Self-imported = 1if producer self-import DOCs, 0 otherwise Local importer = 1 if the source of DOCs is local importer, 0 otherwise Local supplier = 11 if the source of DOCs is local supplier, 0 otherwise
Hired labor	Proportion of total labor hired

In addition to farm and farmer characteristics, farm management characteristics covering the type of feed (own feed, commercial feed, mixed feed), the source of day-old-chicks (own, self-imported, local importer, local supplier) and the proportion of hired labor were included in the efficiency effect model, r_i, as explanatory variables (see Table 4:2 for detailed description of these variables). Flexibility associated with own feed preparation gives farmers better control over the cost, and quality of self-compounded feed. Hence, the use of own feed is expected to correlate positively with efficiency. With respect to the source of day-old-chicks, their effect on farm performance is uncertain due to the lack of empirical or theoretical evidence in the literature. Hired labor has differing effect on efficiency in the empirical literature. It is expected that with a marginal product of hired labor less than the competitive market wage, increasing the level of hired labor will reduce farm performance, ceteris paribus. On the contrary, if the marginal product of hired labor is greater than the competitive market wage, then increasing the level of hired labor will increase farm performance, ceteris paribus.

Table 4:3 Definition of Variables Included in the Feed Demand Models

Variable	Description
Dependent variable: Hurdle 1	
Produce own feed	1 if produce own feed, 0 otherwise
Purchase commercial feed	1 if purchase commercial feed, 0 otherwise
Dependent variable: Hurdle 2	
Own feed	Quantity of self-prepared feed (Kg)
Commercial feed purchased	Quantity of feed purchased from commercial sources (Kg)
Explanatory variables	
Broiler price	Market price of broiler chicken (GHS/bird)
Egg price	Market price of chicken eggs (GHS/crate)
Maize price	Market price of maize (GHS/Kg)
Commercial feed price	Market price of commercial feed (GHS/Kg)
Explanatory variables included in Hurdle 2	
Own feed manufacturing method	Automated = 1 if the method of own feed production is fully or semi-automatic mill, 0 otherwise
	Manual mixing = 1 if the method of own feed production is manual mixing, 0 otherwise
	Toll milling = 1 if the method of own feed production is toll milling, 0 otherwise
Source of commercial feed	FBOs = 1 if commercial feed is purchased from governmental and non-governmental (NGO) sources, 0 otherwise
	Private retail = 1 if commercial feed is purchased from private retail sources, 0 otherwise
	Commercial feed mills = 1 if commercial feed is purchased from small or large commercial feed mills, 0 otherwise

Other explanatory variables were included in both the first and second hurdle feed demand models – x_i, h_i, and z_i – are market-related factors: egg price per crate, broiler price per bird, market price of maize and the observed average commercial feed price (see Table 4:3). Maize price is used as a proxy for the cost of self-compounded feed and is expected to negatively influence own feed demand. In the same way, commercial feed price is expected to be inversely related to commercial feed demand. We expect egg price and broiler price to positively correlate with feed demand, but their effects on the demand of each feed type are indeterminate.

Once the feed type decision has been made (in the first hurdle), the source of commercial feed (farmer-based organization, private retail, commercial feed mill) or the own feed preparation method (automated mill, toll mill, manual mixing) become important determinants of the quantity of feed to purchase or produce. Hence, the feed preparation method and the feed source variables were included in the second hurdle truncated regression models – h_i and z_i – to determine their extent of influence on the quantity of commercial feed purchased or own feed produced. We hypothesize that the use of automated mill rather than toll mill or manual mixing has a positive effect on the quantity of own feed used. However, the *aproiri* effect of comercial feed sources on quantity used are unclear due to the lack of empirical evidence in the literature. Farmers who selected to use a specific feed type were asked to rank certain factors relevant to motivating their demand for commercial or own feed. These motivating factors include better cost control over own feed, flexibility in own feed formulation to meet specific bird's needs; lower relative cost of commercial feed compared to own feed and consistent quality of commercial feed. Responses to the rank of these factors are also included as explanatory variables in the second hurdle truncated models through principal component analysis. A description of the dependent as well as the explanatory variables used in the feed demand models is provided in Table 4:3.

4.4 Summary of Data Characteristics

This subsection provides a profile of the socio-demographic characteristics of farms, farm structure and farm management characteristics or practices to contextualizes the data and provide a framework for interpreting the results. Table 4:4 presents some socio-economic characteristics used as explanatory variables in the efficiency effect and feed demand models for each chicken enterprise. The descriptive statistics show that farm operators differ by specialization in several important ways. Producers of mixed farms tend to be older (45.5 years), more experienced (12.7 years), and more educated (97.9% have some education) than layer (44.5 years old, 9.8 years of experience and 96.2% with some education) and broiler producers (45.4 years old, 10.7 years of experience and 96.7% with some education).

Table 4:4 Summary statistics of operator characteristics by farm operation

Farm and Operator Characteristics	Layer Enterprise (N=1536)		Broiler Enterprise (N=762)		Mixed Enterprise (N=532)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	44.53	12.31	45.38	12.02	45.48	12.17
Experience (years)	9.77	8.51	10.65	8.85	12.65	9.70
Education (%)						
None	3.78	19.07	3.02	17.12	2.07	14.24
Elementary	29.82	45.76	31.76	46.58	20.49	40.39
Secondary	36.26	48.09	33.60	47.26	32.89	47.03
Post-Secondary	30.14	45.90	31.63	46.53	44.55	49.74
Primary Income (%)	70.05	45.82	55.25	49.76	69.74	45.98
Producer Organization (%)	44.21	49.68	38.32	48.65	53.76	49.91
Operate Crop Farm (%)	49.80	50.02	49.48	50.03	51.69	50.02
Owner Operated Farm (%)	70.25	45.73	85.30	35.43	75.00	43.34
Rural (%)	67.19	46.97	43.70	49.63	52.63	49.98

Operator characteristics such as farm as a primary income source, membership of a producer organization and the proportion of producers operating a crop farm also varies across farm specialization. Income from the chicken enterprise served as the primary source of income for a higher proportion of layer producers (70.1%) relative to broiler (55.3%) and mixed (69.7%) farm operators. With respect to the percentage of producers belonging to a national or regional producer organization, more mixed farm operators (53.8%) than layer (44.2%) or broiler (38.3%) producers tend to belong to a producer association. Approximately half of layer (49.8%) and broiler (49.5%) producers, compared to about 51.7% of mixed farm producers, operate at least a crop farm alongside their chicken enterprise[21].

[21] The difference between the proportion of layer and broiler producers that operate a crop farm was not statistically significant ($t = 0.1487$; $P > t = 0.8818$). Likewise, the difference between the proportion of farms that operate a crop farm in layer and mixed enterprises as well as between broiler and mixed enterprises were both not statistically significant at the 10% level [($t = -0.75$; $P > t = 0.453$) and ($t = -0.784$; $P > t = 0.433$)]. Thus, statistically speaking, the proportion of crop producing chicken farmers were not different among chicken enterprises.

Table 4:5 Size of layer operation by farm management characteristics

Farm Management Characteristics	Small Scale (N=1334)		Medium Scale (N=107)		Large Scale (N=95)		All (N=1536)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DOC Stocking (%)								
Own DOC	2.32	15.07	0.93	9.67	4.21	20.19	2.34	15.13
Self-imported	5.02	21.85	10.28	30.51	15.79	36.66	6.05	23.86
Local importer	31.71	46.55	42.06	49.60	57.89	49.63	34.05	47.40
Local supplier	60.94	48.81	46.73	50.13	22.11	41.72	57.55	49.44
Feed type (%)								
Own feed only	44.15	49.68	71.96	45.13	64.21	48.19	47.33	49.94
Commercial feed only	37.71	48.48	14.02	34.88	22.11	41.72	35.09	47.74
Mixed Feed	18.14	38.55	14.02	34.88	13.68	34.55	17.58	38.08
Hired labor (%)	59.67	45.60	82.97	35.77	88.52	30.96	63.08	45.06

Table 4:6 Size of broiler operation by farm management characteristics

Farm Management Characteristics	Small Scale (N=664)		Medium Scale (N=61)		Large Scale (N=37)		All (N=762)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DOC Stocking (%)								
Own DOC	4.82	21.43	3.28	17.96	2.70	16.44	4.59	20.95
Self-imported	2.71	16.25	6.56	24.96	35.14	48.40	4.59	20.95
Local importer	42.47	49.47	52.46	50.35	21.62	41.73	42.26	49.43
Local supplier	50.00	50.04	37.70	48.87	40.54	49.77	48.56	50.01
Feed type (%)								
Own feed only	26.20	44.01	31.15	46.69	40.54	49.77	27.30	44.58
Commercial feed only	45.63	49.85	34.43	47.91	29.73	46.34	43.96	49.67
Mixed Feed	28.16	45.01	34.43	47.91	29.73	46.34	28.74	45.28
Hired labor (%)	41.48	46.92	60.90	47.23	70.82	44.64	44.46	47.45

Table 4:7 Size of mixed operation by farm management characteristics

Farm Management Characteristics	Small Scale (N=457)		Medium Scale (N=34)		Large Scale (N=41)		All (N=532)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DOC Stocking (%)								
Own DOC	2.84	16.64	2.94	17.15	9.76	30.04	3.38	18.10
Self-imported	1.75	13.13	0.00	0.00	7.32	26.37	2.07	14.24
Local importer	49.45	50.05	64.71	48.51	58.54	49.88	51.13	50.03
Local supplier	45.95	49.89	32.35	47.49	24.39	43.48	43.42	49.61
Feed type (%)								
Own feed only	33.92	47.39	55.88	50.40	60.98	49.39	37.41	48.43
Commercial feed only	44.42	49.74	20.59	41.04	9.76	30.04	40.23	49.08
Mixed Feed	21.66	41.24	23.53	43.06	29.27	46.06	22.37	41.71
Hired labor (%)	57.37	45.84	95.54	16.34	81.53	37.99	61.67	45.28

Variations in the size of farm, farm management (i.e. whether farm is owner-operated), as well as the farm location may reveal additional heterogeneity in both the level of efficiency and producers' feed demand across farm enterprises. Owner-operated farms represent 70.3% of all layer farms, 85.3% of all broiler farms and 75.0% of all dual enterprises. This proportion, however, declines with farm size for all specialization. Regarding farm location, about 67.2% of layer farms were identified by farm managers to be located in rural areas and the remaining 32.8% located in urban areas. This contrasts with broiler and mixed farms where about 43.7% and 52.6% are located in rural areas, respectively. Transaction costs, such as access to feed and market access, may be higher for chicken farms located in rural areas contributing to their expected lower allocative efficiency and probability of using commercial feed.

In addition to these explanatory variables, the source of day-old-chicks, the type of feed used by producers as well as the proportion of hired labor may affect production performance. The descriptive statistics on these explanatory variables are reported in Table 4:5, Table 4:6 and Table 4:7. Noticeable differences are observed in the mean values reported under the three chicken enterprises. For example, a little over one-fourth of broiler farms used only self-compounded feed compared with more than one-third of mixed farms and 47.3% of layer farms. About 44.0% of broiler farms, 35.1% of layer farms and 40.2% of mixed farms used commercial feed only. The remaining 17.6%, 28.7% and 22.4% of farms, respectively, used both commercial and self-prepared feed simultaneously. The primary stocking method used is day-old-chicks. Four sources of day-old-chicks were identified in this study: own production; self-imported day-old-chicks; importer or distributor day old chicks; and local day-old-chicks' suppliers. More than 90% of farms in each enterprise procured their day-olds from either local suppliers or local importers. However, only 5.5% of mixed farms compared with 8.4% of layer farms and 9.2% of broiler farms either produced their own day-old-chicks or self-imported day-old-chicks. About 63.1% of layer farms compared to 44.5% of broiler farms and 61.7% of mixed farms had hired employees. This proportion increase by scale for each chicken enterprise.

Table 4:8 Descriptive statistics of additional variables used in the feed demand analysis

Variables	Layer Enterprise		Broiler Enterprise		Mixed Enterprise	
	Mean	SD	Mean	SD	Mean	SD
Dependent Variable: Hurdle 1 (%)						
Use Own Feed	64.91	47.74	56.04	49.67	59.77	49.08
Purchase Commercial Feed	52.67	49.94	72.70	44.58	62.59	48.43
Dependent Variable: Hurdle 2 (Kg/bird)						
Quantity of Own Feed	15.54	10.17	3.56	13.85	10.73	9.37
Quantity of Commercial Feed	19.51	18.57	4.18	6.96	12.69	12.48
Feed Source/Preparation Methods (%)						
Commercial Feed Source						
Farmer Based Organization	12.87	33.49	13.36	34.05	18.11	38.56
Private Retail	68.97	46.29	63.54	48.18	60.24	49.01
Commercial Feed mills	18.16	38.48	23.10	42.19	21.37	41.05
Own Feed Production Method						
Automated	19.16	39.37	10.77	31.04	20.13	40.16
Manual Mixing	66.30	47.29	74.71	43.52	65.72	47.54
Toll Milling	14.54	35.27	14.52	35.27	14.15	34.91
Market Conditions						
Maize price (GHS)	1.28	0.39	1.24	0.43	1.28	0.39

The descriptive statistics of the dependent and additional explanatory variables for the double hurdle feed demand models are reported in Table 4:8. The double hurdle assumes that producers face two hurdle decisions before recording positive quantities for each feed type. The first hurdle consists of producers making a binary decision of whether to use each feed type. About 56.0% of all broiler farms indicated producing some or all of their feed while 72.7% used at least some commercial feed. For mixed farms, 59.8% produced some or all their feed, while nearly

62.6% purchased some or all their feed from commercial source. In contrast, the proportion of layer farms that produced at least some of their feed (64.9%) was higher than those that purchased some or all of their feed (52.7%). The relatively large proportion of farms purchasing commercial feed as well as producing on-farm feed is a common operational strategy in Ghana. Farmers would use commercial feed to start their flocks and switch when the birds are established. Conditional on the first hurdle being met (i.e. produce and/or purchase feed), producers decide on the quantity of feed to produce and/or purchase in the second hurdle. The average own feed quantity for layer farms was estimated at 15.5 kg per bird compared to 3.6 kg per bird for broilers and 10.7 kg per bird for mixed farms. Likewise, the average commercial feed quantity for layer farms was estimated at 19.5 kg per bird compared to 4.2 kg per bird for broilers and 12.7 kg per bird for mixed farms.

The primary source of commercial feed for chicken producers was retail outlets, with approximately 69.0% of all layer farms, 63.5% of broiler farms and 60.2% of mixed farms selecting it. Commercial feed mills supplied 18.2% of layer farms, 23.1% of broiler farms and 21.4% of mixed farms while farmer-based organizations supplied 12.9%, 13.4% and 18.1% of farms, respectively. However, the majority of on-farm feed processing was done manually (66.3% of layer farms, 74.7% of broiler farms and 65.7% of mixed farms). The remaining farms either used automated mill (19.2% layer farms, 10.8% broiler farms and 20.1% mixed farms) or a toll mill (14.5% of layer farms, 14.5% of broiler farms and 14.2% mixed farms) for their on-farm feed processing. The price of maize is also hypothesized to influence producers demand for chicken feed, especially self-prepared feed, since maize forms the bulk of chicken feed. The average price[22] of maize was estimated to be lower in broiler operations (GHS 1.24 per kg) than layer (GHS 1.28

[22] The cedi-dollar exchange rate at the time of the survey was about GHS 3.7841 to $1 (source: Bank of Ghana daily interbank FX rate).

per kg) and mixed farms (GHS 1.28 per kg) despite layer and mixed farms producing larger volumes of self-compounded feed on average[23].

Producer perceptions about the importance of certain attributes of a feed type may influence their decision on the quantity of feed to use once acquisition decision has been made. As a result, producers were asked to rank the importance (from "not at all important" to "very important") of eleven factors that motivate the production of own feed and eight factors that motivate the purchase of commercial feed. Using principal component analysis and setting the minimum Eigenvalue to 0.9, the eleven factors loaded orthogonally onto three components for each of the three chicken enterprises, which together accounted for 60%, 64% and 57% of the factors' cumulative variance for layer, broiler and mixed farms, respectively. The three components for the layer and mixed operations are labeled as "external control", "access to low cost feed and feed ingredients" and "feed quality and quality control" (Table 4:9 and Table 4:11). Better control over the availability, accessibility, and affordability of feed are associated with "external control". Easy access to domestic feed inputs, lower cost of domestic feed inputs and easy access to necessary ingredients are associated with "access to low cost feed and feed ingredients". Better control over quality and higher quality of feed are associated with "feed quality and quality control". In the case of broiler operations, the three components are labeled as "external control", "feed quality and quality control" and "control over low feed cost". Lower cost of domestic feed inputs and better control over cost are associated with "control over low feed cost"

[23] While there was statistically significant difference between the average price of maize for layer and broiler farms ($|t| = 2.2007$; $P > |t| > 0.0279$), the differences between those two on the one hand, and mixed farms on the other, were not statistically significant at the 1 percent level. Between layer and mixed farms, $|t| = 0.1354$ and $P > |t| = 0.8923$, while the statistics for broiler and mixed with a difference in mean value of $|1.97|$, $|t| = -1.5726$; and $P > |t| = 0.1160$.

The eight factors motivating commercial feed use also loaded orthogonally onto three components for each of the three chicken enterprises, which together accounted for 57%, 71% and 71% of the factors' cumulative variance for layer, broiler and mixed farms, respectively. The three components are labeled as "no search and quality concerns", "higher and consistent feed quality", and "control over low cost feed" (Table 4:10). Avoid worries searching for ingredients, avoid worries about the quality of ingredients and overall lower production risk are associated with "no search and quality concerns". Lower relative cost compared to own feed and better control over cost are associated with "control over low cost feed". Higher quality of feed and consistent feed quality are associated with "higher and consistent feed quality". There is no clear theoretical guidance regarding the inclusion of these motivating factors in the double hurdle model. Therefore, the expected relationship between these factors and the actual quantity of feed used cannot be determined *a priori*.

Table 4:9 Principal component analysis of motivating factors influencing own feed use by layer producers

Motivating Factors	Component 1	Component 2	Component 3	Component Description	kmo
Overall better control over accessibility to feed	**0.5603**	0.0258	-0.0095		0.7332
Overall better control over availability of feed	**0.5529**	0.0036	0.0158	"External Control"	0.7532
Overall better control over affordability of feed	**0.5268**	0.0501	-0.1043		0.8492
Easy access to domestic feed inputs	-0.0474	**0.5597**	0.0361	"Access to low cost feed and feed ingredients"	0.7193
Lower cost of domestic feed inputs	0.0342	**0.4792**	-0.0405		0.8452
Easy access to necessary ingredients	-0.0447	**0.5598**	0.0469		0.7347
Better control over quality	0.0244	-0.0756	**0.6341**	"Feed quality and quality control"	0.666
Higher quality of feed	-0.0412	-0.0122	**0.6256**		0.6711
Ability to import ingredients at cost competitive prices	0.0543	0.3336	0.008		0.853
Better control over cost	0.3032	-0.0738	0.2378		0.8371
Freedom to adjust inputs to meet specific bird needs	-0.0151	0.1335	0.3654		0.8696

60% explained; Kaiser-Meyer-Olkin (kmo) measure of sampling adequacy averaged 0.76

Table 4:10 Principal component analysis of motivating factors influencing own feed use by broiler producers

Motivating Factors	Component 1	Component 2	Component 3	Component Description	kmo
Overall better control over accessibility to feed	**0.418**	-0.041	-0.194		0.813
Overall better control over availability of feed	**0.404**	0.014	-0.208	"External Control"	0.806
Overall better control over affordability of feed	**0.363**	-0.065	0.045		0.873
Better control over quality	0.128	**0.584**	-0.166	"Feed quality and	0.616
Higher quality of feed	0.111	**0.557**	-0.257	quality control"	0.625
Lower cost of domestic feed inputs	0.310	-0.148	**0.421**	"Control over low	0.877
Better control over cost	0.120	0.254	**0.776**	cost feed"	0.675
Easy access to necessary ingredients	0.395	-0.172	-0.060		0.788
Ability to import ingredients at cost competitive prices	0.245	-0.004	-0.015		0.909
Freedom to adjust inputs to meet specific bird needs	0.152	0.424	0.184		0.760
Easy access to domestic feed inputs	0.385	-0.211	-0.068		0.779

64% explained; Kaiser-Meyer-Olkin (kmo) measure of sampling adequacy averaged 0.78

Table 4:11 Principal component analysis of motivating factors influencing own feed use by mixed farm producers

Motivating Factors	Component 1	Component 2	Component 3	Component Description	kmo
Overall better control over accessibility to feed	**0.502**	0.036	0.028	"External Control"	0.787
Overall better control over availability of feed	**0.525**	-0.038	0.089		0.788
Overall better control over affordability of feed	**0.559**	-0.063	-0.126		0.786
Easy access to domestic feed inputs	-0.073	**0.606**	0.046	"Access to low cost feed and feed ingredients	0.701
Lower cost of domestic feed inputs	0.037	**0.481**	0.007		0.763
Easy access to necessary ingredients	-0.014	**0.565**	0.028		0.732
Better control over quality	-0.008	-0.079	**0.665**	"Feed quality and quality control"	0.597
Higher quality of feed	-0.059	-0.001	**0.624**		0.617
Ability to import ingredients at cost competitive prices	0.151	0.238	-0.115		0.813
Freedom to adjust inputs to meet specific bird needs	0.152	0.065	0.351		0.852
Better control over cost	0.319	0.078	0.061		0.778

57% explained; Kaiser-Meyer-Olkin (kmo) measure of sampling adequacy averaged 0.75

Table 4:12 Principal component analysis of motivating factors influencing commercial feed use by layer producers

Motivating Factors	Component 1	Component 2	Component 3	Component Description	kmo
Avoid worries searching for ingredients	**0.634**	-0.095	-0.053	"No search and quality concerns"	0.700
Avoid worries about the quality of ingredients	**0.540**	-0.081	0.131		0.737
Overall lower production risk	**0.474**	0.121	-0.073		0.893
Lower relative cost compared to own feed	0.005	**0.677**	-0.016	"Control over low cost feed"	0.656
Better control over cost	-0.034	**0.669**	0.023		0.657
Higher quality of feed	0.025	-0.022	**0.690**	"Higher and consistent feed quality"	0.790
Consistent quality	-0.029	0.034	**0.705**		0.774
Easy access	0.278	0.246	0.005		0.912

57% explained; Kaiser-Meyer-Olkin (kmo) measure of sampling adequacy averaged 0.74

Table 4:13 Principal component analysis of motivating factors influencing commercial feed use by broiler producers

Motivating Factors	Component 1	Component 2	Component 3	Component Description	kmo
Avoid worries searching for ingredients	**0.633**	-0.012	-0.161	"No search and quality concerns"	0.635
Avoid worries about the quality of ingredients	**0.579**	0.023	0.032		0.693
Overall lower production risk	**0.474**	0.021	0.137		0.861
Lower relative cost compared to own feed	-0.066	**0.657**	-0.018	"Control over low cost feed"	0.646
Better control over cost	-0.061	**0.641**	0.049		0.673
Higher quality of feed	0.024	-0.024	**0.696**	"Higher and consistent feed quality"	0.672
Consistent quality	0.013	0.010	**0.681**		0.691
Easy access	0.172	0.393	-0.039		0.866

71% explained; Kaiser-Meyer-Olkin (kmo) measure of sampling adequacy averaged 0.86

Table 4:14 Principal component analysis of motivating factors influencing commercial feed use by mixed farm producers

Motivating Factors	Component 1	Component 2	Component 3	Component Description	kmo
Avoid worries searching for ingredients	**0.409**	-0.384	-0.225	"No search and quality concerns"	0.702
Avoid worries about the quality of ingredients	**0.433**	-0.377	-0.234		0.676
Overall lower production risk	**0.412**	-0.208	-0.049		0.877
Lower relative cost compared to own feed	0.260	**0.581**	-0.275	"Control over low cost feed"	0.645
Better control over cost	0.281	**0.543**	-0.289		0.667
Higher quality of feed	0.354	0.122	**0.487**	"Higher and consistent feed quality"	0.791
Consistent quality	0.295	0.107	**0.702**		0.713
Easy access	0.338	0.080	-0.036		0.881

71% explained; Kaiser-Meyer-Olkin (kmo) measure of sampling adequacy averaged 0.75

Finally, the mean and standard deviation of the input and output variables used in the nonparametric efficiency models are presented in Table 4:15. As layer farms are generally larger with longer production cycles[24] than broiler farms, they use more input quantities than broiler farms on average. However, on a per bird basis, the average labor hours for broiler farms (9.4 hours/bird) was about three times higher than that for layer (3.6 hours/bird) and mixed (3.3 hours/bird) farms. An indication that broiler farms are more labor intensive compared to layer and mixed farms. The average quantity of feed per bird for layer (21.2 kg) and mixed (17.4 kg) farms were, respectively, 3.0 and 2.4 times higher compared to broiler farms (7.2 kg). This may be explained by the longer production cycles for layers vis-à-vis broilers. Layers are kept in production for an average of 77 weeks whereas a typical production cycle for broilers is 7 weeks. The average broiler production was estimated as 1,385 birds per farm for broiler enterprise and 1,148 birds per farm for mixed enterprise with standard deviations of 4,768 and 2,457 birds. Each with a median of 500 birds. On the other hand, the average flock size for layer production was 3,338 birds per farm with a standard deviation of 12,222 birds and a median of 1,000 birds. This contrasts with the average size of layers in mixed enterprise: 2,920 birds per farm, a standard deviation of 14,252 birds, and a median of 800 birds. With respect to the number of eggs produced, the average output per farm in layer operation was 17,405 crates, with a standard deviation of 84,411 crates and a median of 4,726 crates. In contrast, the average output for mixed operations was about 14,201 crates per farm, with a standard deviation of 65,426 crates and a median of 3,318 crates.

Interestingly, average per unit input costs were higher in layer and mixed operations than in broiler operations. The cost of day-old chicks and veterinary service per bird were GHS 4.3 and

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[24] A typical production cycle for broilers averages 2 cycles in a year, whiles layers could be kept for more than 130 weeks.

GHS 0.5 for broiler farms compared to GHS 4.4 and GHS 1.2 for layer farms and GHS 4.6 and GHS 0.7 for mixed farms. Feed cost average about GHS 3.21 per kg for layer farms, GHS 3.05 per kg for mixed farms and GHS 2.44 per kg for broiler farms while the average labor cost per hour was GHS 1.28, GHS 1.26 and GHS 0.95, respectively[25]. The average price[26] of layer eggs per crate was estimated as GHS 13.33 for layer farms and GHS 13.57 for mixed farms while the average price producers received for live-bird was GHS 35.29 for broiler farms and GHS 34.94 for mixed farms.

[25] The difference in DOC costs between mixed farms on one hand and layer and broiler farms on the other were statistically significant at the 1% level [(t = -4.38; Pr > t = 0.000) and (t = 5.46; Pr > t = 0.000)]. The opposite is true for the difference between layer and broiler farms (t = 1.40; Pr > t = 0.16). The difference in veterinary costs between layer and broiler farms was statistically significant at the 1% level (t = 2.85; Pr > t = 0.004). However, the difference in veterinary costs between layer and mixed farms and between broiler and mixed farms were both not statistically significant [(t = 1.58; Pr > t = 0.1146) and (t = 1.0827; Pr > t = 0.2792)]. The difference in feed costs between layer and broiler farms, between layer and mixed farms and between broiler and mixed farms were all statistically significant at the 1% level [(t = 29.98; Pr > t = 0.000) and (t = 6.285; Pr > t = 0.000) and (t = 16.9408; Pr > t = 0.000)]. The difference in labor costs between broiler on one side and layer and mixed farms were both statistically significant at the 1% level [(t = 15.9032; Pr > t = 0.000) and (t = 11.8210; Pr > t = 0.000)]. The difference in feed costs between layer and mixed farms was GHS 0.31, with a t = 0.8504 and Pr > t = 0.3952, causing us to fail to reject the hypothesis that the two are equal.

[26] Chicken products – live birds and/or eggs – are sold through seven possible channels: direct-to-consumers, wholesalers, retailers, hawkers, chop bars, processors, and hotels, restaurants and institutions.

Table 4:15 Summary statistics of variables use in the DEA stage

Variables	Layer Enterprise		Broiler Enterprise		Mixed Enterprise	
	Mean	SD	Mean	SD	Mean	SD
Input and Output Quantity						
Feed (Kg/bird)	21.22	14.96	7.22	9.36	17.41	11.09
Labor (hour/bird)	3.63	2.92	9.48	139.07	3.32	2.76
Broilers (head)	^	^	1,384.79	4,767.68	1,148.45	2,456.70
Egg (crate/bird)	17,405.22	84,411.03	^	^	14,200.72	65,425.77
Layers (head)	3,337.50	12,222.37	^	^	2,920.41	14,252.03
Input and Output Quantity Prices						
Feed (GHS/Kg)	3.21	0.50	2.44	0.72	3.05	0.51
Labor (GHS/hour)	1.28	0.48	0.95	0.43	1.26	0.50
DOC (GHS/bird)	4.38	0.94	4.32	0.82	4.58	0.87
Vet cost (GHS/bird)	1.23	6.74	0.52	1.41	0.73	4.88
Broiler (GHS/bird)	^	^	35.29	4.41	34.94	4.58
Eggs (GHS/crate)	13.33	0.96	^	^	13.57	1.17

^ denotes data not available for the variable given the type of chicken enterprise

Chapter 5 - Empirical Results

This Chapter presents and discusses the empirical results of the various analyses conducted to achieve the study's objectives. Section 5.1 presents results from the estimation of the non-parametric DEA technical, cost, allocative and scale efficiency. This section also identifies and estimates the determinants of each efficiency measure by chicken enterprise using the truncated regression model. We test whether farm size, operating a crop farm, producing own feed, dependence on farm as a primary income source and farm location are significant determinants of farm performance. In Section 5.2, results from the estimation of producers' demand for self-compounded and/or commercial feed are then presented. We test whether farm size, operating a crop farm, feed price, source of commercial feed and own feed preparation methods are significant determinants of producers' feed demand decision.

5.1 Efficiency Estimation Results

Input-oriented efficiency measures – technical, cost, scale, allocative – were computed for each farm relative to the best practice frontier constructed from the data based on deviations of observed input intensity or production cost from the efficient frontier. If a farm's actual input combination or cost of production is on the efficient frontier, it is considered to be perfectly efficient i.e., with efficiency score of one. If it is off the frontier it is considered to be inefficient i.e., with efficiency score of less than one but greater than zero. Thus, the relative distance of farms from the frontier, measures the level of inefficiencies that may exist. Identifying and eliminating these inefficiencies will result in cost savings and improved performance of Ghana's chicken industry. For this reason, examination of the factors influencing farm inefficiencies was conducted following the regression model presented in Section 3.4.

Efficiency scores were estimated by four different linear programming techniques defined by equations (3.3) (3.5) and (3.6). The optimal solutions to equations (3.3) and (3.5) for each farm are, respectively, the overall technical (under CRS) and pure technical (under VRS) efficiency scores. With the availability of input price data, equation (3.3) was extended to (3.6) to estimate the level of cost efficiency under CRS condition. It is particularly noteworthy that the cost efficiency estimates under CRS condition are the same for both the input-oriented and output-oriented models and have sometimes been referred to as economic or overall efficiency in the literature (Thanassoulis 2001). To estimate cost efficiency scores for each farm under VRS condition, a convexity constraint was appended to Equation (3.6). Scale efficiency (SE) was then calculated residually as the ratio of cost efficiency under CRS to cost efficiency under VRS whiles allocative efficiency was also estimated residually as the ratio of scale efficiency to technical efficiency under VRS. Subsequently, each efficiency measure was regressed on farm and farmer specific characteristics such as experience and level of education of farm operator, whether the chicken farm is producers' primary source of income, whether farm is owner operated, etc., to determine their extent and direction of influence on the performance of each chicken enterprise. Estimated efficiency scores and results from the efficiency effect models for each chicken enterprise are presented in the subsequent subsections.

5.1.1 Technical Efficiency

The average technical efficiency scores under CRS (overall technical efficiency) and VRS (pure technical efficiency) technologies for layer, broiler and mixed enterprises are summarized in Table 5:1. On average, broiler farms were the least technical efficient with a mean technical efficiency of 0.54 under CRS and 0.60 under VRS. The mean technical efficiency for mixed farms was 0.73 under CRS and 0.77 under VRS. By contrast, layer farms, on average, reached 85% and 87% of the "best practice" technical efficiency under CRS and VRS technology, respectively. These estimates suggest that the potential input reduction that could be realized by efficiently using inputs is higher for broiler operation (between 40% and 46% depending on the technology) compared to mixed operation (between 23% and 27% depending on the technology) and layer operation (between 13% and 15% depending on the technology). Thus, the proportion of production cost that is due to farm specific technical inefficiency is substantial in broiler production than in mixed or layer production. Alternatively, the overall technical efficiency scores suggest that on average, broiler, layer and mixed farms, respectively, potentially could produce 2.0 times, 1.37 times and 1.18 times (1/CRS) as much outputs from the same level of inputs if they were to be more overall technical efficient.

Table 5:1 DEA estimates of input-oriented technical efficiency by chicken enterprise

TE	Layer Farms (N=1536)	Broiler Farms (N=762)	Mixed Farms (N=532)
Overall Technical Efficiency (CRS)			
Mean point estimate	0.852	0.543	0.734
SD	0.203	0.179	0.207
Score of least efficient farm	0.301	0.162	0.183
Median point estimate	0.921	0.531	0.761
Coefficient of variation	0.238	0.329	0.282
Efficient farms	1.17%	2.89%	9.02%
Pure Technical Efficiency (VRS)			
Mean point estimate	0.869	0.601	0.769
SD	0.195	0.189	0.204
Score of least efficient farm	0.301	0.163	0.193
Median point estimate	0.942	0.583	0.811
Coefficient of variation	0.224	0.315	0.266
Efficient farms	3.99%	5.60%	16.73%

The range in mean technical efficiency estimates from 0.54 (broiler farms) to 0.87 (layer farms) reveals the importance in analyzing separate production frontiers for each chicken enterprise and not simply considering the chicken industry as being homogeneous. In terms of the number of efficient farms, only 1.2% of layer farms, 2.9% of broiler farms and 9.0% of mixed farms were fully efficient under the CRS technology. Under VRS, the proportion of efficient farms increases to 4.0% for layer farms, 5.6% for broiler farms and 16.7% for mixed farms. Thus, technical efficiency score is higher with variable returns to scale, largely due to the relative restrictiveness of the CRS technology set than the VRS technology set.

Technical efficiency was found to vary by farm size. The results show that mean technical efficiency increased with farm size for all chicken enterprises under VRS but among mixed and layer enterprises, medium farms were the most overall technical efficient (under CRS) followed by large farms and then small farms. Accordingly, the mean technical efficiency for broiler farms by farm size were 0.52 under CRS and 0.58 under VRS for small farms, 0.64 under CRS and 0.65 under VRS for medium farms and 0.78 under CRS and 0.84 under VRS for large farms (Table 5:2). The mean technical efficiency for mixed farms by farm size were 0.72 under CRS and 0.76 under VRS for small farms, 0.83 under CRS and 0.85 under VRS for medium farms and 0.79 under CRS and 0.86 under VRS for large farms (Table 5:3). The mean technical efficiency for layer farms by farm size were 0.84 under CRS and 0.86 under VRS for small farms, 0.92 under CRS and 0.94 under VRS for medium farms and 0.91 under CRS and 0.95 under VRS for large farms (Table 5:4). These estimates seem to suggest that while broiler farms are the most technically inefficient, in general smaller chicken farms have a greater potential to reduce cost by scaling down current input level to the minimum possible level while maintaining current production. The proportion of technically efficient farms increased with the size of farm except for layer operation where the proportion of overall technical efficient small-scale farms (1.20% under CRS) was higher than the proportion of overall technical efficient medium scale farms (0.00% under CRS).

Table 5:2 DEA estimates of input-oriented technical efficiency for broiler farms by farm size

TE	Small Scale (N=664)	Medium Scale (N=61)	Large Scale (N=37)
Overall Technical Efficiency (CRS)			
Mean point estimate	0.520	0.643	0.784
SD	0.165	0.166	0.209
Score of least efficient farm	0.162	0.315	0.370
Median point estimate	0.513	0.649	0.810
Coefficient of variation	0.317	0.258	0.266
Efficient farms	0.75%	8.2%	32.43%
Pure Technical Efficiency (VRS)			
Mean point estimate	0.583	0.654	0.836
SD	0.183	0.161	0.181
Score of least efficient farm	0.163	0.344	0.444
Median point estimate	0.567	0.654	0.933
Coefficient of variation	0.313	0.246	0.216
Efficient farms	3.47%	8.2%	40.54%

Table 5:3 DEA estimates of input-oriented technical efficiency for mixed farms by farm size

TE	Small Scale (N=457)	Medium Scale (N=34)	Large Scale (N=41)
Overall Technical Efficiency (CRS)			
Mean point estimate	0.723	0.828	0.790
SD	0.206	0.195	0.206
Score of least efficient farm	0.183	0.423	0.207
Median point estimate	0.749	0.906	0.820
Coefficient of variation	0.285	0.235	0.260
Efficient farms	7.44%	17.65%	19.51%
Pure Technical Efficiency (VRS)			
Mean point estimate	0.755	0.845	0.863
SD	0.202	0.199	0.195
Score of least efficient farm	0.193	0.426	0.212
Median point estimate	0.789	0.931	1.000
Coefficient of variation	0.268	0.235	0.227
Efficient farms	12.91%	26.47%	51.22%

Table 5:4 DEA estimates of input-oriented technical efficiency for layer farms by farm size

TE	Small Scale (N=1334)	Medium Scale (N=107)	Large Scale (N=95)
Overall Technical Efficiency (CRS)			
Mean point estimate	0.842	0.915	0.909
SD	0.208	0.132	0.163
Score of least efficient farm	0.301	0.303	0.311
Median point estimate	0.917	0.949	0.956
Coefficient of variation	0.247	0.144	0.179
Efficient farms	1.20%	0.00%	2.11%
Pure Technical Efficiency (VRS)			
Mean point estimate	0.858	0.941	0.949
SD	0.199	0.129	0.158
Score of least efficient farm	0.301	0.309	0.326
Median point estimate	0.930	0.980	0.993
Coefficient of variation	0.232	0.138	0.166
Efficient farms	3.61%	2.80%	10.53%

Variation in technical efficiency was also apparent across spatial or geographic dimensions, ranging from 0.74 in Central Region to 0.90 in Brong-Ahafo Region under CRS for layer farms (Table 5:5). Under VRS, the mean technical efficiency ranged between a minimum of 0.76 in Central Region and a maximum of 0.92 in Brong-Ahafo Region. A similar relationship can be observed in broiler operation where the mean technical efficiency varies from 0.51 in Greater Accra Region to 0.65 in Brong-Ahafo Region under CRS and 0.55 in the Northernmost Regions to 0.70 in Brong-Ahafo Region under VRS (Table 5:6). In terms of mixed operation, the mean technical efficiency varies from 0.67 in Greater Accra Region to 0.80 in Western Region under CRS and 0.71in Greater Accra Region to 0.83 in Western Region under VRS (Table 5:7). These estimates clearly show that for specialized operations (broiler or layer only production) Brong-Ahafo farms, on average, exhibit the most technical efficient whereas in diversified or mixed operations, farms in Greater Accra, on average, exhibit the most technical efficient.

Distributional information of each technical efficiency measure for each chicken enterprise and size category are presented in Table 5:8 to Table 5:13 (frequency distribution), and Figure 5:1 to Figure 5:8 (Cumulative distribution). The results clearly show that the distribution of technical efficiency scores for layer operation is positive skewed towards higher efficiency levels, indicating that majority of layer farms produce close to their maximum technical efficiency. For instance, more than three fourth of layer farms (81.05% under CRS technology and 81.96% under VRS technology) display high performance levels presenting efficiency scores greater than or equal to 0.90. The high majority of layer farms (87.83% under CRS technology and 89.08% under VRS technology) with above average performance (technical efficiency greater than 0.5) represents a telltale sign of competition, reflecting the neoclassical picture of a homogenous or highly competitive layer industry.

Estimated individual technical efficiency indices for broiler farms, however, showed a flat distribution. Most broiler farms (77.6% under CRS and 70.0% under VRS) had technical efficiency scores within the range from 0.3 to less than 0.7. The proportion with technical efficiency scores below 0.3 were 5.0%% under CRS and 3.0% under VRS whereas approximately 17.5% under CRS and 26.9% under VRS had technical efficiency scores equal to or greater than 0.7. This distribution indicates a wide variation in the level of technical efficiency among broiler farms with close to one third exhibiting below average performance. Thus, in general majority of broiler farms have not been successful in efficiently combining their resources, suggesting the importance of farm specific characteristics such as producer's managerial skills in attaining higher levels of productive efficiency and competitiveness. For mixed farms, most observations (84.0% under CRS and 86.9% under VRS) for technical efficiency were located within the range from 0.5 to 1.0. This means that only 16% under CRS and 13.1% under VRS have technical efficiency less than 0.4. Despite the high proportion of mixed farms producing on the efficient frontier than layer and broiler farms, more layer farms (81%) than mixed (27%) and broiler farms (4.8%) fall under the efficient group (above 90%).

It is evident from the frequency and cumulative distributions that the technical efficiency scores by farm size or geographic location for each chicken enterprise do not fit within a standard normal distribution. As a result, the Kruskal-Wallis nonparametric test was performed to test if the efficiency difference is statistically significant among farms in different size classes and regional locations. The null hypothesis is that the mean rank of technical efficiency scores is the same across the different farm sizes and spatial location of farms. Table 5:14 presents the results for each chicken enterprise. Significant differences in technical efficiency exists among the farm size classes and spatial location of farms, indicating that farm size and regional location of farms does matter when comparing farm technical efficiency.

Table 5:5 DEA estimates of input-oriented technical efficiency for layer farms by region

Regions	Ashanti (N=451)	Brong-Ahafo (N=346)	Central (N=124)	Eastern (N=183)	Greater-Accra (N=123)	Northernmost (N=68)	Volta (N=73)	Western (N=168)
TE - CRS								
Mean point estimate	0.886	0.902	0.744	0.841	0.838	0.854	0.877	0.745
SD	0.170	0.140	0.267	0.210	0.232	0.176	0.168	0.257
Score of least efficient farm	0.301	0.301	0.301	0.301	0.301	0.320	0.330	0.301
Median point estimate	0.928	0.926	0.906	0.920	0.940	0.908	0.919	0.904
Coefficient of variation	0.192	0.155	0.359	0.250	0.277	0.206	0.191	0.346
TE - VRS								
Mean point estimate	0.902	0.916	0.760	0.868	0.856	0.872	0.894	0.765
SD	0.162	0.138	0.262	0.193	0.225	0.172	0.156	0.246
Score of least efficient farm	0.301	0.303	0.303	0.304	0.304	0.320	0.374	0.306
Median point estimate	0.948	0.948	0.912	0.945	0.957	0.921	0.936	0.913
Coefficient of variation	0.180	0.151	0.345	0.223	0.263	0.197	0.174	0.322

Table 5:6 DEA estimates of input-oriented technical efficiency for broiler farms by region

Regions	Ashanti (N=85)	Brong-Ahafo (N=98)	Central (N=124)	Eastern (N=161)	Greater-Accra (N=162)	Northernmost (N=26)	Volta (N=42)	Western (N=64)
TE - CRS								
Mean point estimate	0.515	0.652	0.519	0.554	0.508	0.520	0.530	0.540
SD	0.196	0.217	0.149	0.174	0.155	0.204	0.161	0.153
Score of least efficient farm	0.176	0.206	0.196	0.236	0.162	0.199	0.219	0.302
Median point estimate	0.501	0.630	0.532	0.549	0.528	0.430	0.529	0.507
Coefficient of variation	0.381	0.332	0.286	0.315	0.305	0.393	0.303	0.282
TE - VRS								
Mean point estimate	0.567	0.700	0.563	0.621	0.586	0.553	0.611	0.574
SD	0.214	0.211	0.147	0.197	0.172	0.199	0.206	0.145
Score of least efficient farm	0.213	0.227	0.205	0.241	0.163	0.353	0.230	0.370
Median point estimate	0.552	0.685	0.569	0.603	0.591	0.477	0.593	0.540
Coefficient of variation	0.377	0.301	0.262	0.317	0.293	0.359	0.338	0.253

Table 5:7 DEA estimates of input-oriented technical efficiency for mixed farms by region

Regions	Ashanti (N=104)	Brong-Ahafo (N=70)	Central (N=68)	Eastern (N=81)	Greater-Accra (N=107)	Northernmost (N=8)	Volta (N=26)	Western (N=68)
TE - CRS								
Mean point estimate	0.755	0.757	0.730	0.705	0.672	0.959	0.708	0.801
SD	0.196	0.203	0.202	0.229	0.215	0.032	0.193	0.170
Score of least efficient farm	0.183	0.183	0.271	0.220	0.207	0.911	0.208	0.333
Median point estimate	0.767	0.785	0.754	0.717	0.692	0.961	0.732	0.833
Coefficient of variation	0.259	0.268	0.277	0.324	0.320	0.033	0.272	0.213
TE - VRS								
Mean point estimate	0.789	0.786	0.770	0.739	0.707	0.989	0.759	0.828
SD	0.196	0.201	0.199	0.221	0.214	0.023	0.204	0.161
Score of least efficient farm	0.213	0.193	0.271	0.223	0.212	0.935	0.222	0.378
Median point estimate	0.835	0.840	0.815	0.767	0.751	1.000	0.815	0.862
Coefficient of variation	0.248	0.255	0.259	0.300	0.302	0.024	0.269	0.195

Table 5:8 Frequency distribution of overall technical efficiency estimates for layer enterprise

Range of Efficiency	% Layer Farms in OTE Interval			
	Small scale	Medium scale	Large scale	All
TE < 0.10	0.00	0.00	0.00	0.00
0.10 ≤ TE < 0.20	0.00	0.00	0.00	0.00
0.20 ≤ TE < 0.30	0.00	0.00	0.00	0.00
0.30 ≤ TE < 0.40	9.15	3.74	6.32	8.59
0.40 ≤ TE < 0.50	4.05	0.00	1.05	3.58
0.50 ≤ TE < 0.60	3.67	1.87	0.00	3.32
0.60 ≤ TE < 0.70	1.8	0.93	0.00	1.63
0.70 ≤ TE < 0.80	1.27	0.00	0.00	1.11
0.80 ≤ TE < 0.90	0.82	0.00	0.00	0.72
0.90 ≤ TE <1.00	78.04	93.46	90.53	79.88
TE =1.00	1.2	0.00	2.11	1.17

Table 5:9 Frequency distribution of pure technical efficiency estimates for layer enterprise

Range of Efficiency	% Layer Farms in PTE Interval			
	Small scale	Medium scale	Large scale	All
TE < 0.10	0.00	0.00	0.00	0.00
0.10 ≤ TE < 0.20	0.00	0.00	0.00	0.00
0.20 ≤ TE < 0.30	0.00	0.00	0.00	0.00
0.30 ≤ TE < 0.40	7.61	1.87	5.26	7.06
0.40 ≤ TE < 0.50	4.22	1.87	1.05	3.86
0.50 ≤ TE < 0.60	3.09	1.87	0.00	2.81
0.60 ≤ TE < 0.70	2.56	0.00	0.00	2.22
0.70 ≤ TE < 0.80	1.51	0.93	0.00	1.37
0.80 ≤ TE < 0.90	0.83	0.00	0.00	0.72
0.90 ≤ TE <1.00	76.58	90.65	83.16	77.97
TE =1.00	3.61	2.8	10.53	3.99

Table 5:10 Frequency distribution of overall technical efficiency estimates for broiler enterprise

Range of Efficiency	% Broiler Farms in OTE Interval			
	Small scale	Medium scale	Large scale	All
TE < 0.10	0.00	0.00	0.00	0.00
0.10 ≤ TE < 0.20	0.75	0.00	0.00	0.66
0.20 ≤ TE < 0.30	4.97	0.00	0.00	4.33
0.30 ≤ TE < 0.40	22.59	4.92	5.41	20.34
0.40 ≤ TE < 0.50	17.47	14.75	5.41	16.67
0.50 ≤ TE < 0.60	24.7	21.31	18.92	24.15
0.60 ≤ TE < 0.70	15.81	26.23	10.81	16.4
0.70 ≤ TE < 0.80	7.68	14.75	8.11	8.27
0.80 ≤ TE < 0.90	3.61	9.84	10.81	4.46
0.90 ≤ TE <1.00	1.66	0.00	8.11	1.84
TE =1.00	0.75	8.2	32.43	2.89

Table 5:11 Frequency distribution of pure technical efficiency estimates for broiler enterprise

Range of Efficiency	% Broiler Farms in PTE Interval			
	Small scale	Medium scale	Large scale	All
TE < 0.10	0.00	0.00	0.00	0.00
0.10 ≤ TE < 0.20	0.15	0.00	0.00	0.13
0.20 ≤ TE < 0.30	3.32	0.00	0.00	2.89
0.30 ≤ TE < 0.40	13.14	3.28	0.00	11.71
0.40 ≤ TE < 0.50	19.64	13.11	2.7	18.29
0.50 ≤ TE < 0.60	21	21.31	10.81	20.53
0.60 ≤ TE < 0.70	18.88	29.51	13.51	19.47
0.70 ≤ TE < 0.80	11.33	14.75	13.51	11.71
0.80 ≤ TE < 0.90	5.59	9.84	8.11	6.05
0.90 ≤ TE <1.00	3.47	0.00	10.81	3.55
TE =1.00	3.47	8.2	40.54	5.66

Table 5:12 Frequency distribution of overall technical efficiency estimates for mixed enterprise

Range of Efficiency	% Mixed Farms in OTE Interval			
	Small scale	Medium scale	Large scale	All
TE < 0.10	0.00	0.00	0.00	0.00
0.10 ≤ TE < 0.20	0.44	0.00	0.00	0.38
0.20 ≤ TE < 0.30	2.19	0.00	4.88	2.26
0.30 ≤ TE < 0.40	4.81	0.00	0.00	4.14
0.40 ≤ TE < 0.50	9.41	14.71	2.44	9.21
0.50 ≤ TE < 0.60	10.5	5.88	9.76	10.15
0.60 ≤ TE < 0.70	16.41	0.00	17.07	15.41
0.70 ≤ TE < 0.80	14	11.76	12.2	13.72
0.80 ≤ TE < 0.90	18.16	11.76	7.32	16.92
0.90 ≤ TE <1.00	16.63	38.24	26.83	18.8
TE =1.00	7.44	17.65	19.51	9.02

Table 5:13 Frequency distribution of pure technical efficiency estimates for mixed enterprise

Range of Efficiency	% Mixed Farms in PTE Interval			
	Small scale	Medium scale	Large scale	All
TE < 0.10	0.00	0.00	0.00	0.00
0.10 ≤ TE < 0.20	0.22	0.00	0.00	0.19
0.20 ≤ TE < 0.30	1.75	0.00	4.88	1.88
0.30 ≤ TE < 0.40	3.5	0.00	0.00	3.01
0.40 ≤ TE < 0.50	8.53	11.76	0.00	8.08
0.50 ≤ TE < 0.60	10.28	8.82	0.00	9.4
0.60 ≤ TE < 0.70	12.47	0.00	19.51	12.22
0.70 ≤ TE < 0.80	14.44	8.82	4.88	13.35
0.80 ≤ TE < 0.90	17.94	11.76	12.2	17.11
0.90 ≤ TE <1.00	17.94	32.35	7.32	18.05
TE =1.00	12.91	26.47	51.22	16.73

Table 5:14 Kruskal-Wallis test results

	Broiler				Layer				Mixed			
	Region		Scale		Region		Scale		Region		Scale	
	Chi-sq	p-value	Chi-sq	p-value	Chi-sq	p-value	Chi-sq	p-value	Chi-sq	p-value	Chi-sq	p-value
CRS	33.150	0.0001	68.914	0.0001	38.632	0.0001	29.154	0.0001	30.686	0.0001	14.048	0.0009
VRS	33.519	0.0001	54.330	0.0001	48.897	0.0001	155.061	0.0001	29.314	0.0001	23.039	0.0001
SE	40.648	0.0001	229.768	0.0001	57.911	0.0001	41.280	0.0001	50.793	0.0001	106.360	0.0001
AE	99.794	0.0001	2.904	0.2341	13.970	0.0517	1.120	0.5711	20.285	0.0050	5.949	0.0511
CE-CRS	109.626	0.0001	3.314	0.1907	55.939	0.0001	39.577	0.0001	36.309	0.0001	1.294	0.5235
CE-VRS	113.054	0.0001	31.197	0.0001	64.080	0.0001	44.001	0.0001	36.730	0.0001	3.213	0.2006

Degrees of freedom: Region=7, Scale=2

Figure 5:1 Cumulative distribution of overall technical efficiency point estimates by chicken enterprise

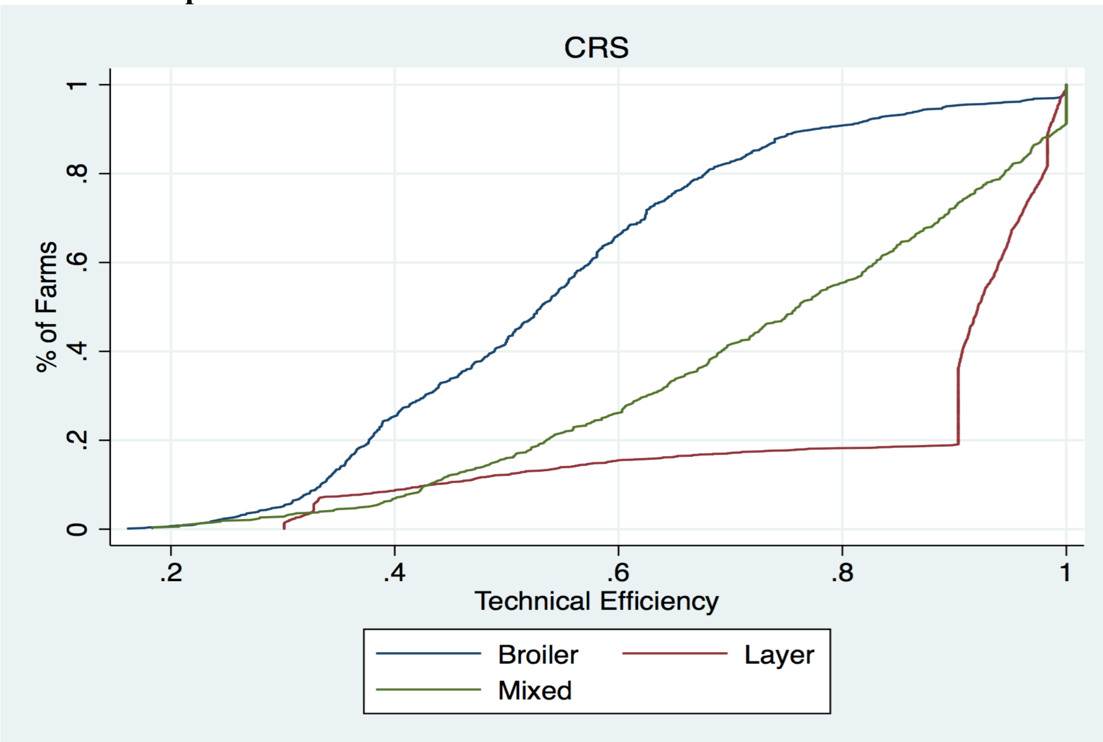


Figure 5:2 Cumulative distribution of pure technical efficiency point estimates by chicken enterprise

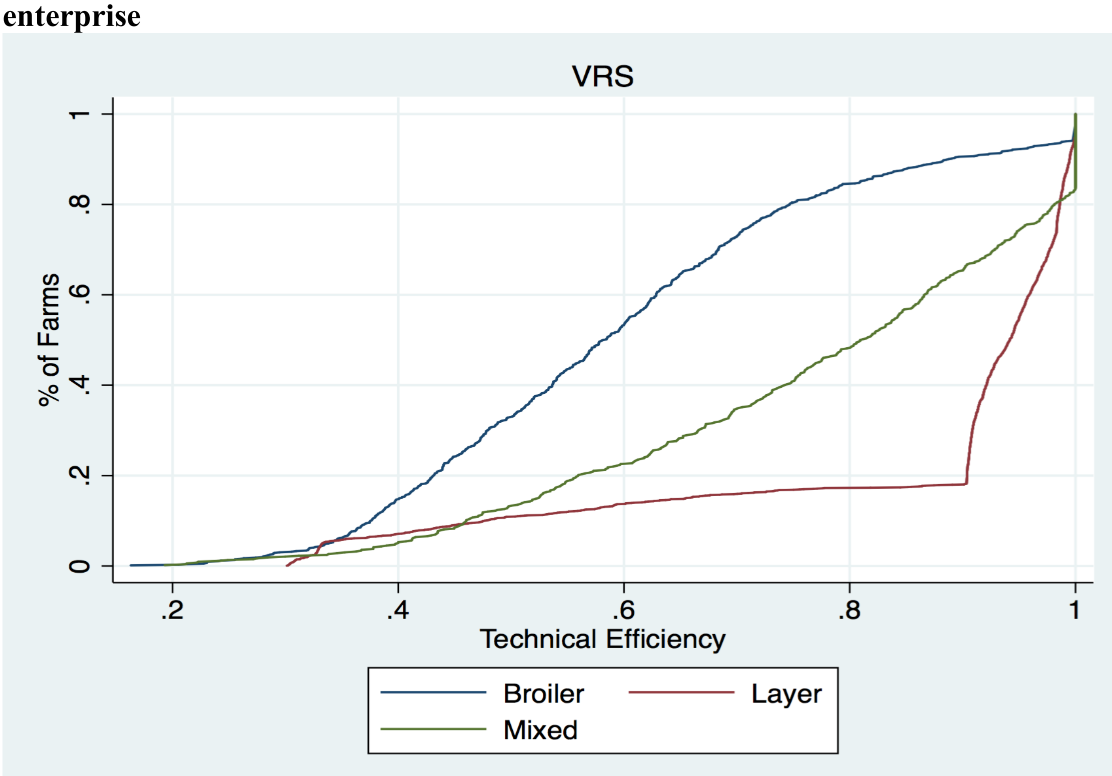


Figure 5:3 Cumulative distribution of overall technical efficiency point estimates for broiler farms by farm size

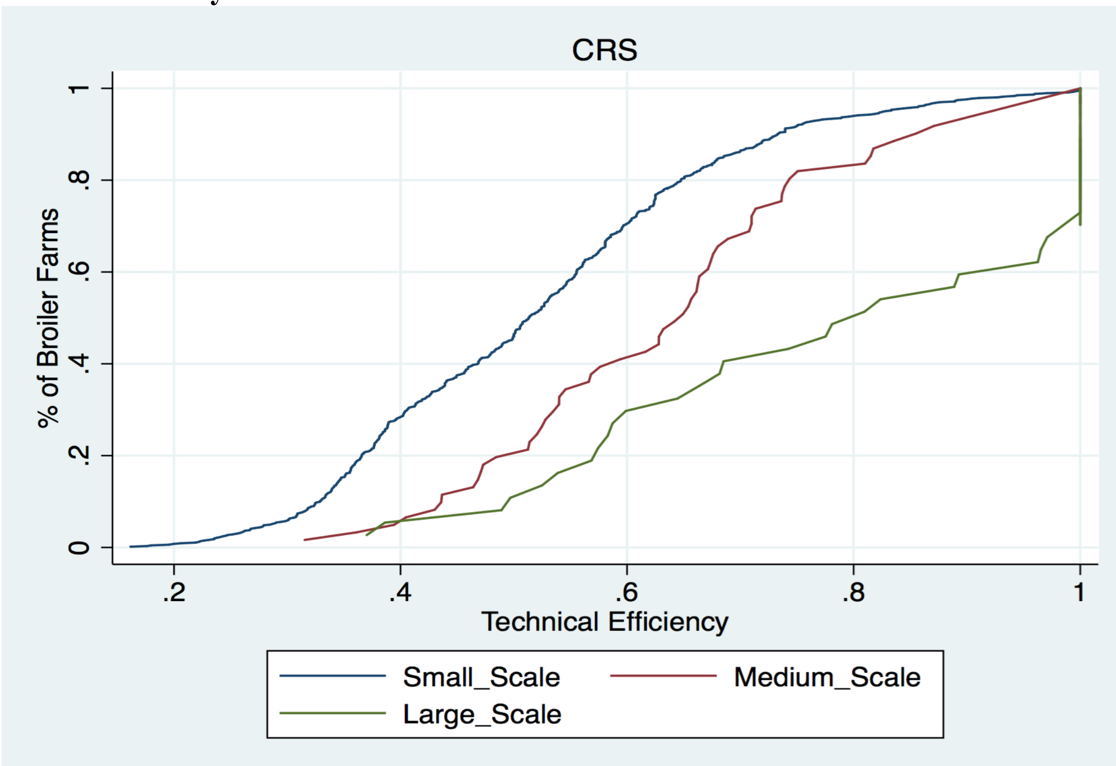


Figure 5:4 Cumulative distribution of pure technical efficiency point estimates for broiler farms by farm size

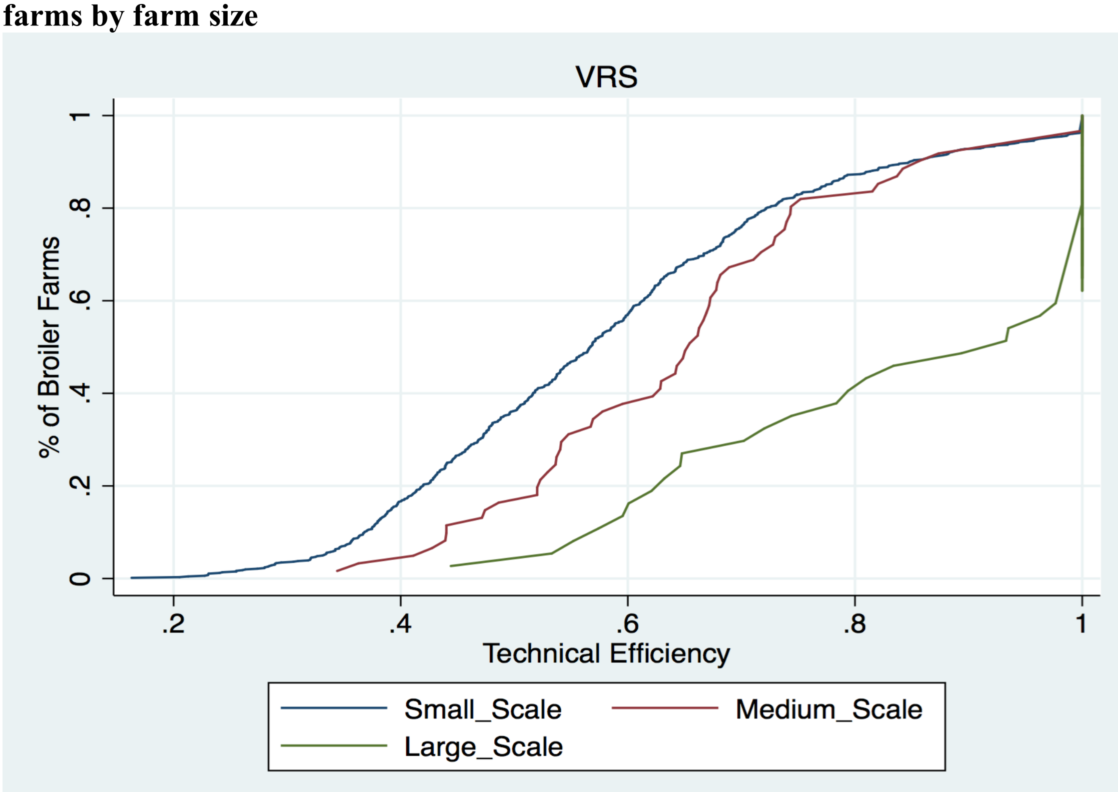


Figure 5:5 Cumulative distribution of overall technical efficiency point estimates for layer farms by farm size

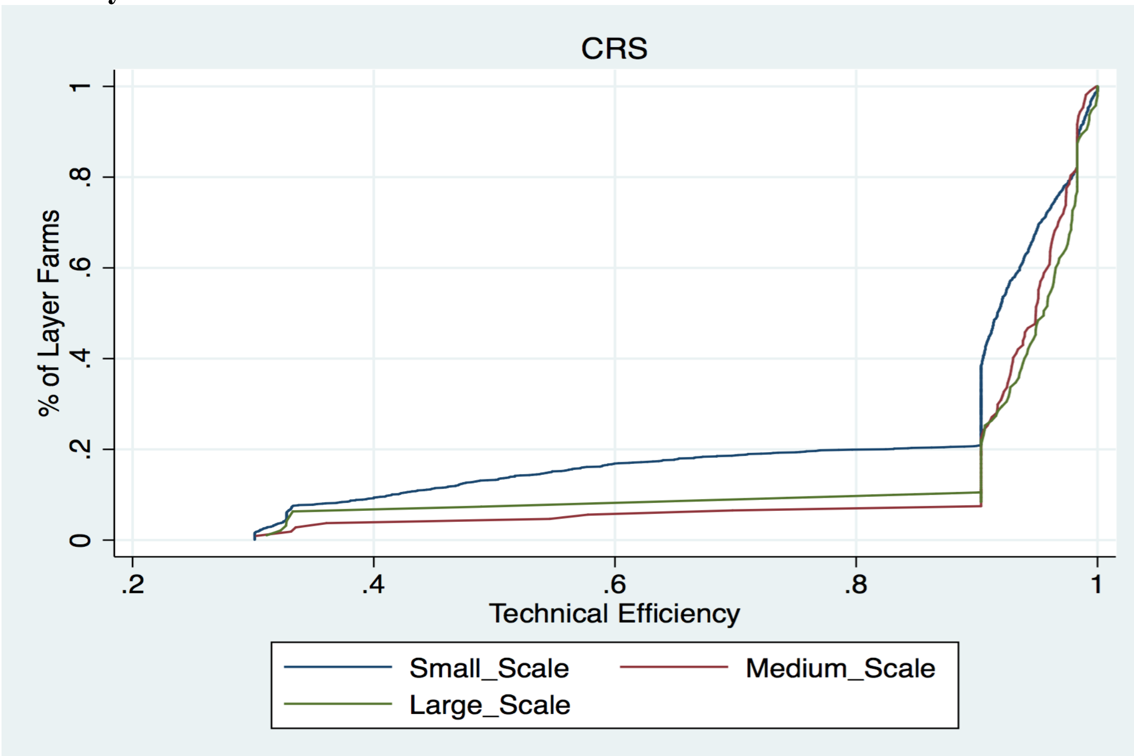


Figure 5:6 Cumulative distribution of pure technical efficiency point estimates for layer farms by farm size

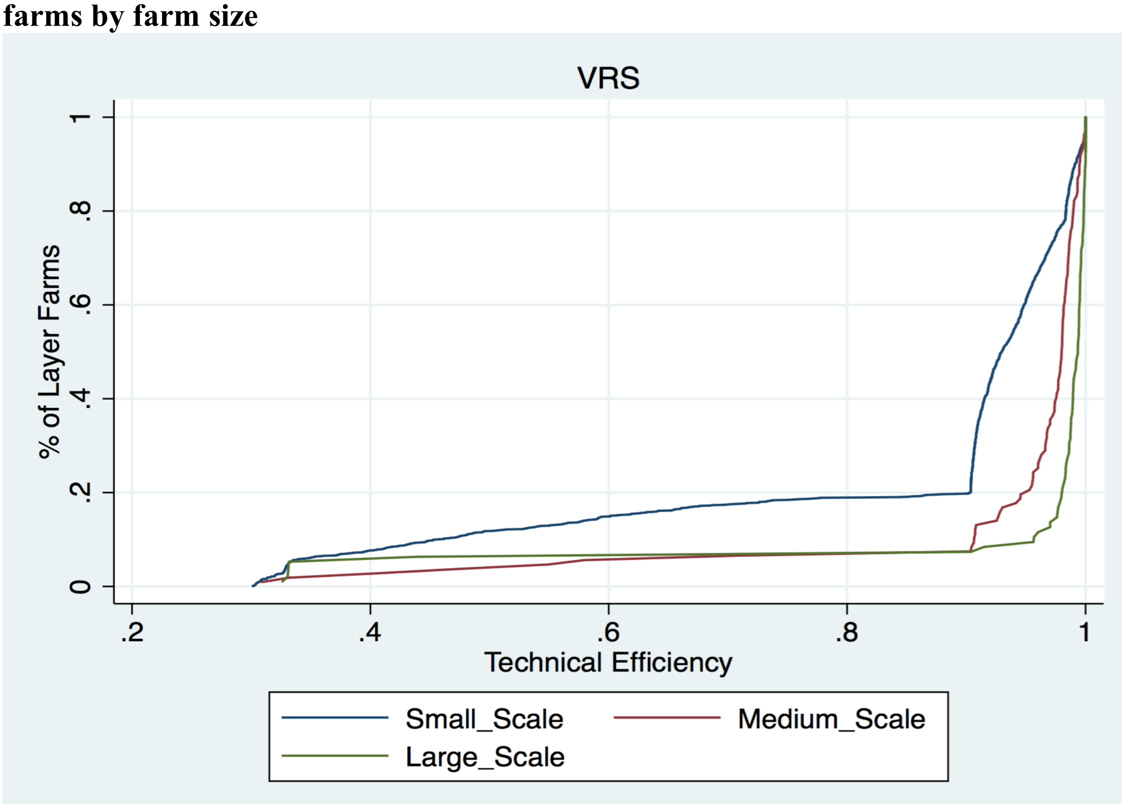


Figure 5:7 Cumulative distribution of overall technical efficiency point estimates for mixed farms by farm size

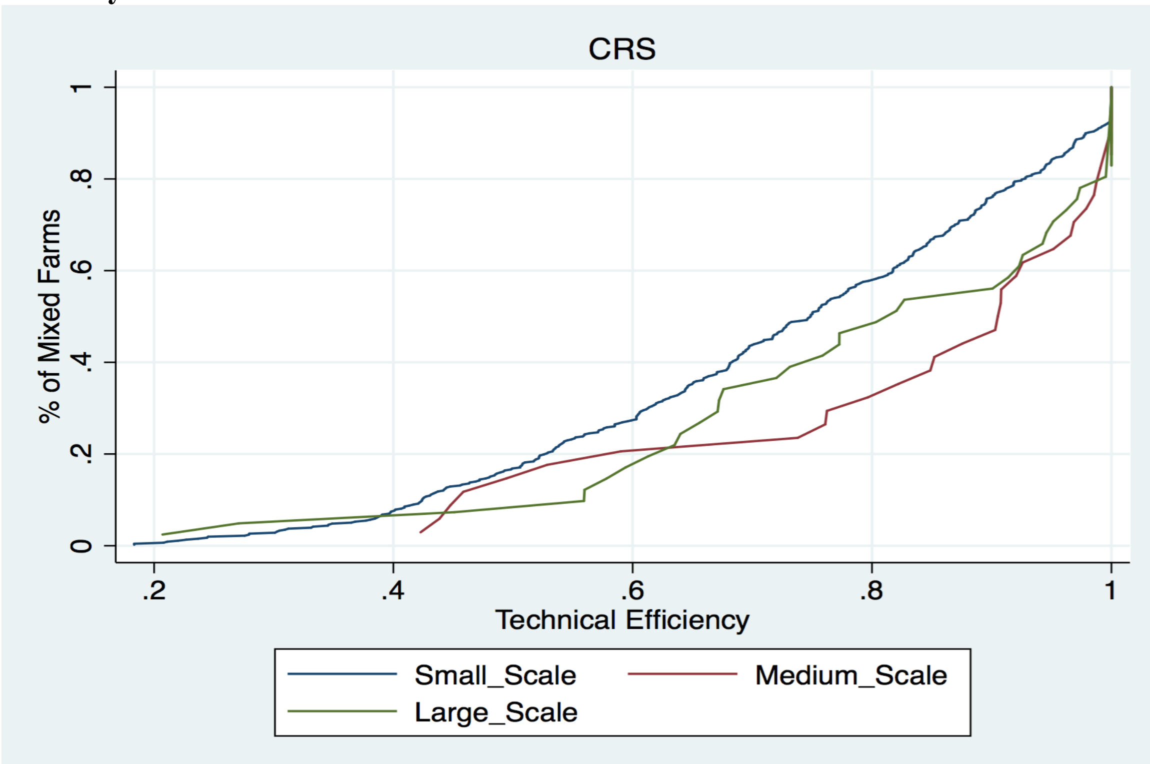
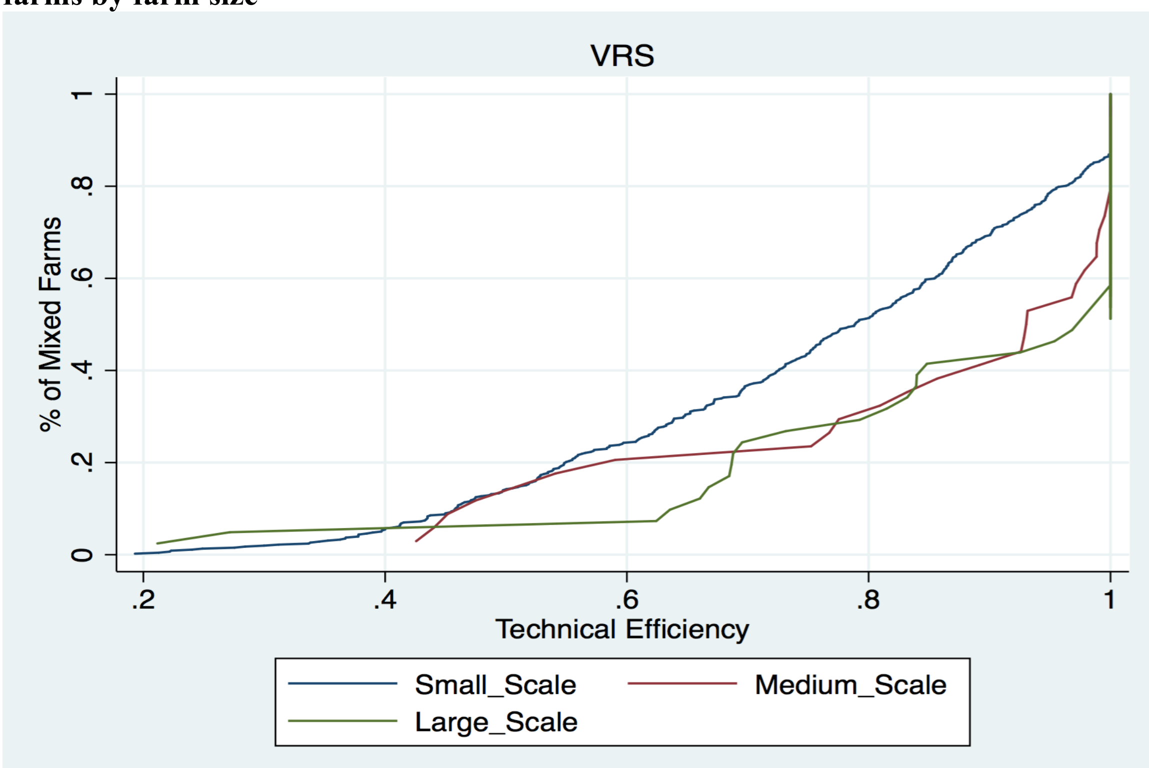


Figure 5:8 Cumulative distribution of pure technical efficiency point estimates for mixed farms by farm size



5.1.2 Scale Efficiency

Summary statistics of the relative scale efficiency measure estimated for each chicken enterprise are presented in Table 5:15 – Table 5:18. In general, the potential gains from attaining an efficient scale appears to be minimal in Ghana's chicken industry, particularly, layer farms. Average scale efficiency ranged from 0.78 for broiler farms to 0.98 for layer farms. This suggests that most chicken farms operate at close to optimal farm size and hence close to the minimum point on the aggregate average cost curve. Thus, the average broiler or layer farm could have produced the same level of output while reducing input costs by 22% or 2%, respectively, if they were operating at optimal size.

Table 5:15 DEA estimates of input-oriented scale efficiency by chicken enterprise

SE	Broiler farms (N=762)	Mixed farms (N=532)	Layer farms (N=1536)
Mean point estimate	0.772	0.960	0.983
SD	0.163	0.081	0.055
Score of least efficient farm	0.210	0.272	0.265
Median point estimate	0.804	0.981	0.996
Coefficient of variation	0.211	0.084	0.056
Efficient farms	0.59%	0.13%	0.38%

Potential cost savings associated with output expansion appear to increase with farm size in broiler production. The average scale efficiency for broiler farms ranged from 0.75 for small-sized broiler farms to 0.96 for large-sized broiler farms. In layer and mixed production, medium-sized farms were, on average, the most scale efficient, with a mean scale efficiency of 0.99 for each chicken enterprise. However, small-sized mixed farms (0.96) were slightly scale efficient than large-sized mixed farms (0.94) whereas large-sized layer farms (0.99) were slightly scale efficient than small-sized layer farms (0.98). By implication, small-sized broiler and layer farms are more able to lower their cost of production by spreading cost over a larger range of output (i.e., exploiting reduction in average unit cost) compared to their medium-sized and large counterparts. This assertion holds true for large-sized mixed farms relative small- and medium-sized mixed farms.

Table 5:16 DEA estimates of input-oriented scale efficiency for broiler farms by farm size

SE	Small Scale (N=664)	Medium Scale (N=61)	Large Scale (N=37)
Mean point estimate	0.745	0.956	0.962
SD	0.155	0.015	0.103
Score of least efficient farm	0.210	0.904	0.516
Median point estimate	0.786	0.955	0.989
Coefficient of variation	0.209	0.015	0.107
Efficient farms	0.0%	0.0%	2.7%

Table 5:17 DEA estimates of input-oriented scale efficiency for layer farms by farm size

SE	Small Scale (N=1334)	Medium Scale (N=107)	Large Scale (N=95)
Mean point estimate	0.981	0.997	0.995
SD	0.059	0.004	0.007
Score of least efficient farm	0.265	0.982	0.952
Median point estimate	0.996	0.998	0.997
Coefficient of variation	0.060	0.004	0.007
Efficient farms	0.67%	0.0%	0.0%

Table 5:18 DEA estimates of input-oriented scale efficiency for mixed farms by farm size

SE	Small Scale (N=457)	Medium Scale (N=34)	Large Scale (N=41)
Mean point estimate	0.960	0.994	0.938
SD	0.068	0.013	0.178
Score of least efficient farm	0.272	0.920	0.307
Median point estimate	0.978	0.997	0.999
Coefficient of variation	0.071	0.013	0.189
Efficient farms	0.0%	0.0%	4.88%

Frequency and cumulative distribution of scale efficiency scores for each chicken enterprise by farm size are presented in Table 5:19 to Table 5:21 and Figure 5:9 to Figure 5:12. In general, the tail of the distribution is skewed to the right with a high proportion of chicken farms in the higher scale efficient segment. This suggest that majority of farms produce their maximum potential or near their most productive scale. Indeed, 96.6% of layer farms, 92.4% of mixed farms and 26.3% of broiler farms displayed high scale efficiency between 0.9 and 1.0, and only 0.33% and 1.13% of them displayed scale efficiency less than 0.50[27]. However, the percentage of scale efficient farms, tends to be low, averaging 0.59% for layer farms, 0.38% for mixed farms and 0.13% for broiler farms. With respect to the geographic variations in scale efficiency, the mean scale efficiency ranged from 0.72 in Greater Accra Region to 0.84 in Brong-Ahafo Region for the broiler enterprise (Table 5:23), 0.96 in the Northernmost Regions to 0.99 in Brong-Ahafo Region for layer enterprise and 0.94 in Central Region to 0.98 in Ashanti Region for mixed farms (Table 5:25).

Table 5:19 Frequency distribution of scale efficiency estimates for layer enterprise

Range of Efficiency	% Layer Farms in SE Interval			
	Small scale	Medium scale	Large scale	All
SE < 0.10	0.00	0.00	0.00	0.00
0.10 ≤ SE < 0.20	0.00	0.00	0.00	0.00
0.20 ≤ SE < 0.30	0.15	0.00	0.00	0.13
0.30 ≤ SE < 0.40	0.07	0.00	0.00	0.07
0.40 ≤ SE < 0.50	0.15	0.00	0.00	0.13
0.50 ≤ SE < 0.60	0.37	0.00	0.00	0.33
0.60 ≤ SE < 0.70	0.52	0.00	0.00	0.46
0.70 ≤ SE < 0.80	0.52	0.00	0.00	0.46
0.80 ≤ SE < 0.90	2.1	0.00	0.00	1.82
0.90 ≤ SE <1.00	95.43	100	100	96.03
SE =1.00	0.67	0.00	0.00	0.59

[27] No farm had a scale efficiency score of below 0.20.

Table 5:20 Frequency distribution of scale efficiency estimates for broiler enterprise

Range of Efficiency	% Broiler Farms in SE Interval			
	Small scale	Medium scale	Large scale	All
SE < 0.10	0.00	0.00	0.00	0.00
0.10 ≤ SE < 0.20	0.00	0.00	0.00	0.00
0.20 ≤ SE < 0.30	2.11	0.00	0.00	1.84
0.30 ≤ SE < 0.40	0.15	0.00	0.00	0.13
0.40 ≤ SE < 0.50	7.68	0.00	0.00	6.69
0.50 ≤ SE < 0.60	6.63	0.00	2.7	5.91
0.60 ≤ SE < 0.70	17.17	0.00	2.7	15.09
0.70 ≤ SE < 0.80	21.84	0.00	0.00	19.03
0.80 ≤ SE < 0.90	28.46	0.00	2.7	24.93
0.90 ≤ SE <1.00	15.96	100	89.19	26.25
SE =1.00	0.00	0.00	2.7	0.13

Table 5:21 Frequency distribution of scale efficiency estimates for mixed enterprise

Range of Efficiency	% Mixed Farms in SE Interval			
	Small scale	Medium scale	Large scale	All
SE < 0.10	0.00	0.00	0.00	0.00
0.10 ≤ SE < 0.20	0.00	0.00	0.00	0.00
0.20 ≤ SE < 0.30	0.22	0.00	0.00	0.19
0.30 ≤ SE < 0.40	0.44	0.00	7.32	0.94
0.40 ≤ SE < 0.50	0.00	0.00	0.00	0.00
0.50 ≤ SE < 0.60	0.22	0.00	0.00	0.19
0.60 ≤ SE < 0.70	0.22	0.00	0.00	0.19
0.70 ≤ SE < 0.80	0.88	0.00	2.44	0.94
0.80 ≤ SE < 0.90	5.69	0.00	2.44	5.08
0.90 ≤ SE <1.00	92.34	100	82.93	92.11
SE =1.00	0.00	0.00	4.88	0.38

A further classification of farms into production regions exhibiting decreasing returns scale (i.e., technology exhibit non-increasing returns to scale), increasing returns to scale (i.e., technology exhibit non-decreasing returns to scale) or constant returns to scale is provided following the conditions outlined in Section 3.2.2. A frontier exhibiting decreasing returns to scale (DRS) suggests that output rises by a smaller percentage than inputs. Farms operating in this region have supra-optimal scale size and are too large to take advantage of scale. Alternatively, if output rises by a larger percentage than inputs, there are increasing returns to scale (IRS). Farms operating in this region have sub-optimal scale size and can therefore expand, *ceteris paribus*, to take full advantage of scale in the long run. Table 5:22 lists the percentages of farms operating at IRS, CRS and DRS for each chicken enterprise by farm size.

Table 5:22 Categorization of farms into return to scale regions

		Broiler Farms		Layer Farms		Mixed Farms	
	Returns-to-scale	Freq.	%	Freq.	%	Freq.	%
Small size	DRS	624	93.98	915	68.59	340	74.4
	IRS	35	5.27	403	30.21	83	18.16
	CRS	5	0.75	16	1.2	34	7.44
Medium size	DRS	39	63.93	1	0.93	5	14.71
	IRS	17	27.87	106	99.07	23	67.65
	CRS	5	8.2	0	0	6	17.65
Large size	DRS	1	2.7	2	2.11	1	2.44
	IRS	24	64.86	91	95.79	32	78.05
	CRS	12	32.43	2	2.11	8	19.51
Pooled	DRS	664	87.14	918	59.77	346	65.04
	IRS	76	9.97	600	39.06	138	25.94
	CRS	22	2.89	18	1.17	48	9.02

In general, decreasing returns to scale is observed to be the predominant form of scale inefficiency in Ghana's poultry industry. Among the broiler farms 87.4% exhibit decreasing returns to scale, 9.9% exhibit increasing returns to scale and 2.9% exhibit constant returns to scale. For layer farms, 59.7% exhibit decreasing returns to scale, 39.1% exhibit increasing returns to scale and 1.2% exhibit constant returns to scale. Likewise, 65.0% of mixed farms exhibit decreasing returns to scale, 25.9% exhibit increasing returns to scale and 9.0% exhibit constant returns to scale. However, the concentration of farms in each return to scale region tends to vary by farm size for each farm operation. For instance, most small farms are characterized by decreasing returns to scale (93.9% in broiler operations, 68.6% in layer operations and 74.4% in mixed operations). Broiler farms (63.9%) have a higher proportion of medium farms in the decreasing returns to scale region than layer (0.9%) and mixed (14.71) farms. On the contrary, many medium-size layer (99.1%) and mixed (67.5%) farms exhibit increasing returns to scale compared to broiler farms (27.9%). However, the distributions of returns to scale for large-sized farms is concentrated in the IRS for all chicken enterprises. The significance of the RTS implies that farms operating above their optimal size can enhance their technical efficiency by downsizing whereas scaling up seems to be an appropriate strategic option for farms operating in the IRS region in their pursuit to reduce unit costs.

The Kruskal-Wallis nonparametric test carried out to test the hypothesis that the mean rank of scale efficiency scores is the same across the different farm sizes and spatial location of farms is reported in Table 5:14. The results show that significant differences in scale efficiency exists among the farm size classes and spatial location of farms, indicating that farm size and regional location of farms does matter when comparing farm scale efficiency.

Figure 5:9 Cumulative distribution of scale efficiency estimates by chicken enterprise

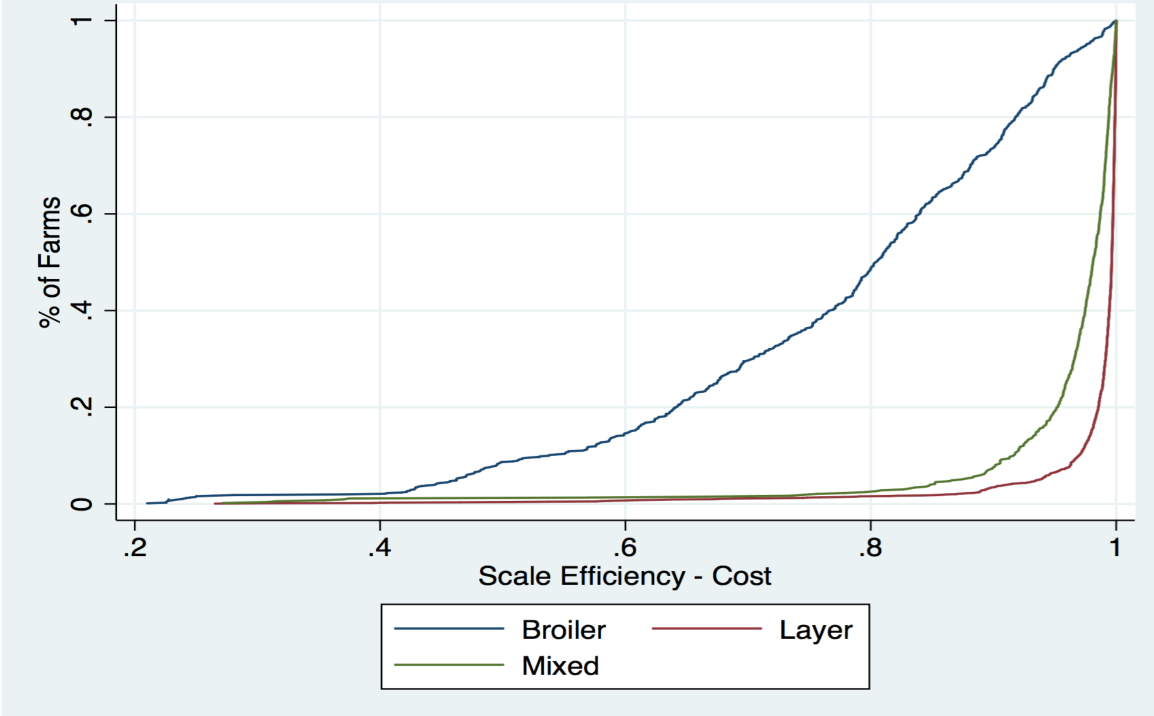


Figure 5:10 Cumulative distribution of scale efficiency estimates for broiler farms by farm size

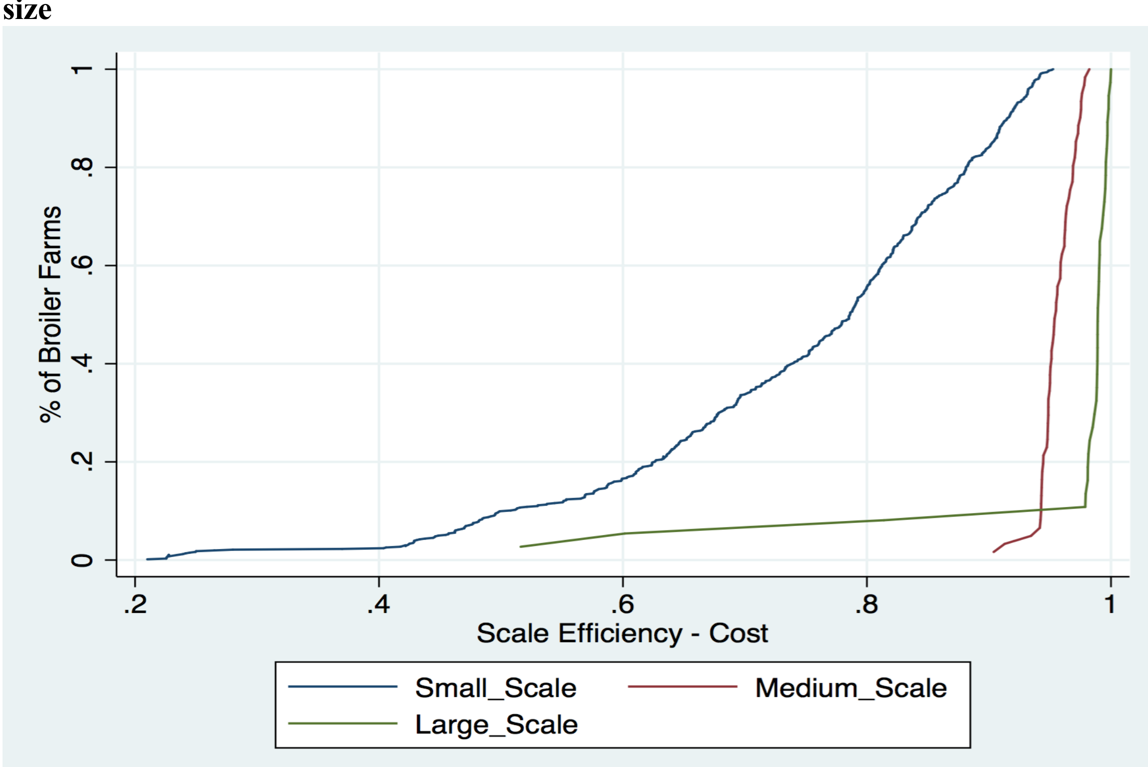


Figure 5:11 Cumulative distribution of pure technical efficiency point estimates for layer farms by farm size

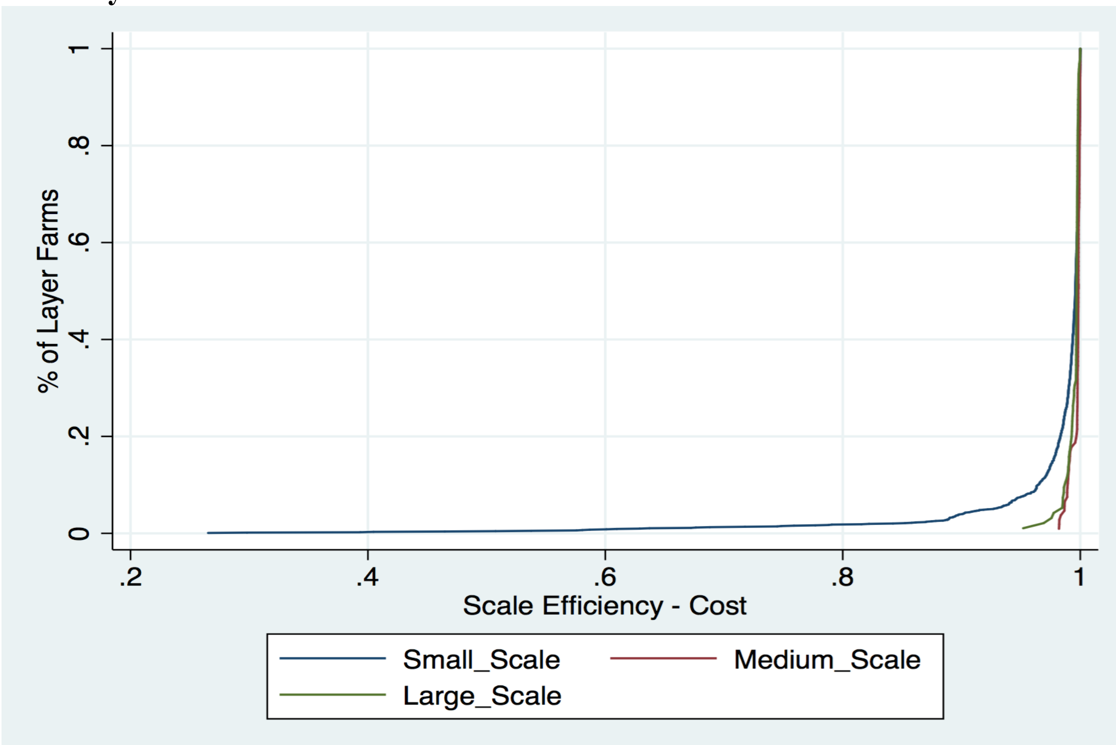


Figure 5:12 Cumulative distribution of pure technical efficiency point estimates for mixed farms by farm size

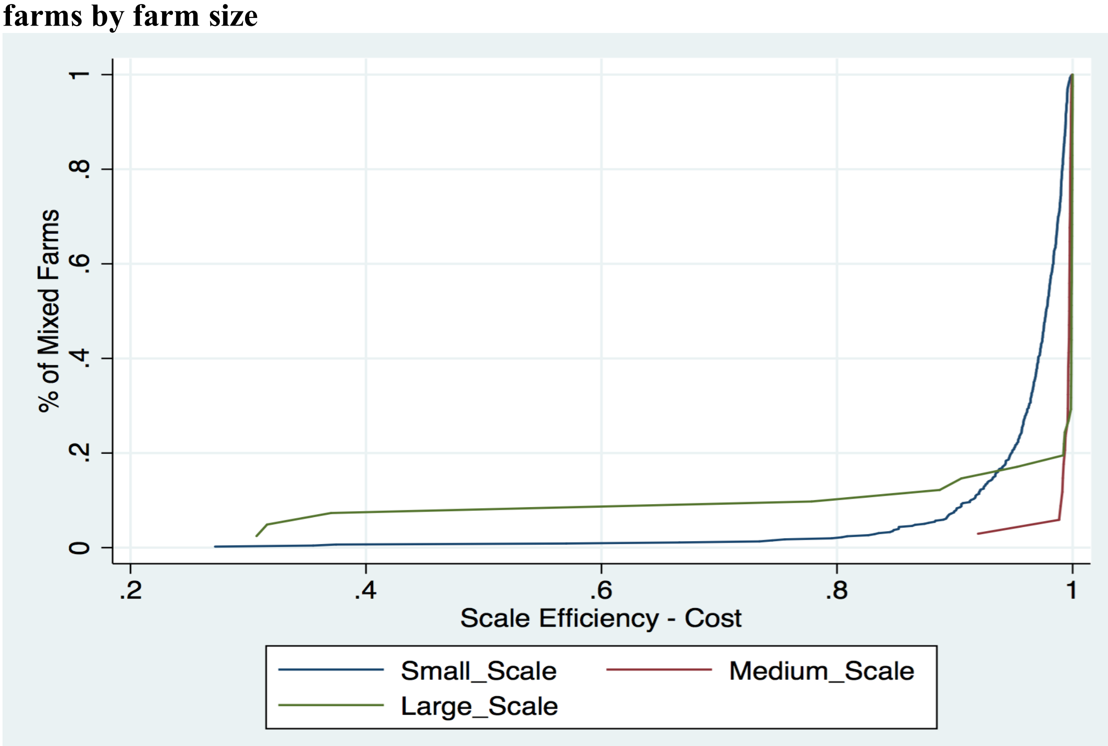


Table 5:23 DEA estimates of input-oriented scale efficiency for broiler farms by region

Regions	Ashanti (N=85)	Brong-Ahafo (N=98)	Central (N=124)	Eastern (N=161)	Greater-Accra (N=162)	Northernmost (N=26)	Volta (N=42)	Western (N=64)
SE								
Mean point estimate	0.772	0.841	0.779	0.779	0.718	0.782	0.743	0.786
SD	0.147	0.151	0.154	0.162	0.187	0.141	0.132	0.141
Score of least efficient farm	0.210	0.226	0.228	0.226	0.228	0.425	0.513	0.455
Median point estimate	0.797	0.876	0.812	0.812	0.761	0.822	0.770	0.806
Coefficient of variation	0.190	0.180	0.198	0.208	0.261	0.181	0.177	0.180

Table 5:24 DEA estimates of input-oriented scale efficiency for layer farms by region

Regions	Ashanti (N=104)	Brong-Ahafo (N=70)	Central (N=68)	Eastern (N=81)	Greater-Accra (N=107)	Northernmost (N=8)	Volta (N=26)	Western (N=68)
SE								
Mean point estimate	0.978	0.969	0.940	0.960	0.946	0.918	0.958	0.973
SD	0.043	0.086	0.126	0.078	0.095	0.092	0.037	0.025
Score of least efficient farm	0.666	0.316	0.272	0.355	0.307	0.734	0.864	0.866
Median point estimate	0.990	0.990	0.979	0.979	0.969	0.946	0.973	0.980
Coefficient of variation	0.044	0.088	0.134	0.081	0.101	0.100	0.039	0.025

Table 5:25 DEA estimates of input-oriented scale efficiency for mixed farms by region

Regions	Ashanti (N=451)	Brong-Ahafo (N=346)	Central (N=124)	Eastern (N=183)	Greater-Accra (N=123)	Northernmost (N=68)	Volta (N=73)	Western (N=168)
SE								
Mean point estimate	0.986	0.989	0.986	0.975	0.985	0.959	0.970	0.982
SD	0.056	0.028	0.023	0.074	0.031	0.112	0.072	0.059
Score of least efficient farm	0.298	0.637	0.893	0.405	0.791	0.265	0.508	0.576
Median point estimate	0.997	0.997	0.995	0.996	0.997	0.989	0.992	0.996
Coefficient of variation	0.056	0.028	0.023	0.076	0.032	0.117	0.074	0.060

5.1.3 Allocative Efficiency

Evidence on allocative efficiency for each chicken enterprise and by farm size is summarized in Table 5:26 to Table 5:29. Allocative efficiency averaged 0.87, 0.79 and 0.42 for the layer, mixed and broiler farms with standard deviations of 0.15, 0.17 and 0.19, respectively. This implies that layer, mixed and broiler producers potentially could reduce their input cost by as much as 13%, 21% and 58%, respectively, if they were perfectly allocative efficient while producing the same level of output. However, allocative efficiency is achieved by only 0.46% of layer farms, 1.5% of mixed farms and 0.52% of broiler farms.

Table 5:26 DEA estimates of input-oriented allocative efficiency by chicken enterprise

AE	Layer farms (N=1536)	Broiler farms (N=762)	Mixed farms (N=532)
Mean point estimate	0.872	0.420	0.791
SD	0.151	0.191	0.166
Score of least efficient farm	0.119	0.038	0.094
Median point estimate	0.932	0.415	0.841
Coefficient of variation	0.173	0.454	0.209
Efficient farms	0.46%	0.52%	1.50%

The results on average allocative efficiency exhibits no apparent trend across farm size except for mixed farms where the mean allocative efficiency declines with farm size. In layer production, medium-sized farms achieved the highest average allocative efficiency of 0.89 followed by large farms (0.88) and then small farms (0.87). On the contrary, in broiler production, small-sized farms achieved the highest average allocative efficiency of 0.42 while medium-sized farms achieved the least average allocative efficiency of 0.39. Large-sized broiler farms posted a mean allocative efficiency of 0.41. These estimates suggest that allocative inefficiency raised input costs by an average of 12%, 11% and 13% among large, medium and small size layer farms, respectively. An opposite trend exists in broiler operation, albeit higher potential cost savings of 60% for medium farms, 59% for large farms and 58% for small farms. By implication, medium-sized broiler farms, small-sized layer farms and large-sized mixed farms are on average less allocative efficient relative to their respective counterparts. These farms are not using inputs in cost-minimizing levels giving the input prices they face to produce the given output level. The mean allocative efficiency index also varies across region, ranging from 0.25 in Northernmost Regions to 0.48 in Western Region for broiler farms (Table 5:30), from 0.83 in Northernmost Regions to 0.89 in Greater Accra Region for layer farms (Table 5:31) and from 0.72 in Volta Region to 0.82 in Western Region for mixed farms (Table 5:32).

Table 5:27 DEA estimates of input-oriented allocative efficiency for broiler farms by farm size

AE	Small Scale (N=664)	Medium Scale (N=61)	Large Scale (N=37)
Mean point estimate	0.423	0.396	0.412
SD	0.185	0.194	0.273
Score of least efficient farm	0.040	0.038	0.070
Median point estimate	0.422	0.370	0.309
Coefficient of variation	0.438	0.489	0.662
Efficient farms	0.15%	0.0%	2.11%

Table 5:28 DEA estimates of input-oriented allocative efficiency for layers farms by farm size

AE	Small Scale (N=1334)	Medium Scale (N=107)	Large Scale (N=95)
Mean point estimate	0.870	0.894	0.878
SD	0.156	0.110	0.127
Score of least efficient farm	0.119	0.377	0.335
Median point estimate	0.934	0.930	0.919
Coefficient of variation	0.179	0.123	0.145
Efficient farms	0.37%	0.0%	8.11%

Table 5:29 DEA estimates of input-oriented allocative efficiency for mixed farms by farm size

AE	Small Scale (N=457)	Medium Scale (N=34)	Large Scale (N=41)
Mean point estimate	0.801	0.756	0.699
SD	0.153	0.186	0.242
Score of least efficient farm	0.094	0.188	0.284
Median point estimate	0.845	0.820	0.737
Coefficient of variation	0.191	0.246	0.346
Efficient farms	0.66%	0.0%	12.2%

The distribution of allocative efficiency for each chicken enterprise by farm size is presented in Table 5:33 to Table 5:35 and Figure 5:13 to Figure 5:16. Almost two-thirds of layer farms have allocative efficiency greater than or equal 0.9, depicting a positively skewed distribution. Among broiler farms, only 1.14% have allocative efficiency greater than or equal 0.9. Most (70.5%) of them have allocative efficiency scores ranging from 0.3 to less than 0.6. However, the tail of the distribution is skewed to left with more broiler farms located below the average allocative efficiency score than above it. The distribution of allocative efficiency for mixed farms shows most observations (92.7%) with allocative efficiency ranging from 0.5 to 1, depicting a right skewed tail but with a long tail on the left.

From the Kruskal-Wallis nonparametric test reported in Table 5:14, it is clear that significant spatial differences in allocative efficiency exists, indicating that regional location of farms does matter when comparing farm allocative efficiency. However, the allocative efficiency for layer and broiler farms exhibit no significant differences across farm size.

Table 5:30 DEA estimates of input-oriented allocative efficiency for broiler farms by region

Regions	Ashanti (N=85)	Brong-Ahafo (N=98)	Central (N=124)	Eastern (N=161)	Greater-Accra (N=162)	Northernmost (N=26)	Volta (N=42)	Western (N=64)
AE								
Mean point estimate	0.272	0.429	0.429	0.442	0.460	0.246	0.459	0.480
SD	0.194	0.195	0.158	0.176	0.202	0.184	0.147	0.141
Score of least efficient farm	0.040	0.038	0.080	0.044	0.068	0.046	0.088	0.187
Median point estimate	0.205	0.408	0.429	0.444	0.451	0.220	0.460	0.490
Coefficient of variation	0.716	0.455	0.367	0.399	0.440	0.746	0.321	0.293

Table 5:31 DEA estimates of input-oriented allocative efficiency for layer farms by region

Regions	Ashanti (N=451)	Brong-Ahafo (N=346)	Central (N=124)	Eastern (N=183)	Greater-Accra (N=123)	Northernmost (N=68)	Volta (N=73)	Western (N=168)
AE								
Mean point estimate	0.876	0.870	0.883	0.861	0.887	0.827	0.864	0.880
SD	0.156	0.160	0.134	0.147	0.129	0.160	0.171	0.135
Score of least efficient farm	0.169	0.119	0.395	0.328	0.335	0.340	0.184	0.267
Median point estimate	0.940	0.934	0.942	0.927	0.936	0.867	0.932	0.928
Coefficient of variation	0.178	0.184	0.152	0.171	0.145	0.194	0.198	0.153

Table 5:32 DEA estimates of input-oriented allocative efficiency for mixed farms by region

Regions	Ashanti (N=104)	Brong-Ahafo (N=70)	Central (N=68)	Eastern (N=81)	Greater-Accra (N=107)	Northernmost (N=8)	Volta (N=26)	Western (N=68)
AE								
Mean point estimate	0.798	0.812	0.791	0.765	0.782	0.903	0.720	0.816
SD	0.170	0.200	0.131	0.173	0.150	0.102	0.216	0.138
Score of least efficient farm	0.284	0.188	0.429	0.244	0.284	0.768	0.094	0.339
Median point estimate	0.855	0.889	0.821	0.818	0.817	0.932	0.772	0.852
Coefficient of variation	0.213	0.246	0.166	0.226	0.192	0.113	0.300	0.170

Table 5:33 Frequency distribution of allocative efficiency estimates for layer enterprise

Range of Efficiency	Small scale	Medium scale	Large scale	All
AE < 0.10	0.00	0.00	0.00	0.00
0.10 ≤ AE < 0.20	0.37	0.93	0.00	0.33
0.20 ≤ AE < 0.30	0.67	0.00	0.00	0.59
0.30 ≤ AE < 0.40	1.8	0.00	2.11	1.76
0.40 ≤ AE < 0.50	1.72	0.00	1.05	1.56
0.50 ≤ AE < 0.60	3.15	0.93	1.05	2.86
0.60 ≤ AE < 0.70	5.32	7.48	4.21	5.4
0.70 ≤ AE < 0.80	9.07	3.74	9.47	8.72
0.80 ≤ AE < 0.90	14.47	19.63	22.11	15.3
0.90 ≤ AE <1.00	63.04	67.29	57.89	63.02
AE =1.00	0.37	0.00	2.11	0.46

Table 5:34 Frequency distribution of scale efficiency estimates for broiler enterprise

Range of Efficiency	Small scale	Medium scale	Large scale	All
AE < 0.10	2.86	4.92	2.7	3.02
0.10 ≤ AE < 0.20	9.34	9.84	16.22	9.71
0.20 ≤ AE < 0.30	16.57	22.95	29.73	17.72
0.30 ≤ AE < 0.40	16.57	18.03	13.51	16.54
0.40 ≤ AE < 0.50	19.13	13.11	5.41	17.98
0.50 ≤ AE < 0.60	18.98	14.75	10.81	18.24
0.60 ≤ AE < 0.70	9.04	11.48	2.7	8.92
0.70 ≤ AE < 0.80	5.42	1.64	2.7	4.99
0.80 ≤ AE < 0.90	1.51	1.64	8.11	1.84
0.90 ≤ AE <1.00	0.45	1.64	0.00	0.52
AE =1.00	0.15	0.00	8.11	0.52

Table 5:35 Frequency distribution of scale efficiency estimates for mixed enterprise

Range of Efficiency	Small scale	Medium scale	Large scale	All
AE < 0.10	0.22	0.00	0.00	0.19
0.10 ≤ AE < 0.20	0.00	2.94	0.00	0.19
0.20 ≤ AE < 0.30	0.66	0.00	4.88	0.94
0.30 ≤ AE < 0.40	1.31	5.88	14.63	2.63
0.40 ≤ AE < 0.50	3.5	0.00	4.88	3.38
0.50 ≤ AE < 0.60	5.69	11.76	12.2	6.58
0.60 ≤ AE < 0.70	9.19	8.82	9.76	9.21
0.70 ≤ AE < 0.80	15.1	11.76	9.76	14.47
0.80 ≤ AE < 0.90	35.23	44.12	14.63	34.21
0.90 ≤ AE <1.00	28.45	14.71	17.07	26.69
AE =1.00	0.66	0.00	12.2	1.5

Figure 5:13 Cumulative distribution of allocative efficiency estimates by chicken enterprise

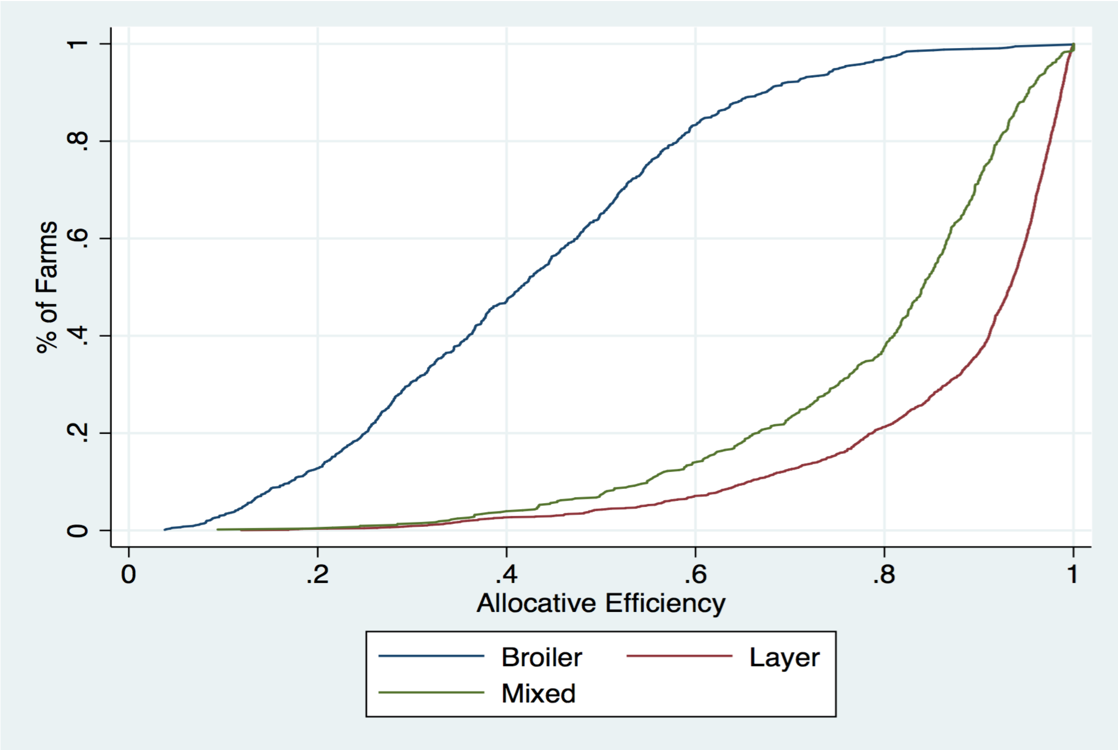


Figure 5:14 Cumulative distribution of allocative efficiency estimates for broiler farms by farm size

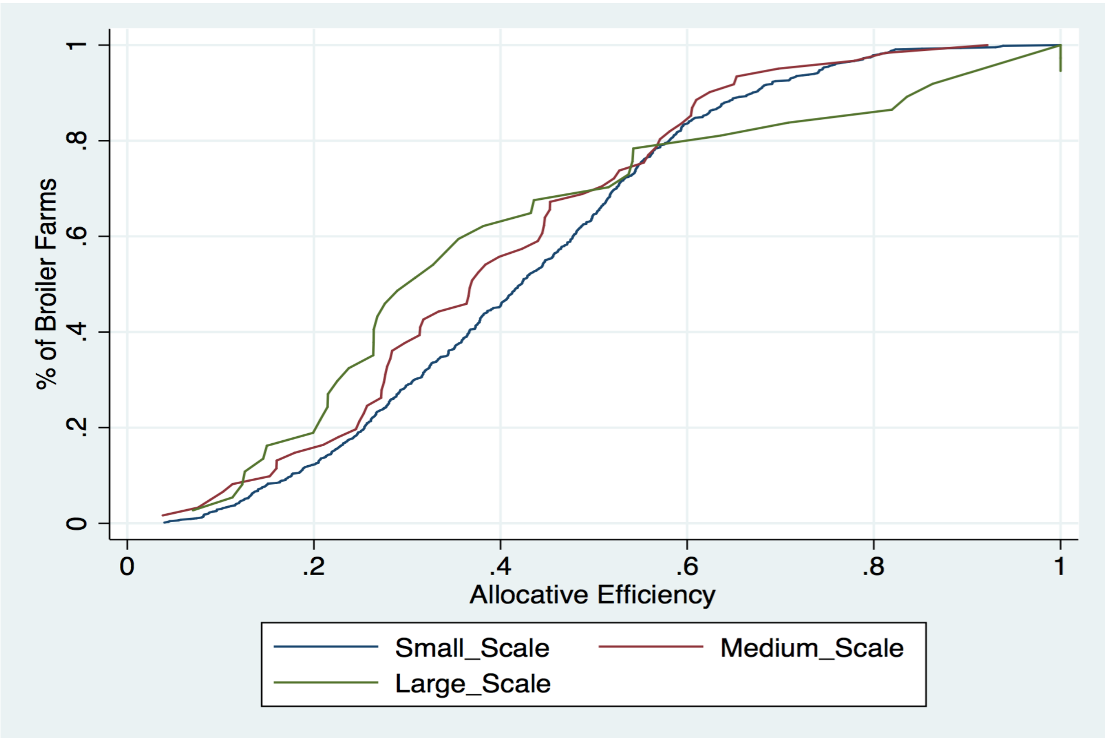


Figure 5:15 Cumulative distribution of allocative efficiency estimates for layer farms by farm size

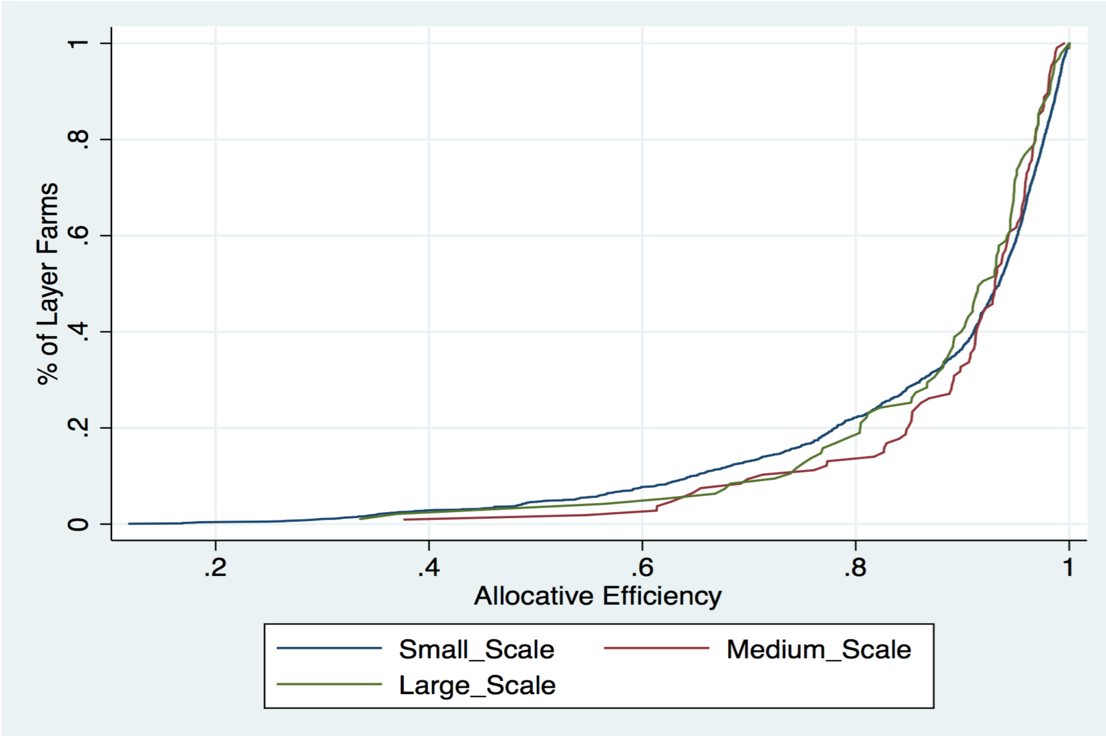
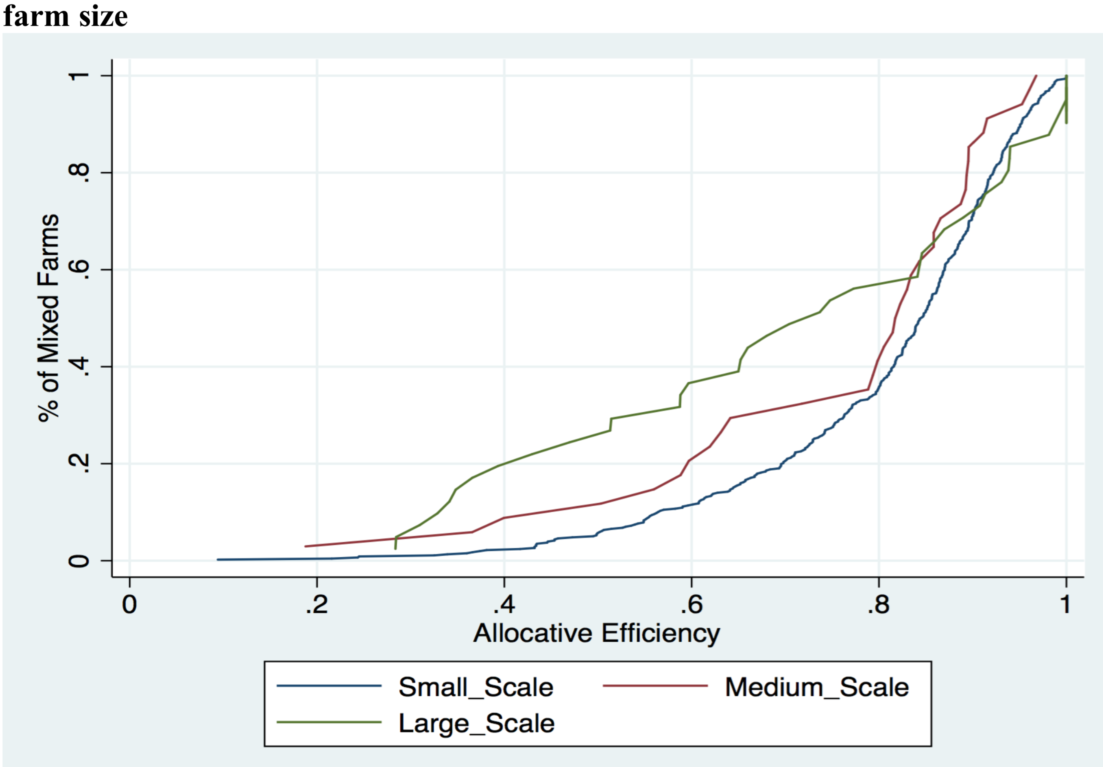


Figure 5:16 Cumulative distribution of allocative efficiency estimates for mixed farms by farm size



5.1.4 Cost Efficiency

Analysis of cost efficiency was done under two competing assumptions of the technological set: constant returns-to-scale and variable returns-to-scale. As indicated previously, cost efficiency under CRS has a wider meaning as overall efficiency, measured as the product of technical efficiency under VRS, allocative efficiency under VRS and scale efficiency. Based on the results, technical inefficiency seems to be a larger source of cost inefficiency than allocative inefficiency among layer and mixed farms. The opposite is true for broiler farms where the results indicates that a greater proportion of cost inefficiency was due to farms not using optimal input mix. However, the summary statistics of estimated cost efficiency scores presented in Table 5:36 indicate low level of cost efficiency in broiler production than in layer and dual productions.

Table 5:36 DEA estimates of input-oriented cost efficiency by chicken enterprise

CE	Layer Farms (N=1536)	Broiler Farms (N=762)	Mixed Farms (N=532)
CRS			
Mean point estimate	0.750	0.194	0.585
SD	0.229	0.125	0.212
Score of least efficient farm	0.094	0.007	0.060
Median point estimate	0.855	0.163	0.593
Coefficient of variation	0.305	0.643	0.363
Efficient farms	0.13%	0.13%	0.38%
VRS			
Mean point estimate	0.760	0.254	0.609
SD	0.223	0.155	0.212
Score of least efficient farm	0.110	0.008	0.060
Median point estimate	0.862	0.217	0.620
Coefficient of variation	0.294	0.611	0.348
Efficient farms	0.46%	0.52%	1.5%

Specifically, cost efficiency averaged 0.19 under CRS and 0.25 under VRS for broiler farms; 0.75 under CRS and 0.76 under VRS for layer farms; and 0.59 under CRS and 0.61 under VRS for mixed farms. This indicates that if farms operate on the minimum cost frontier, the average broiler farm could reduce costs by 75% to 81%, to match its performance with the best practice broiler farm producing the same output and facing the same technology. Likewise, average layer and mixed farms could reduce costs by 24% to 25% and 39% to 41%, respectively, if they were to operate on the minimum cost frontier.

From the examination of cost efficiency for the different size classes, it appears that potential cost savings declines with size among broiler farms, since there is an apparent downward trend in cost inefficiency as farm size increases. However, medium-sized layer and mixed farms have relatively high average cost efficiency than their counterparts with fewer than 5,000 birds or more than 10,000 birds. On average, large-sized broiler farms (with cost efficiency of 0.33 under CRS and 0.36 under VRS) are closer to the cost frontier ("best-practice" frontier) than medium-sized (with cost efficiency of 0.24 under CRS and 0.26 under VRS) and small-sized (with cost efficiency of 0.18 under CRS and 0.25 under VRS) broiler farms. On the other hand, medium sized layer farms (with cost efficiency of 0.84 under CRS and 0.85 under VRS) are closer to the cost frontier than large-sized (with cost efficiency of 0.83 under both CRS and VRS) and small-sized (with cost efficiency of 0.74 under CRS and 0.75 under VRS) layer farms. Thus, by operating on the cost frontier, small-sized layer and broiler farms can generate higher cost savings than medium- and large-sized layer and broiler farms, respectively, since they are less cost efficient. In the dual enterprise, average cost efficiency levels were highest for farms with 5,000 to 10,000 birds. However, mixed farms with fewer than 5,000 birds, on average, were producing close to the minimum cost frontier than those with more than 10,000 birds. Regional variation in cost efficiency also exist. Table 5:43 shows that the mean cost efficiency index for layer enterprise ranged from 0.67 under CRS and VRS in Central Region to 0.79 under CRS and 0.80 under VRS in Brong-Ahafo Region. The mean cost efficiency index for the mixed enterprise also ranged from

0.52 under CRS and 0.56 under VRS in Greater Accra Region to 0.66 under CRS and 0.68 under VRS in Western Region. In broiler production, the mean cost efficiency index ranged from 0.11 under CRS and 0.15 under VRS in Northernmost Regions to 0.26 under CRS and 0.30 under VRS in Brong-Ahafo Region.

Table 5:37 DEA estimates of input-oriented cost efficiency for layer farms by farm size

CE	Small Scale (N=1334)	Medium Scale (N=107)	Large Scale (N=95)
CRS			
Mean point estimate	0.737	0.842	0.828
SD	0.233	0.167	0.185
Score of least efficient farm	0.094	0.299	0.300
Median point estimate	0.847	0.908	0.901
Coefficient of variation	0.316	0.198	0.223
Efficient farms	0.15%	57.01%	51.58%
VRS			
Mean point estimate	0.748	0.845	0.832
SD	0.227	0.167	0.186
Score of least efficient farm	0.110	0.303	0.301
Median point estimate	0.853	0.910	0.904
Coefficient of variation	0.304	0.198	0.224
Efficient farms	0.37%	0.00%	2.11

Table 5:38 DEA estimates of input-oriented cost efficiency for broiler farms by farm size

CE	Small Scale (N=664)	Medium Scale (N=61)	Large Scale (N=37)
CRS			
Mean point estimate	0.182	0.246	0.332
SD	0.109	0.130	0.237
Score of least efficient farm	0.007	0.030	0.067
Median point estimate	0.158	0.225	0.244
Coefficient of variation	0.600	0.529	0.713
Efficient farms	0.0%	0.0%	2.70%
VRS			
Mean point estimate	0.248	0.257	0.362
SD	0.145	0.136	0.283
Score of least efficient farm	0.008	0.033	0.068
Median point estimate	0.216	0.246	0.247
Coefficient of variation	0.584	0.529	0.780
Efficient farms	0.15%	0.00%	8.11%

Table 5:39 DEA estimates of input-oriented cost efficiency for mixed farms by farm size

CE	Small Scale (N=457)	Medium Scale (N=34)	Large Scale (N=41)
CRS			
Mean point estimate	0.583	0.642	0.562
SD	0.206	0.229	0.263
Score of least efficient farm	0.071	0.093	0.060
Median point estimate	0.590	0.661	0.488
Coefficient of variation	0.353	0.357	0.468
Efficient farms	4.81%	8.82%	4.88%
VRS			
Mean point estimate	0.606	0.644	0.613
SD	0.205	0.228	0.271
Score of least efficient farm	0.076	0.102	0.060
Median point estimate	0.621	0.663	0.588
Coefficient of variation	0.338	0.355	0.442
Efficient farms	0.62%	0.00%	12.2%

Table 5:40 to Table 5:42 and Figure 5:17 to Figure 5:20, respectively, show the frequency and cumulative distribution of cost efficiency level for the size categories by chicken enterprise. The results for the distribution remain similar for CRS and VRS estimations for each chicken enterprise and size categories. Among the layer and broiler enterprises, the highest percentages of observations are mainly concentrated in the extremes of the distribution. While individual cost efficiency is concentrated at the left tail of the distribution towards higher efficiency levels for layer farms, the reverse is true for broiler farms. Approximately 70.5% of layer farms fall within the range 0.70 to 1. On the other hand, the frequency of the cost efficiency scores ranging between 0 and 0.4 represents about 84.3% of broiler farms. This implies that very few broiler farmers are fairly efficient in producing at the given level of output using the cost minimizing input ratios. Hence, most broiler farms need to minimize the waste of resources associated with their production to be competitive. With regards to the distribution of cost efficiency for mixed farms, the results reveal more than 84% of farms with cost efficiency scores between 0.3 and 0.6. However, the tail

of the distribution is skewed to the left since majority (66.5%) of the cost efficiency scores are clustered between 0.50 to 1.

Table 5:40 Frequency distribution of cost efficiency estimates for layer enterprise

Range of Efficiency	% Layer Farms in CE Interval			
	Small scale	Medium scale	Large scale	All
CE < 0.10	0.00	0.00	0.00	0.00
0.10 ≤ CE < 0.20	1.12	0.00	0.00	0.98
0.20 ≤ CE < 0.30	3.45	0.00	0.00	2.99
0.30 ≤ CE < 0.40	9.37	5.61	8.42	9.05
0.40 ≤ CE < 0.50	4.8	0.93	1.05	4.3
0.50 ≤ CE < 0.60	6.3	5.61	2.11	5.99
0.60 ≤ CE < 0.70	6.15	1.87	4.21	5.73
0.70 ≤ CE < 0.80	9.52	6.54	11.58	9.44
0.80 ≤ CE < 0.90	24.29	22.43	20	23.89
0.90 ≤ CE <1.00	34.63	57.01	50.53	37.17
CE =1.00	0.37	0.00	2.11	0.46

Table 5:41 Frequency distribution of cost efficiency estimates for broiler enterprise

Range of Efficiency	% Broiler Farms in CE Interval			
	Small scale	Medium scale	Large scale	All
CE < 0.10	14.16	14.75	10.81	14.04
0.10 ≤ CE < 0.20	29.22	29.51	29.73	29.27
0.20 ≤ CE < 0.30	28.46	18.03	18.92	27.17
0.30 ≤ CE < 0.40	13.4	22.95	5.41	13.78
0.40 ≤ CE < 0.50	8.28	11.48	8.11	8.53
0.50 ≤ CE < 0.60	4.07	3.28	10.81	4.33
0.60 ≤ CE < 0.70	1.36	0.00	0.00	1.18
0.70 ≤ CE < 0.80	0.6	0.00	2.7	0.66
0.80 ≤ CE < 0.90	0.15	0.00	5.41	0.39
0.90 ≤ CE <1.00	0.15	0.00	0.00	0.13
CE =1.00	0.15	0.00	8.11	0.52

Table 5:42 Frequency distribution of cost efficiency estimates for mixed enterprise

Range of Efficiency	% Mixed Farms in CE Interval			
	Small scale	Medium scale	Large scale	All
CE < 0.10	0.22	0.00	2.44	0.38
0.10 ≤ CE < 0.20	1.97	2.94	0.00	1.88
0.20 ≤ CE < 0.30	5.25	2.94	12.2	5.64
0.30 ≤ CE < 0.40	10.94	14.71	12.2	11.28
0.40 ≤ CE < 0.50	14.66	8.82	14.63	14.29
0.50 ≤ CE < 0.60	13.57	11.76	12.2	13.35
0.60 ≤ CE < 0.70	17.07	11.76	4.88	15.79
0.70 ≤ CE < 0.80	15.32	8.82	12.2	14.66
0.80 ≤ CE < 0.90	14.44	29.41	7.32	14.85
0.90 ≤ CE <1.00	5.91	8.82	9.76	6.39
CE =1.00	0.66	0.00	12.2	1.5

Table 5:43 DEA estimates of input-oriented cost efficiency for layer farms by region

Regions	Ashanti (N=451)	Brong-Ahafo (N=346)	Central (N=124)	Eastern (N=183)	Greater-Accra (N=123)	Northernmost (N=68)	Volta (N=73)	Western (N=168)
CE - CRS								
Mean point estimate	0.784	0.792	0.665	0.738	0.751	0.690	0.757	0.668
SD	0.215	0.202	0.258	0.229	0.232	0.213	0.220	0.257
Score of least efficient farm	0.094	0.098	0.157	0.112	0.133	0.217	0.126	0.142
Median point estimate	0.872	0.878	0.752	0.848	0.862	0.749	0.846	0.772
Coefficient of variation	0.274	0.255	0.389	0.311	0.309	0.309	0.290	0.385
CE - VRS								
Mean point estimate	0.793	0.799	0.673	0.750	0.759	0.721	0.774	0.676
SD	0.209	0.199	0.260	0.218	0.229	0.204	0.213	0.252
Score of least efficient farm	0.155	0.110	0.173	0.157	0.168	0.286	0.174	0.195
Median point estimate	0.877	0.883	0.754	0.855	0.875	0.788	0.862	0.775
Coefficient of variation	0.263	0.249	0.386	0.290	0.301	0.284	0.276	0.373

Table 5:44 DEA estimates of input-oriented cost efficiency for broiler farms by region

Regions	Ashanti (N=85)	Brong-Ahafo (N=98)	Central (N=124)	Eastern (N=161)	Greater-Accra (N=162)	Northernmost (N=26)	Volta (N=42)	Western (N=64)
CE - CRS								
Mean point estimate	0.120	0.256	0.184	0.213	0.185	0.107	0.213	0.217
SD	0.123	0.173	0.085	0.126	0.103	0.105	0.110	0.100
Score of least efficient farm	0.007	0.018	0.021	0.026	0.026	0.030	0.012	0.066
Median point estimate	0.064	0.185	0.156	0.167	0.156	0.078	0.181	0.187
Coefficient of variation	1.020	0.678	0.460	0.595	0.556	0.987	0.514	0.461
CE - VRS								
Mean point estimate	0.158	0.304	0.242	0.270	0.271	0.149	0.278	0.272
SD	0.155	0.194	0.125	0.143	0.155	0.194	0.117	0.104
Score of least efficient farm	0.008	0.028	0.028	0.038	0.030	0.034	0.020	0.101
Median point estimate	0.087	0.219	0.204	0.234	0.224	0.094	0.281	0.247
Coefficient of variation	0.977	0.639	0.517	0.528	0.571	1.297	0.421	0.382

Table 5:45 DEA estimates of input-oriented cost efficiency for mixed farms by region

Regions	Ashanti (N=104)	Brong-Ahafo (N=70)	Central (N=68)	Eastern (N=81)	Greater-Accra (N=107)	Northernmost (N=8)	Volta (N=26)	Western (N=68)
CE - CRS								
Mean point estimate	0.614	0.625	0.565	0.541	0.524	0.817	0.532	0.660
SD	0.209	0.242	0.187	0.216	0.197	0.112	0.230	0.179
Score of least efficient farm	0.135	0.093	0.202	0.127	0.060	0.695	0.071	0.180
Median point estimate	0.631	0.648	0.526	0.509	0.539	0.789	0.581	0.669
Coefficient of variation	0.340	0.387	0.331	0.398	0.376	0.137	0.432	0.271
CE - VRS								
Mean point estimate	0.627	0.643	0.607	0.560	0.555	0.893	0.552	0.677
SD	0.209	0.236	0.189	0.209	0.202	0.112	0.234	0.178
Score of least efficient farm	0.139	0.102	0.203	0.158	0.060	0.718	0.076	0.200
Median point estimate	0.645	0.657	0.585	0.546	0.575	0.921	0.617	0.683
Coefficient of variation	0.333	0.368	0.311	0.374	0.363	0.125	0.423	0.263

Figure 5:17 Cumulative distribution of cost efficiency estimates by chicken enterprise

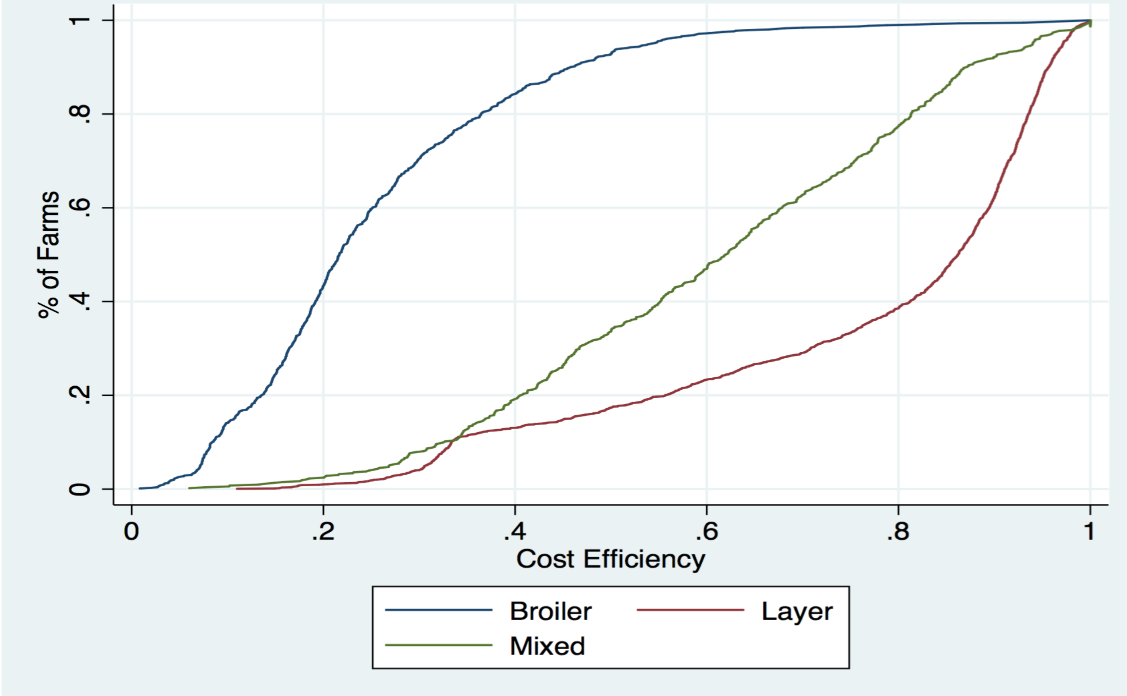


Figure 5:18 Cumulative distribution of cost efficiency estimates for broiler farms by farm size

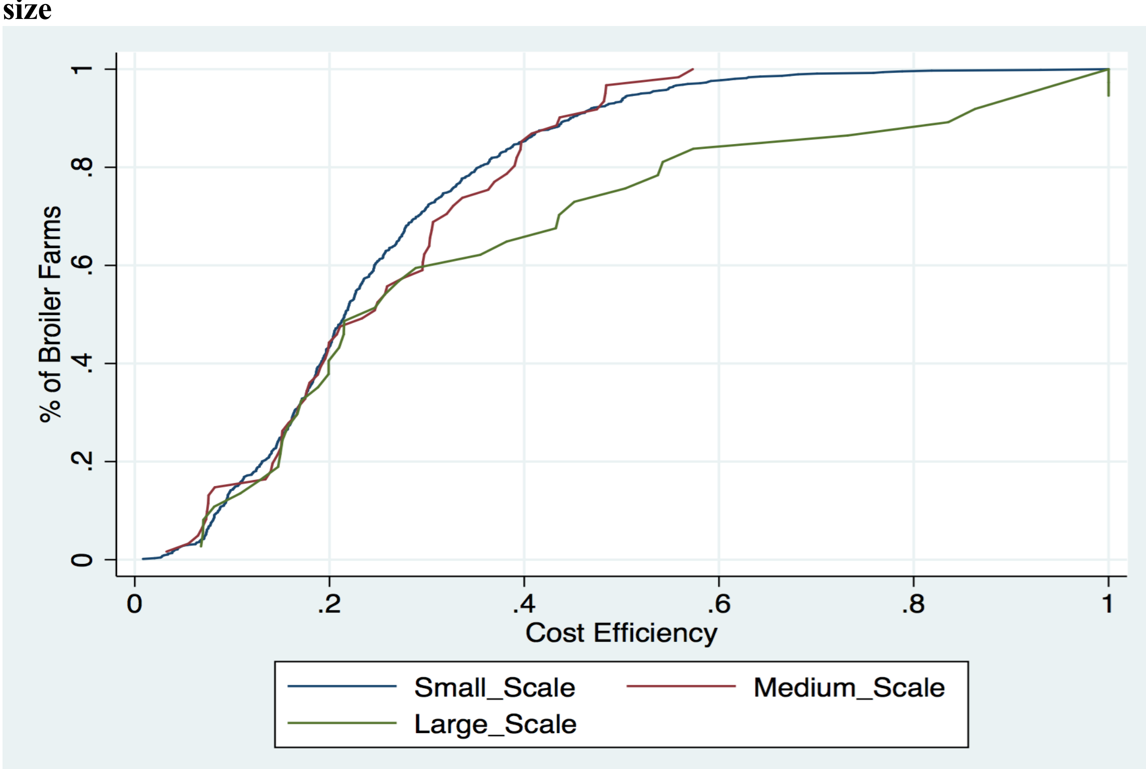


Figure 5:19 Cumulative distribution of cost efficiency estimates for layer farms by farm size

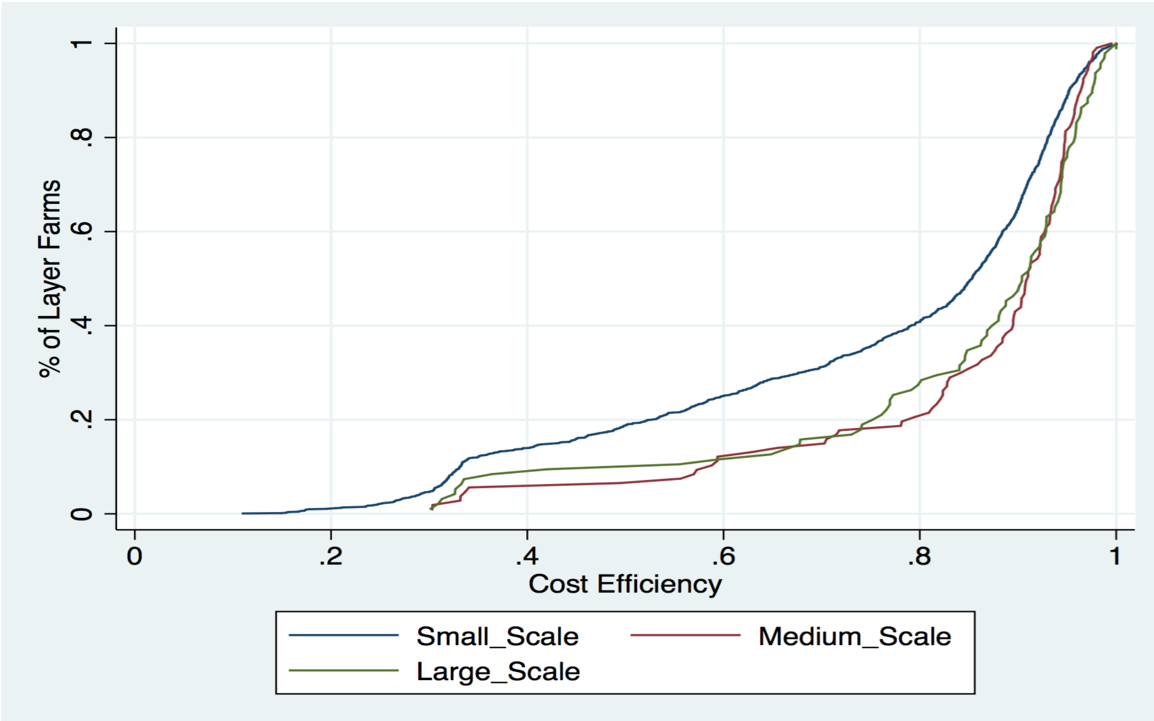
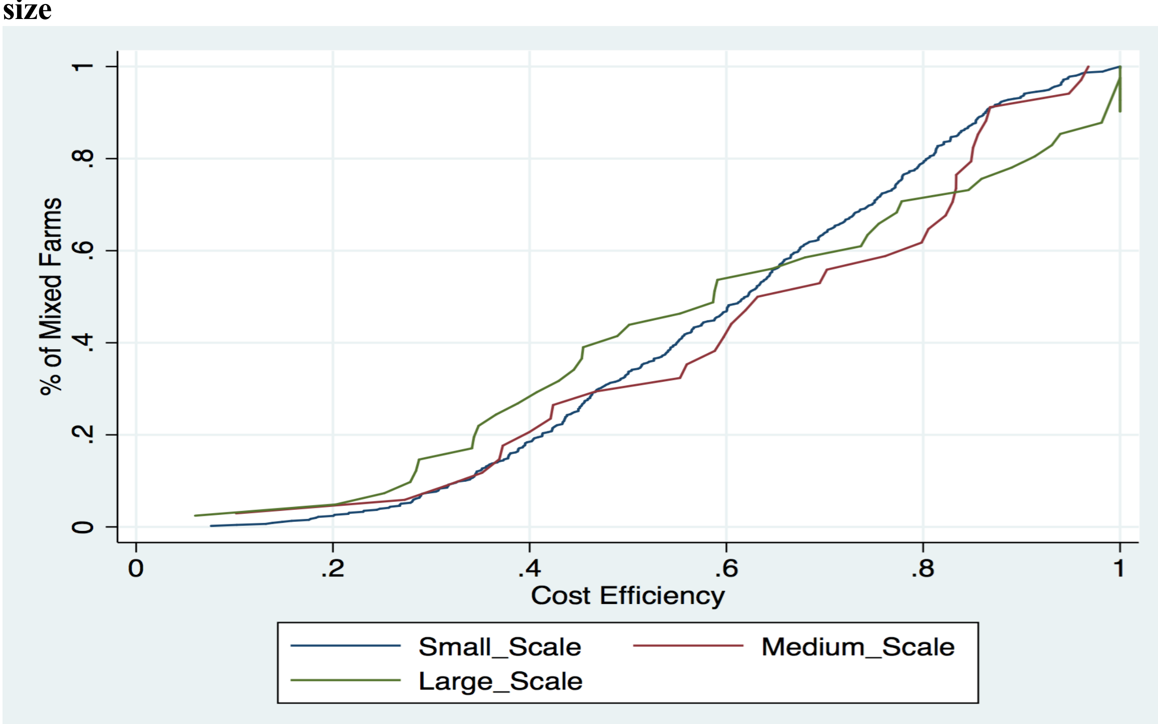


Figure 5:20 Cumulative distribution of cost efficiency estimates for mixed farms by farm size



5.1.4 Determinants of Efficiency

DEA efficiency scores serve as performance indicators to determine whether Ghana's chicken farms are operating in an efficient way. Therefore, understanding the determinants of efficiency is expected to guide chicken producers in their strategic decisions and also inform policies aimed at improving performance and competitiveness of domestic chicken production in Ghana. Factors such as farm structure, socio-demographic characteristics of farm operator as well as and farm management characteristics were hypothesized to cause chicken farms in Ghana to combine inputs in less than efficient manner and/or operate at less than optimal size. The empirical effects of these variables on efficiency are explained in this subsection following the regression procedure outlined in Section 3.3. Estimation results of the regression models examining factors related to the different efficiency measures are presented in Table 5:46 to Table 5:48. Standard errors are in parentheses. One variable is found to have no statistically significant effect on any of the efficiency measures across the three types of chicken enterprises: whether chicken producer operates a crop farm. This suggest that chicken farms with crop farm are as efficient as those without crop farm. There is no theoretical foundation to expect otherwise. All the remaining factors are significant for at least one efficiency measure at the 10% level or less. However, the set of significant factors differ for each efficiency measure and farm operation.

Farmer experience is found to significantly enhance technical and cost efficiency in layer operations as well as enhance scale efficiency in dual operations. However, no evidence of significant effect on any of the efficiency measures for broiler operation is observed. Layer producers who remain in the industry for longer periods may perhaps have a higher tendency to adopt newer, more efficient practices than those who are likely to exit the industry to justify additional investments in improved technologies.

Table 5:46 Estimation results for the efficiency effects models of broiler operations

Variables	TE-CRS	TE-VRS	SE	AE	CE-VRS	CE-CRS
Experience	-0.0002	0.0001	-0.0003	0.0009	0.0006	0.0002
	(0.0006)	(0.0007)	(0.0006)	(0.0008)	(0.0007)	(0.0006)
Education (Post-Secondary=Base)						
None	-0.0082	-0.0278	0.1002**	-0.0013	-0.0350	0.0236
	(0.0354)	(0.0382)	(0.0325)	(0.0430)	(0.0415)	(0.0347)
Elementary	-0.0088	-0.0390	0.1172***	-0.0133	-0.0573	0.0203
	(0.0353)	(0.0381)	(0.0324)	(0.043)	(0.0414)	(0.0346)
Secondary	0.0081	-0.0094	0.1040**	0.0015	-0.0309	0.0324
	(0.0354)	(0.0382)	(0.0324)	(0.0430)	(0.0415)	(0.0347)
Primary income source	-0.0067	-0.0301*	0.0300**	0.0019	-0.0156	0.0042
	(0.0120)	(0.0130)	(0.0110)	(0.0143)	(0.0141)	(0.0113)
Producer organization	-0.042***	-0.0393**	0.0142	0.0011	-0.0215	-0.0118
	(0.0123)	(0.0132)	(0.0112)	(0.0147)	(0.0145)	(0.0116)
Operate crop farm	-0.0063	-0.0079	-0.0078	0.0201	0.0058	0.0104
	(0.0125)	(0.0135)	(0.0114)	(0.0149)	(0.0146)	(0.0117)
Farm size (Small Scale = Base)						
Medium	0.1472***	0.1046***	0.1936***	-0.0152	0.0447	0.105***
	(0.0211)	(0.0228)	(0.0194)	(0.0256)	(0.0247)	(0.0188)
Large	0.2403***	0.2555***	0.1740***	0.0064	0.158***	0.176***
	(0.0282)	(0.0305)	(0.0259)	(0.0342)	(0.0314)	(0.0244)
Owner operated farm	0.0018	0.0033	-0.0163	0.0541**	0.04485*	0.0299
	(0.0170)	(0.0184)	(0.0156)	(0.0208)	(0.0205)	(0.0162)
Rural	0.0051	-0.0115	0.0206	-0.0206	-0.0256	-0.0106
	(0.0127)	(0.0137)	(0.0117)	(0.0153)	(0.0150)	(0.0120)
Region (Ashanti = Base)						
Brong-Ahafo	0.0951***	0.0955***	0.0545*	0.151***	0.165***	0.155***
	(0.0246)	(0.0265)	(0.0225)	(0.0310)	(0.0317)	(0.0255)
Central	-0.0325	-0.05751*	0.0390	0.099***	0.0324	0.0384
	(0.0230)	(0.02484)	(0.0210)	(0.0290)	(0.0301)	(0.0243)
Eastern	0.0134	0.0169	0.0390	0.104***	0.0736*	0.0782**
	(0.0227)	(0.0245)	(0.0208)	(0.0286)	(0.0296)	(0.0239)
Greater-Accra	-0.0193	-0.0076	-0.0216	0.123***	0.0815**	0.0514*
	(0.0242)	(0.0261)	(0.0222)	(0.0304)	(0.0314)	(0.0255)
Northernmost	0.0392	0.0104	0.0441	-0.0201	0.0113	0.0044
	(0.0377)	(0.0407)	(0.0345)	(0.0504)	(0.052)	(0.0437)
Volta	0.0337	0.0496	0.0234	0.153***	0.134***	0.123***
	(0.0321)	(0.0346)	(0.0294)	(0.0391)	(0.0393)	(0.0317)
Western	-0.0112	-0.0389	0.0270	0.1876***	0.1065**	0.1021***
	(0.0263)	(0.0284)	(0.0241)	(0.0326)	(0.0336)	(0.0269)
Feed type (Commercial feed only = Base)						
Self-prepared feed only	0.1316***	0.1361***	-0.0056	0.170***	0.230***	0.191***
	(0.0154)	(0.0166)	(0.0140)	(0.0186)	(0.0203)	(0.0165)
Both Feed	0.0651***	0.0682***	-0.0249	0.0619**	0.117***	0.096***
	(0.0160)	(0.0172)	(0.0146)	(0.0195)	(0.0208)	(0.0167)

Table 5:47 continues…

Variables	TE-CRS	TE-VRS	SE	AE	CE-VRS	CE-CRS
DOC stocking (Local supplier = Base)						
Own doc	-0.0490	-0.0763*	0.0407	-0.0557	-0.1050**	-0.0545
	(0.0301)	(0.0325)	(0.0275)	(0.0378)	(0.0405)	(0.0325)
Self-imported	-0.0349	-0.0670	-0.0114	0.0362	-0.0217	-0.0258
	(0.0316)	(0.0342)	(0.0290)	(0.0379)	(0.0363)	(0.0285)
Local importer	-0.075***	-0.079***	-0.0092	0.0096	-0.0386*	-0.0355**
	(0.0138)	(0.0149)	(0.0127)	(0.0165)	(0.0162)	(0.0130)
Hired labor	0.0002	0.000002	0.000324**	-0.0002	-0.0001	0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Constant	0.4876***	0.5974***	0.609***	0.1625**	0.0437	-0.0724
	(0.0444)	(0.0479)	(0.0407)	(0.0551)	(0.0553)	(0.0462)
sigma	0.1523***	0.1644***	0.1400***	0.1743***	0.1528***	0.1205***
	(0.0039)	(0.0042)	(0.0035)	(0.0051)	(0.0055)	(0.0044)
N	762	762	762	762	762	762
Chi-square	290.57	248.88	271.84	214.22	225.26	270.25
Log likelihood	355.833	296.525	416.725	299.652	531.788	735.293

*, **, and *** represents significance at the 10%, 5%, and 1% levels, respectively; numbers in parentheses are estimated standard errors.

Educational level of chicken producers in Ghana is high with over three fourth of farm operators having at least a secondary education. As a proxy for managerial input, a higher level of education was expected to lead to better information gathering and application, in effect better farm decision and higher performance. However, operator education was found to significantly impact only the scale efficiency of broiler producers. Even so, the results are not consistent with *a priori* expectation which stipulates a positive relationship between higher educational attainment and higher efficiency. Relative to post-secondary education, elementary education, secondary education as well as no formal education increases scale efficiency in broiler operation. This might suggest that a high level of education beyond the secondary level does not necessarily contribute to the ability of farmers to access and apply useful information for chicken production. Also, given that farmers with no formal education are relatively efficient, education schemes tailored to the specific technical needs of chicken producers would be more beneficial to improving performance.

The education level of chicken producers in Ghana is, therefore, not a major constraint to their production performance.

The coefficient on primary income source is positive and significant at the 5% and 10% level in the scale efficiency model of broiler and layer operations, respectively, and also negative and significant at the 5% level in the technical efficiency model of broiler operation. Thus, producers obtaining their primary income from the chicken farm is associated with higher scale efficiency of broiler and layer operations as well as lower technical efficiency of broiler operation. This might suggest that focusing attention on the chicken operation is important for improving scale efficiency of broiler and layer operations. Membership with a producer organization appears to be negatively correlated with technical efficiency of broiler operation but slightly increase the scale efficiency of layer operations. Additionally, increases in the proportion of hired labor is found to have positive and significant effect on scale, allocative and cost efficiency of layer operations and also positively impact scale efficiency of broiler and dual operations. The implication is this: in layer production, increasing the proportion of hired labor may result to cost savings from the optimal choice of input mix at prevailing market prices. Thus, the marginal value product (or benefit) generated from additional hired labor corresponds to the marginal cost. Therefore, an increase in the reliance on hired labor to more productive tasks in layer production could raise performance.

Farm size is found to be a statistically significant factor explaining the different efficiency measures, albeit with differing effects across chicken enterprise. In layer operations, increases in flock size contribute to higher technical, scale (lower unit costs associated with growth, due to increasing returns to scale) and cost efficiency. This narrative generally holds true in broiler operation as well except that scale efficiency is not associated with broiler farm size. However, dual operations with less than 5,000 birds tend to be more scale and allocative efficiency than those with more than 5,000 birds (see Table 5:48). This is consistent with the mean scale efficiency scores presented in Table 5:16 to Table 5:18, which suggests that unlike broiler and layer operations, small-sized mixed farms are on average, more scale efficient than large-sized mixed farms. The results also show that the source of day-old chicks or stocking material affects performance measures. Farms that depend on self-production and/or imports as the primary source day-old-chicks tend to be less efficient than those that depend on local suppliers for day-old-chicks. The type of feed used by producers significantly influence the performance of layer and broiler operations. However, the use of self-prepared feed only or mixed feed is found to benefit technical, allocative and cost efficiency of broiler operations compared to using commercial feed only whereas layer that use commercial feed only tend to be more technical, scale and cost efficient.

Few clear insights may be gained from the parameter estimates for the geographic location of farms, and educational level of farm operator across performance indicators. Although regional variations in the estimated average efficiencies are not large in magnitude, the parameter coefficients suggest higher technical and cost efficiency (statistically significant) for layer operations in Brong-Ahafo and Volta Regions than in Ashanti Region. Conversely, allocative and cost efficiencies for layer operations appears to be negatively impacted (statistically significant) if a farm is located in Northernmost Regions than in Ashanti Region. In broiler operations, the coefficient for the different regional location of farms indicate that farms in Brong-Ahafo, Northernmost and Volta Regions are significantly more technical efficient than farms in Ashanti Region. However, broiler farms in Central and Greater Accra Regions, are respectively, less cost and scale efficient than their counterparts in Ashanti Region.

Table 5:47 Estimation results for the efficiency effects models of layer operations

Variables	TE-CRS	TE-VRS	SE	AE	CE-VRS	CE-CRS
Experience	0.0011	0.0011	0.0001	0.0007	0.0014*	0.0015*
	(0.0005)	(0.0005)	(0.0001)	(0.0004)	(0.0006)	(0.0006)
Education (Post-Secondary=Base)						
None	-0.0067	-0.0063	-0.0073	-0.0100	-0.0168	-0.0217
	(0.0256)	(0.0247)	(0.0077)	(0.0214)	(0.0297)	(0.0304)
Elementary	-0.0150	-0.0083	-0.0036	-0.0023	-0.0079	-0.0101
	(0.0127)	(0.0123)	(0.0038)	(0.0106)	(0.0148)	(0.0151)
Secondary	-0.0045	-0.0042	0.0020	-0.0086	-0.0099	-0.0085
	(0.0119)	(0.0115)	(0.0035)	(0.0099)	(0.0138)	(0.0141)
Primary income source	-0.0031	-0.0082	0.0057	0.0022	-0.0054	-0.0010
	(0.0109)	(0.0106)	(0.0033)	(0.0091)	(0.0127)	(0.0130)
Producer organization	-0.0028	-0.0060	0.0056	0.0074	-0.0001	0.0029
	(0.0097)	(0.0093)	(0.0029)	(0.0081)	(0.0113)	(0.0115)
Operate crop farm	0.0151	0.0102	0.0009	0.0037	0.0146	0.0161
	(0.0097)	(0.0094)	(0.0029)	(0.0081)	(0.0113)	(0.0115)
Farm size (Small Scale = Base)						
Medium	0.0175	0.0357*	0.0068	0.0196	0.0509*	0.0539*
	(0.0186)	(0.0180)	(0.0056)	(0.0155)	(0.0216)	(0.0221)
Large	0.0256	0.0581**	0.0020	0.0031	0.0504*	0.0499*
	(0.0206)	(0.0199)	(0.0062)	(0.0172)	(0.0239)	(0.0244)
Owner operated farm	-0.0119	-0.0113	0.0002	-0.0049	-0.0125	-0.0116
	(0.0112)	(0.0108)	(0.0033)	(0.0093)	(0.0130)	(0.0133)
Rural	0.0227*	0.0156	0.0050	0.0045	0.0183	0.0196
	(0.0104)	(0.0100)	(0.0031)	(0.0086)	(0.0120)	(0.0123)
Region (Ashanti = Base)						
Brong-Ahafo	0.0399**	0.0336*	0.0065	0.0078	0.0343*	0.0378*
	(0.0136)	(0.0131)	(0.0041)	(0.0113)	(0.0158)	(0.0161)
Central	-0.0278	-0.0363	0.0057	0.0124	-0.0219	-0.0196
	(0.0201)	(0.0194)	(0.0060)	(0.0168)	(0.0234)	(0.0239)
Eastern	0.0496**	0.0558**	-0.0057	-0.0110	0.0388	0.0368
	(0.0177)	(0.0171)	(0.0053)	(0.0147)	(0.0205)	(0.0210)
Greater-Accra	0.04108*	0.0363	0.0040	0.0195	0.0463*	0.0491*
	(0.0201)	(0.0194)	(0.0060)	(0.0167)	(0.0233)	(0.0238)
Northernmost	0.0032	0.0049	-0.019*	-0.0465*	-0.0394	-0.0573
	(0.0250)	(0.0242)	(0.0075)	(0.0209)	(0.0291)	(0.0298)
Volta	0.0785**	0.077***	-0.0117	-0.0048	0.0626*	0.0562
	(0.0243)	(0.0235)	(0.0073)	(0.0203)	(0.0283)	(0.0289)
Western	-0.0309	-0.0341	0.0040	0.0147	-0.0169	-0.0127
	(0.0185)	(0.0179)	(0.0051)	(0.0155)	(0.0216)	(0.0221)
Feed type (Commercial feed only = Base)						
Self-prepared feed only	-0.177**	-0.162**	-0.0075*	-0.0057	-0.146**	-0.150**
	(0.0124)	(0.012)	(0.0037)	(0.0103)	(0.0144)	(0.0147)
Both Feed	-0.126**	-0.118**	-0.0058	0.0035	-0.098**	-0.101**
	(0.0132)	(0.0128)	(0.0040)	(0.0110)	(0.0154)	(0.0157)

Table 5:48 continues ….

Variables	TE-CRS	TE-VRS	SE	AE	CE-VRS	CE-CRS
DOC stocking (Local supplier = Base)						
Own doc	0.0351	0.0301	-0.0077	0.0077	0.0403	0.0327
	(0.0310)	(0.0299)	(0.0093)	(0.0258)	(0.035)	(0.0368)
Self-imported	-0.0074	-0.0009	-0.0027	-0.067***	-0.0538*	-0.0538*
	(0.0209)	(0.0202)	(0.0063)	(0.0174)	(0.0243)	(0.0249)
Local importer	-0.0122	-0.0165	0.0057	0.0006	-0.0143	-0.0109
	(0.0111)	(0.0107)	(0.0033)	(0.0092)	(0.0128)	(0.0131)
Hired labor	0.0001	0.0001	0.0001***	0.0002	0.0002	0.0003*
	(0.0001)	(0.0001)	(0.00003)	(0.0009)	(0.0001)	(0.0001)
Constant	0.897***	0.923***	0.964***	0.854***	0.785***	0.764***
	(0.0202)	(0.0195)	(0.0061)	(0.0169)	(0.0235)	(0.0240)
sigma	0.179***	0.172***	0.054***	0.149***	0.207***	0.212***
	(0.0032)	(0.0031)	(0.0009)	(0.0027)	(0.0037)	(0.0038)
N	1536	1536	1536	1536	1536	1536
Chi-square	433.18	417.12	80.5	37.72	245.83	252.53
Log likelihood	462.981	515.993	2302.49	740.574	238.761	206.475

*, **, and *** represents significance at the 10%, 5%, and 1% levels, respectively; numbers in parentheses are estimated standard errors.

Table 5:48 Estimation results for the efficiency effects models of mixed operations

Variables	TE-CRS	TE-VRS	SE	AE	CE-VRS	CE-CRS
Experience	0.0002	-0.0004	0.0007*	0.00001	-0.0002	0.0004
	(0.0009)	(0.0009)	(0.0003)	(0.0007)	(0.0010)	(0.0010)
Education (Post-Secondary=Base)						
None	-0.0313	0.0269	-0.0288	-0.0668	-0.0408	-0.0686
	(0.0662)	(0.0650)	(0.0251)	(0.0526)	(0.0687)	(0.0694)
Elementary	0.0182	0.0321	-0.0160	-0.0232	0.0117	-0.0023
	(0.0245)	(0.0241)	(0.0093)	(0.0195)	(0.0254)	(0.0256)
Secondary	0.0072	0.0151	-0.0042	0.0007	0.0070	0.0024
	(0.0208)	(0.0204)	(0.0079)	(0.0165)	(0.0216)	(0.0217)
Primary income source	0.0291	0.0200	0.0107	0.0292	0.0380	0.0450*
	(0.0200)	(0.0196)	(0.0076)	(0.0159)	(0.0208)	(0.0209)
Producer organization	0.0064	-0.0008	0.0079	0.0218	0.0220	0.0261
	(0.0183)	(0.0179)	(0.0069)	(0.0145)	(0.0190)	(0.0191)
Operate crop farm	0.0164	0.0120	-0.0056	0.0116	0.0208	0.0158
	(0.0190)	(0.0187)	(0.0072)	(0.0151)	(0.0198)	(0.0199)
Farm size (Small Scale = Base)						
Medium	0.0925*	0.0933*	0.0126	-0.0611*	0.0277	0.0329
	(0.0368)	(0.0362)	(0.0140)	(0.0293)	(0.0381)	(0.0382)
Large	0.0743*	0.1270***	-0.040**	-0.110***	0.0110	-0.0322
	(0.0352)	(-0.034)	(0.0133)	(0.0280)	(0.0365)	(0.0368)
Owner operated farm	0.0077	0.0031	-0.0209*	0.0412*	0.0293	0.0099
	(0.0223)	(0.0219)	(0.0084)	(0.0177)	(0.0231)	(0.0233)
Rural	-0.0149	-0.0226	-0.0002	-0.0212	-0.0303	-0.0300
	(0.0192)	(0.0189)	(0.0073)	(0.0153)	(0.0199)	(0.0200)
Region (Ashanti = Base)						
Brong-Ahafo	0.0141	0.0092	-0.0028	0.0115	0.0225	0.0213
	(0.0316)	(0.0310)	(-0.012)	(0.0251)	(0.0327)	(0.03283)
Central	-0.0026	-0.0003	-0.040**	-0.0144	-0.0094	-0.0443
	(0.0347)	(0.0341)	(0.0131)	(0.0276)	(0.0359)	(0.0361)
Eastern	-0.0468	-0.0393	-0.0252*	-0.0511	-0.073*	-0.086*
	(0.0332)	(0.0326)	(0.0126)	(0.0264)	(0.0345)	(0.0347)
Greater-Accra	-0.073*	-0.064*	-0.044***	-0.0364	-0.071*	-0.101**
	(0.0333)	(0.0327)	(0.0126)	(0.0265)	(0.0346)	(0.0348)
Northernmost	0.2472**	0.2250**	-0.0029	0.0750	0.2611**	0.2487**
	(0.0832)	(0.0818)	(0.0316)	(0.0662)	(0.0858)	(0.0862)
Volta	-0.0281	-0.0071	-0.0315	-0.090*	-0.0632	-0.0835
	(0.0463)	(0.0455)	(0.0176)	(0.0369)	(0.0482)	(0.0485)
Western	0.0646	0.0539	-0.0034	-0.0183	0.0378	0.0322
	(0.0344)	(0.0338)	(0.0130)	(0.0274)	(0.0356)	(0.0357)
Feed type (Commercial feed only = Base)						
Self-prepared feed only	-0.0003	0.0144	0.0002	-0.0058	0.0009	0.0029
	(0.0237)	(0.0232)	(0.0089)	(0.0188)	(0.0246)	(0.0247)
Both Feed	0.0010	0.0196	0.0022	-0.0183	-0.0044	0.0018
	(0.0241)	(0.0237)	(0.0091)	(0.0192)	(0.0250)	(0.0251)

Table 5:49 continues …

Variables	TE-CRS	TE-VRS	SE	AE	CE-VRS	CE-CRS
DOC stocking (Local supplier = Base)						
Own doc	-0.0219	-0.0208	-0.057**	0.0404	0.0211	-0.0333
	(0.0552)	(0.0542)	(0.0209)	(0.0439)	(0.0571)	(0.0578)
Self-imported	-0.0961	-0.0785	-0.0531*	0.0027	-0.0544	-0.0888
	(0.0635)	(0.0623)	(0.0240)	(0.0504)	(0.0660)	(0.0668)
Local importer	0.0115	-0.0020	0.01633*	-0.0136	-0.0121	-0.0023
	(0.0213)	(0.0210)	(0.0081)	(0.0170)	(0.0221)	(0.0223)
Hired labor	0.00001	-0.0002	0.00018*	0.0002	-0.00001	0.0001
	(0.0002)	(0.0002)	(0.0008)	(0.0001)	(0.0002)	(0.0002)
Constant	0.690***	0.746***	0.968***	0.773***	0.574***	0.562***
	(0.0390)	(0.0383)	(0.0148)	(0.0310)	(0.0404)	(0.0406)
sigma	0.197***	0.193***	0.074***	0.157***	0.203***	0.203***
	(0.0061)	(0.0059)	(0.0023)	(0.0048)	(0.0064)	(0.0065)
N	532	532	532	532	532	532
Chi-square	53.6	56.71	81.3	57.42	53.77	59.05
Log likelihood	109.072	117.94	623.483	229.617	98.705	100.099

*, **, and *** represents significance at the 10%, 5%, and 1% levels, respectively; numbers in parentheses are estimated standard errors.

5.2 Producers' Feed Choice Behavior or Demand

We now turn to the results from the analysis of poultry producers' feed demand. Separate models were estimated for each feed type (self-prepared and commercial feed) and farm operation (layer and broiler operations). As discussed earlier, the structural decision mechanism underlying broiler and layer producers own feed demand as well as layer producers' commercial feed demand are assumed to pass through two hurdles. Each hurdle was estimated individually, with the first hurdle (participation in the own feed or commercial feed markets) modelled using Probit regressions and the second hurdle (own and commercial feed demand) modelled using truncated regressions. Contrarily, a reduced form Tobit model was used to estimate the joint simultaneous decision of whether or not to purchase commercial feed and the actual quantity of commercial feed purchased by broiler producers. This is because of the underlying data generating process for broiler operations, where all sampled broiler farms purchased at least some or all of their feed.

Thus, positive probability zero commercial feed values for broiler producers arise due to corner solutions alone (i.e. representing an optimal solution to an optimization problem). The estimated coefficients reported for these models represents the conditional average partial effects (APEs), computed using the *margins* command in STATA. The results of each of the hurdles for each farm operation are discussed below, first, for own feed demand, and then followed by commercial feed demand.

5.2.1 Own Feed Demand

5.2.1.1 Factors Influencing the Probability of Producing Own Feed

The first stage models sought to identify factors that affect the likelihood that a producer will produce some or all of their own feed. The results (Table 5:49) show that most of the factors do not have consistent effects across the three types of chicken enterprises. For example, among the socio-economic covariates, only experience and age of farm operator are found to have statistically significant influence on producers' decision to produce their own feed. However, experience influences the decision of broiler and dual producers to produce own feed such that, the more experienced broiler and mixed farm producers are found to be more likely to self-prepare at least some of their feed. On the other hand, the effect of the age of farm operator was significant for only mixed farm operations. The results suggest that the probability of producing own feed decreases with age for mixed farm operators.

Operating a crop farm alongside the chicken enterprise appears to affect the probability of producing own feed, with broiler farms that operate a crop farm presenting a positive probability of producing their own feed. There is, however, no statistical evidence that operating a crop influence the likelihood of producing own feed in layer and mixed operations. The effect of farm size on the decision to produce own feed was significant in only layer operations. For those layer farms with more than 5,000 birds (medium- and large sized farms), their probability of producing own feed was significantly higher than those with less than 2,000 birds. Many large farms have made huge capital investments in acquiring their own feed plants. Aside the potential to lower feed cost, the flexibility in feed formulation, and other motivating factors, the opportunity cost of the capital investment may serve as an incentive to self-produce their own feed.

Table 5:49 Factors influencing decision to produce own feed

	Layer Farms		Broiler Farms		Mixed Farms	
	APE⊥	Std. Err.	APE⊥	Std. Err.	APE⊥	Std. Err.
Age	0.0007	0.0008	-0.0020	0.0012	-0.0031**	0.0014
Experience	0.0004	0.0011	0.0042**	0.0017	0.0056***	0.0017
Education (Post-secondary = Base)						
None	0.0062	0.0493	0.0194	0.0832	-0.1311	0.1151
Elementary	-0.0219	0.0211	0.0250	0.0335	-0.0603	0.0371
Secondary	-0.0120	0.0201	-0.0441	0.0327	-0.0302	0.0340
Primary income	0.0089	0.0180	-0.0322	0.0286	0.0342	0.0312
Producer organization	-0.0127	0.0162	0.0098	0.0277	-0.0493	0.0309
Operate crop farm	0.0178	0.0162	0.0643**	0.0275	-0.0079	0.0302
Farm size (Small sized = Base)						
Medium-sized	0.1554***	0.0523	0.0431	0.0502	0.0529	0.0604
Large-sized	0.0711*	0.0405	0.0032	0.0602	0.1227	0.0764
Owner operated farm	0.0183	0.0201	0.0300	0.0374	-0.0034	0.0363
Rural	0.0303*	0.0165	0.0044	0.0297	0.0241	0.0313
Region (Ashanti = Base)						
Brong-Ahafo	0.0876***	0.0195	0.1099**	0.0484	0.0387	0.0500
Central	-0.5808***	0.0288	-0.4581***	0.0425	-0.6142***	0.0486
Eastern	-0.1145***	0.0277	-0.1316***	0.0469	-0.1584***	0.0495
Greater-Accra	-0.0513**	0.0236	-0.1016**	0.0450	-0.1801***	0.0582
Northernmost	0.1621***	0.0259	-0.1111	0.1287	^	^
Volta	0.0066	0.0287	0.0949	0.0626	0.0087	0.0618
Western	-0.5712***	0.0254	-0.3853***	0.0504	-0.5618***	0.0526
Maize price	0.7382***	0.0332	0.8621***	0.0448	0.7858***	0.0647
Egg price	-0.0062***	0.0089	^	^	0.0069	0.0115
Broiler price	^	^	0.0002	0.0037	-0.0043	0.0036
No. of observations	1,536		762		524	
Log pseudo likelihood	-431.339		-287.979		-169.097	
Wald χ^2	454.87		255.13		149.71	
Prob > χ^2	0		0		0	
Pseudo R^2	0.5666		0.449		0.5228	

*, **, and *** represents significance at the 10%, 5%, and 1% levels, respectively; numbers in parentheses are estimated standard errors; ⊥ APE denotes average partial effect.

The majority of the geographic or regional variables were statistically significant and with consistent effects across the three types of chicken enterprises. Whenever significant, farm location in the Central, Eastern, Greater Accra, and Western Regions reduces the likelihood of producing own feed whereas farm location in Brong-Ahafo and Northernmost Regions increases the likelihood of producing own feed compared with Ashanti farmers. For instance, Brong-Ahafo layer and broiler farmers are, respectively, 8.8 and 10.9 percentage points more likely to prepare their own feed than Ashanti farmers. On the other hand, layer, broiler and mixed farm operators in Greater Accra Region are respectively, 5.1, 10.2 and 18.0 percentage points less likely to use own feed than Ashanti farmers.

The price of maize, though statistically significant, has a somewhat interesting effect on own feed production decision across chicken enterprises. The positive sign suggests that an increase in the price of maize increases the likelihood of producing own feed. Maize is used in both commercial and own feed. When maize price increases, it increases for both commercial feed mills and on farm feed producers. Therefore, an increase in maize price is expected to increase on farm production since it provides farmers with greater control over their cost.

5.2.1.2 Factors Determining the Quantity of Own Feed Produced

The parameter estimates for the truncated regression models for the decision of the quantity of own feed to produce are given in Table 5:50. A few of the significant variables for these second stage models have diverse effects across farm operations. However, the majority of the variables with significant effect across farm operations were consistent. Farm size and farm as producers' primary income exhibited consistent positive effects on the quantity of feed self-prepared as did the feed manufacturing or preparation method. The results suggest that, conditional on the decision to produce own feed, farms that were the primary income source for the farmer produced more of their feed needs compared to farms that were not. This variable is significant for all three chicken enterprises –broiler, layer, and mixed – at the 10%, 1% and 5% level, respectively. Similarly, compared to manual milling, using a toll mill or automatic mill accompanied the production of higher quantity of own feed by layer farmers. In broiler and layer operations, however, only the automated mill variable had a positive and significant effect on the quantity of own feed produced compared to manual milling. This implies that producers who make capital investment in automated mill or have access to the service of toll millers tended to produce more of their feed needs. Thus, access to toll mills and/or automated mills are likely constraints to the demand for own feed. On the effect of farm size, the results show that the quantity of own feed produced increase with the size of farm. Large and medium-sized layer farms self-produced about 2.7 kg and 1.8 kg more of their feed needs, respectively, compared to small-sized layer farms whereas medium-and large-sized broiler farms produced 1.0 kg and 2.1 kg more of their feed needs, respectively, than their small-sized counterparts. Likewise, large and medium-sized mixed farms self-produced about 2.2 kg and 1.3 kg more of their feed needs, respectively, compared to small-sized mixed farms.

A negative effect was observed for broiler farms that operate a crop farm on the quantity of own feed produced. This result seems to suggest that although broiler farms that operate a crop farm are more likely to produce their own feed, when they do, they tend to produce less of their feed compared to those without crop farms. A possible explanation for the negative sign on operate a crop farm may be that crop production contributes to household food supply, and income and such crops may have higher value in those uses than as feed. Moreover, as expected, broiler farms located in rural areas produce more of their feed once the decision to produce own feed has been made than those located in urban areas. Among layer farms, the independent effect of being owner operated on the quantity of own feed produce once acquisition decision has been made is negative and significant. This effect is not significant in broiler and mixed operations. There is some evidence of the effect of the education level of farm operator on own feed demand. The results indicate that layer farm operators with elementary or no education tend to produce less of their feed than those with post-secondary education. This was also the case for broiler farm operators with no education. The education variables, however, are not useful in explaining the quantity of own feed produced by mixed farms.

Among the regional explanatory variables, it is clear that many variables significant in the own feed acquisition models are also significant in the quantity models. However, in broiler operation, only the Northernmost Region location variable has a significant effect on own feed demand. On the contrary, among layer and mixed farms, there appears to be significant regional variation in the quantity of own feed produced given the larger number of statistically significant regional dummy variables. Layer farmers in all regions except those in Brong-Ahafo and Western Regions tend to produce less own feed than their counterparts in Ashanti Region. Likewise, mixed farms in Brong-Ahafo and Central Region produce less own feed than their counterparts in Ashanti Region.

Maize price relates positively and significantly to the quantity of own feed produced by broiler farms once the decision to produce own feed has been made. As previously mentioned, an increase in maize price may translate into higher commercial feed prices. But, given that farmers have better control over the cost of formulating their own feed, it is not surprising that as maize price increases, broiler farmers tend to produce more of their feed. However, there is no significant differences between maize price and own feed demand in layer and mixed operations.

Table 5:50 Factors influencing the quantity of own feed to produce

	Layer Enterprise		Broiler Enterprise		Mixed Enterprise	
	APE⊥	Std. Err.	APE⊥	Std. Err.	APE⊥	Std. Err.
Age	0.004	0.004	0.001	0.007	-0.002	0.008
Experience	-0.001	0.006	-0.001	0.008	0.006	0.009
Education (Post-secondary = Base)						
None	-0.393**	0.199	-0.612*	0.348	-0.448	0.444
Elementary	-0.208**	0.110	0.094	0.147	-0.013	0.193
Secondary	-0.082	0.099	-0.001	0.141	-0.020	0.168
Primary income	0.315***	0.094	0.213*	0.125	0.317**	0.167
Producer organization	0.090	0.085	0.118	0.132	0.211	0.147
Operate crop farm	0.003	0.085	-0.586***	0.136	-0.044	0.142
Farm size (Small sized = Base)						
Medium sized	1.790***	0.099	1.030***	0.191	1.301***	0.265
Large sized	2.708***	0.153	2.103***	0.300	2.152***	0.254
Owner operated farm	-0.375***	0.097	-0.265	0.198	-0.245	0.189
Rural	0.004	0.091	0.227*	0.130	-0.072	0.148
Region (Ashanti = Base)						
Brong-Ahafo	0.056	0.105	-0.059	0.207	0.198	0.218
Central	-0.614***	0.236	-0.155	0.228	-0.273	0.283
Eastern	-0.577***	0.180	-0.098	0.236	-0.670**	0.279
Greater-Accra	-0.671***	0.183	0.005	0.246	-0.767***	0.269
Northernmost	-1.399***	0.211	0.653**	0.293	-1.482***	0.397
Volta	-1.113***	0.253	-0.334	0.237	-1.126***	0.345
Western	-0.279	0.175	-0.171	0.254	-0.636**	0.263
Maize price	0.115	0.118	0.325**	0.143	-0.052	0.210
Egg price	0.149***	0.047	^	^	0.055	0.065
Broiler price	^	^	0.011	0.015	0.016	0.017
Feed preparation method (Manual mill = Base)						
Automated mill	0.523***	0.116	0.748***	0.247	0.601***	0.195
Toll mill	0.132	0.125	0.250	0.199	0.455**	0.216
Motivating Factors						
External control	-0.023	0.020	-0.004	0.028	0.009	0.038
Access to low cost feed and feed ingredients	0.109***	0.033	0.055	0.044	0.101*	0.056
Feed quality and quality control	-0.003	0.032	^	^	-0.094	0.062
Control over low cost feed	^	^	0.037	0.056	^	^
No. of observations	995		427		294	
Log pseudo likelihood	-1623.98		-655.80		-457.758	
Wald χ^2	1149.46		216.11		264.17	
Prob > χ^2	0		0		0	

*, **, and *** represents significance at the 10%, 5%, and 1% levels, respectively; numbers in parentheses are estimated standard errors.

⊥ APE denotes average partial effect.

The results also show that an increase in the price of egg reduces the probability to produce own feed by layer farms, but once the decision to produce own feed has been made, it increase the quantity of own feed produced. Of the four components loaded on the own feed production motivators only one is statistically significant and at the 1% level. Among layer farms, a unit increase in easy access motivator component leads to about 10.9 percent increase in the quantity of feed needs produced on-farm. Thus, easy access to domestic feed ingredients needed for own feed production, layer producers tended to produce more of their feed needs.

5.2.2 Commercial Feed Demand

5.2.2.1 Factors Influencing the Probability of Purchasing Commercial Layer Feed

Table 5:51 presents the results of the average partial effects of explanatory variables on the probability of chicken farms purchasing commercial feed. The coefficient on the variable for elementary education is positive for layer operations, suggesting that layer farm managers with elementary education are more likely to use commercial feed than those with post-secondary education. The results also show that membership in a producer organization have positive and significant effect on the probability of purchasing commercial feed among layer farms. Meanwhile, the farm being the primary income source reduces the probability of layer and mixed farms using commercial feed by about 3.3% and about 7.8%, respectively, significant at the 5 percent level. Broiler farms that operate a crop farm are also found to be less likely to purchase commercial feed whereas older broiler farmers are more likely to purchase commercial feed. In broiler and mixed farm operation, the experience of the farm operator relates negatively with the likelihood of purchasing commercial. Another significant explanatory variable, owner operated farm, has a negative effect on the probability of purchasing commercial by broiler farms. This negative effect indicates that broiler farms managed by the farm owner rather than a hired manager are less likely users of commercial feed.

Table 5:51 Factors influencing decision to purchase commercial feed

	Layer Enterprise		Broiler Enterprise		Mixed Enterprise	
	APE⊥	Std. Err.	APE⊥	Std. Err.	APE⊥	Std. Err.
Age	0.0002	0.0007	0.0050***	0.0014	0.0028*	0.0015
Experience	-0.0012	0.0010	-0.0050**	0.0021	-0.0063***	0.0019
Education (Post-secondary = Base)						
None	0.0542	0.0473	-0.0546	0.0871	-0.0344	0.1211
Elementary	0.0365*	0.0202	0.0129	0.0374	0.0370	0.0439
Secondary	0.0167	0.0183	0.0596	0.0371	0.0372	0.0353
Primary income	-0.0337*	0.0179	-0.0287	0.0306	-0.0776**	0.0345
Producer organization	0.0479**	0.0161	0.0070	0.0319	0.0413	0.0322
Operate crop farm	0.0068	0.0152	-0.0763**	0.0311	0.0324	0.0330
Farm size (Small-sized = Base)						
Medium-sized	-0.0862***	0.0248	-0.0455	0.0555	-0.0139	0.0615
Large-sized	-0.0369	0.0306	-0.0195	0.0709	0.0250	0.0624
Owner operated farm	-0.0289	0.0186	-0.0856**	0.0435	0.0266	0.0410
Rural	-0.0973***	0.0167	-0.0493	0.0311	-0.0319	0.0340
Region (Ashanti = Base)						
Brong-Ahafo	0.0923***	0.0187	0.1284	0.0780	0.1742**	0.0560
Central	0.3718***	0.0551	0.4422***	0.0648	0.5436***	0.0548
Eastern	0.2166***	0.0470	0.4524***	0.0615	0.4628***	0.0548
Greater-Accra	0.1095**	0.0351	0.3800***	0.0690	0.5873***	0.0455
Northernmost	-0.00163	0.0338	-0.0887	0.1133	0.0576	0.1528
Volta	0.0783**	0.0371	0.5204***	0.0648	0.4914***	0.0920
Western	0.2461***	0.0395	0.1882**	0.0824	0.4879***	0.0589
Commercial feed price	1.1844***	0.0356	0.0129	0.0189	0.7573***	0.0544
Egg price	0.0005	0.0079	^	^	-0.0027	0.0153
Broiler price	^		-0.00544	0.0037	-0.0053	0.0035
No. of observations	1,536		762		532	
Log pseudo likelihood	-417.152		-368.347		-213.814	
Wald χ^2	397.11		142.66		192.05	
Prob > χ^2	0		0		0	
Pseudo R^2	0.6074		0.1754		0.392	

*, **, and *** represents significance at the 10%, 5%, and 1% levels, respectively; numbers in parentheses are estimated standard errors.

⊥ APE denotes average partial effect.

Farm size also presents a negative effect on the probability of using commercial feed, with the coefficient on the medium-size variable for layer operations being statistically significant at the 1 percent level compared to small-sized layer farms. The location of farm is important in determining the likelihood of purchasing commercial feed. Of the regional dummy variable, only Northernmost Region had a statistically insignificant effect on the probability of purchasing commercial feed across the three types of chicken enterprises as well as the location variable for

Brong-Ahafo Region which has no effect on commercial feed purchase in broiler production. But, the likelihood of using commercial feed in all regions except the Northernmost Regions (though insignificant) was higher than the likelihood of using commercial feed had the farms been in Ashanti Region. Moreover, the rural variable (which takes a value of 1 if a farm is located in a rural area) is statistically significant at the 1 percent level and negatively signed. This suggest that farms located in rural instead of urban areas are less likely to purchase commercial feed, ceteris paribus. Perhaps such farms are small-scaled with a higher probability of accessing feed ingredient for own feed production than already prepared commercial feed. The market price of commercial feed was also found to significantly impact layer and mixed farmers' decision to use commercial feed. However, the unexpected positive own price effect of commercial feed on its use probability is consistent for layer and mixed operations. It indicates that with each increase in the price of commercial feed by one Ghana cedi, the probability of purchasing commercial feed increase by about 118% for layer farms and 76% for mixed farms.

5.2.2.2 Factors Determining the Quantity of Commercial Feed Purchased

The truncated parameter estimates for the second hurdle decision of the quantity of commercial feed purchased by chicken producers are given in Table 5:52. The farmer operator's age has a negative and significant effect on the quantity commercial feed purchased by layer farms. While significant in determining the probability of purchasing commercial feed by broiler and mixed farms, experience influence layer farmers' commercial feed quantity decision once acquisition decision has been made. A year's increase in a layer farmer's experience in poultry farming causes a small but statistically significant increase in the quantity of feed needs commercially purchased. The primary income source from broiler farm exhibit significant effect on the quantity of commercial feed purchased, as it did in the first hurdle model for layer and mixed farms. Thus, even though broiler farms that were the primary income source for the farmer are as likely as those with primary off-farm income source, these farms purchased more of their feed needs from commercial sources than those for which the farm was not the primary income source once the decision to use commercial feed has been made. This variable is significant for the broiler model only.

Of the layer and broiler farms that use commercial feed, membership in a producer organization positively and significantly affects how much commercial feed to purchase once the acquisition decision has been made. The coefficient on this variable is statistically significant at the 5% level. Results from the commercial feed demand models also show that farm location significantly influence how much commercial feed a farmer purchases, particularly, among layer and mixed producers. For instance, once acquisition decision has been made, layer farms in Western Region purchase about 0.5kg more commercial feed compared to Ashanti farms whereas those in Volta and Northernmost Regions purchase 0.5kg less. The results are statistically significant at the 1% and 10% levels, respectively. Additionally, Volta broiler and mixed farms purchase less quantity of commercial feed than their counterparts in Ashanti Region. The coefficient of the owner operated farm variable is negative and statistically significant at the 1% level for the broiler model and 5% for the layer and mixed farm models. This indicate that, when a farm is managed by its owner, lower quantity of commercial feed is purchased, *ceteris paribus*.

Farm size does matter in determining the quantity of commercial feed to purchase, once the decision to use commercial feed has been made. However, just like own feed production, the quantity of commercial feed purchased increases with farm size. Medium- and large-size layer farms, respectively, purchase about 1.4 and 2.4 kg more commercial feed than small-size layer farms while medium- and large-size broiler farms purchase about 0.4 and 1.2 kg more commercial feed, respectively, than small-size broiler farms. Similarly, medium- and large-size mixed farms purchase about 0.9 and 2.5 kg more commercial feed, respectively, than small-size mixed farms. The price of commercial feed has a significant but opposite effect in broiler and mixed operations. While an increase in commercial feed price reduces the quantity of commercial feed purchased by broiler farms once acquisition decision has been made, the opposite is true in mixed operations. A price increase of one Ghana cedi in commercial feed, reduces the average quantity purchased by broiler farms by 0.18 kg, but increases the average quantity purchased by mixed farms by 0.37 kg. The reliance on FBOs as well as commercial feed mills for commercial feed accompanied the purchase of more commercial feed compared to purchasing commercial feed from private retailers, ceteris paribus. Specifically, layer and mixed farms that depend on FBOs for commercial feed purchase approximately 0.8 kg and 0.7 kg more commercial feed than their counterparts who obtained their feed from private retailers, ceteris paribus. At the same time, layer farms that depend on commercial feed mills for commercial feed purchase approximately 0.3 kg more commercial feed than their counterparts who obtained their feed from private retailers. The price of egg is positively related to the level of commercial feed purchased by mixed farm operators whereas an increase in broiler price increases the quantity of commercial feed purchased by broiler farms.

Finally, the effects of the three components loaded on the commercial feed purchase motivators are explored. Two of the motivating factor variables are significant at the 5% level. As mentioned earlier, the a priori sign on these variables are unknown. However, the results indicate that in layer operations, the "no search and quality concerns" factor associated with commercial feed purchase positively increase the quantity of commercial feed purchased by about 0.8 kg for every unit increase in the factor. In contrast, the factor scores for "better cost control" significantly reduced the quantity of commercial feed purchased by about 0.1 kg for every unit increase in the factor. This effect is found in only layer and broiler operations, but in general, supports the assumption that farmers have little control over the cost of commercial feed.

Table 5:52 Factors influencing the quantity of commercial feed to purchase

	Layer Enterprise		Broiler Enterprise		Mixed Enterprise	
	APE⊥	Std. Err.	APE⊥	Std. Err.	APE⊥	Std. Err.
Age	-0.0105**	0.0051	-0.0039	0.0055	0.0078	0.0071
Experience	0.0190**	0.0074	0.0010	0.0076	-0.0031	0.0091
Education (Post-secondary = Base)						
None	0.4621	0.3372	-0.0012	0.2755	-0.4835	0.7184
Elementary	0.0644	0.1476	0.1023	0.1489	-0.0757	0.2130
Secondary	0.0283	0.1297	0.1955	0.1333	0.1931	0.1707
Prime income	0.1471	0.1177	0.3163**	0.1173	0.2333	0.1678
Producer organization	0.3595***	0.1050	0.3235**	0.1243	0.1794	0.1531
Operate crop farm	-0.0588	0.1100	0.1017	0.1265	-0.0266	0.1703
Farm size (Small-sized = Base)						
Medium-sized	1.4134***	0.2702	0.4490**	0.2288	0.9588***	0.2828
Large-sized	2.4191***	0.2858	1.1981**	0.4144	2.5134***	0.5235
Owner	-0.3952**	0.1485	-0.7530***	0.1845	-0.4562**	0.1860
Rural	0.0219	0.1140	-0.0011	0.1211	0.0884	0.1665
Region (Ashanti = Base)						
Brong-Ahafo	0.2774	0.2221	-0.4024	0.4096	0.2064	0.4029
Central	0.2955	0.2398	0.0305	0.3527	-0.0220	0.3555
Eastern	0.0216	0.2263	-0.2127	0.3503	0.1554	0.3728
Greater-Accra	-0.2090	0.2484	-0.2566	0.3611	-0.0858	0.3863
Northernmost	-1.1722***	0.3287	-0.0276	0.7214	-2.6435**	1.1358
Volta	-0.5030*	0.2939	-1.0180**	0.3596	-0.7381*	0.4187
Western	0.5321**	0.2194	-0.0889	0.3541	0.2117	0.3278
Commercial feed price	0.0825	0.0895	-0.1822**	0.0819	0.3650**	0.1269
Egg price	-0.0409	0.0549	^	^	-0.1193**	0.0545
Broiler price	^	^	0.0450**	0.0171	0.0234	0.0185
Source of commercial feed (Private Retail = Base)						
FBOs	0.8702***	0.1647	0.2223	0.1692	0.7213***	0.2217
Commercial feed mills	0.3311**	0.1581	0.2012	0.1560	0.0101	0.2239
Motivating Factors						
No search and quality concerns	0.0813**	0.0330	-0.0387	0.0388	0.0049	0.0441
Control over low cost feed	-0.1238**	0.0476	-0.1200**	0.0464	0.0591	0.0653
Higher and consistent feed quality	0.0676	0.0572	0.0694	0.0544	-0.1262	0.0796
No. of observations	793		486		311	
Log pseudo likelihood	-1402.07		-767.157		-505.49	
Wald χ^2	389.76		156.36		142.1	
Prob > χ^2	0		0		0	

*, **, and *** represents significance at the 10%, 5%, and 1% levels, respectively; numbers in parentheses are estimated standard errors.

⊥ APE denotes average partial effect.

Chapter 6 - Conclusions and Implications

This study was primarily concerned with estimating technical and economic efficiencies for chicken farms in Ghana and to identify the structural and economic determinants of efficiency as well as the determinants of farmers' demand for self-prepared and commercial feed. It used data from a census of 3,661 chicken farms collected in 2015/2016 and employed non-parametric methods to estimate technical, scale, allocative and cost efficiency. The double hurdle model was used to estimate self-prepared and commercial feed demand.

6.1 Implications of the Level and Source of Efficiency

In general, notable differences in the production behavior and efficiency level among different farm sizes, among farms located in different geographic regions and across the three types of chicken enterprises are observed. The empirical evidence suggests that overall, layer production exhibits higher efficiencies than broiler and mixed production. On average layer farms are 87% technical efficient, 98% scale efficient, 87% allocative efficient and 76% cost efficient. In contrast, broiler farms were on average 60% technical efficient, 72% scale efficient, 42% allocative efficient and 25% cost efficient while mixed farms are on average 77% technical efficient, 96% scale efficient, 79% allocative efficient and 61% cost efficient. Moreover, the results demonstrate that with few exceptions, the mean efficiency levels were fairly consistent by farm size for each chicken enterprise. For instance, small-scale layer farms were relatively less efficient in all efficiency measures compared to medium-and large-sized layer farms, but small-sized broiler farms, on average, operate much closer to the minimum point on their aggregate average cost curve than medium- and large-sized broiler farms. Likewise, small-sized mixed farms achieved the highest mean allocative efficiency of 80% compared to their medium- and large-sized counterparts. In addition, the findings also reveal that layer and mixed farms raising between 5,000 and 10,000 birds are on average more scale, allocative and cost efficient than those with more than 10,000 birds. Furthermore, farms in Brong-Ahafo Region were found to be most efficient in many of the estimated efficiency measures across chicken enterprises.

The foregoing suggests substantial cost, allocative and technical inefficiencies among broiler farms whiles layer and mixed production exhibit modest levels of inefficiencies. The level of scale efficiency gives an indication that chicken farms, especially layer and mixed farms, operate close to their optimal farm structure. As a result, the pursuit of growth strategies may yield minimal potential benefits since cost advantages to increasing size, in general, do not exist. Rather, further improvements in the performance of Ghana's chicken industry, in general, should emphasize on enhancing producers' ability to produce on the cost or production frontier as well as altering the allocation of inputs rather than adjusting their size or scale of operation. Specifically, the findings suggest that inefficiency in layer and mixed operations, may be ascribed to a large extent to cost and allocative inefficiency, among other factors while inefficiency in broiler operations may be due to technical, allocative and cost inefficiency. From a policy and strategy perspective, improving the performance of chicken production in Ghana will require a more focus of improving farms cost and allocative efficiency rather than farms operating with optimal scale of resources.

In the next step, the estimated farm-specific efficiencies were related to farm operator characteristics, farm structure and farm management characteristics to identify the source of inefficiencies. The significant variables differ substantially among farm operations and among the estimated efficiency measures revealing the importance of sector-specific policies or strategies. The educational level of farm operator did not have much impact on efficiency, but, where it was significant (positively influencing scale efficiency in broiler production), the results show that inefficiency decreases with higher education. This would suggest that, even though access to formal and informal education may help improve farm efficiency, farmers' education level is not a severe constraint to achieving maximum input efficiency. The results also point out that farm size has consistent and positive effect on the performance of broiler and layer farms. But in mixed operations, technical efficiency increases with size while allocative and cost efficiency decreases with farm size. This finding corroborates the estimated average efficiency scores discussed above. The producer organization variable was significant for scale and allocative efficiency improvements among only layer farms. Thus, membership in a producer organization improves only layer producers' ability to choose inputs in a cost minimizing way by producing at the minimum cost curve. The geographic or regional location of farms also emerged as significant determinant of farm efficiency. However, no generalization could be made about the pattern of this effect across efficiency measures and chicken enterprise.

While the use of commercial feed only rather than a combination of both commercial and self-prepared feed or self-prepared feed only improves efficiency in layer production, it reduces technical, cost and allocative efficiency in broiler production. However, maize and soybeans are the major ingredients in both commercial and self-prepared feed. Their availability, accessibility, and affordability must adjust continuously to new demand. Therefore, market access and physical linkages of production areas as well as feed mills to these ingredients is a policy that could enhance farm productivity and efficiency. But, the analysis has also shown that chicken farms operating a crop farms do not have relative advantage compared to those without crop farm in terms of efficiency improvement. As such, there is a need for a careful evaluation of policies that encourage chicken producers to grow maize and other grains with the aim of improving access to chicken feed to enhance the performance of chicken production. A large share of hired labor is associated with higher scale efficiency in broiler and mixed operations but associated with higher scale, allocative and cost efficiency in layer operation. Policies that improve access to high skilled labor should be encouraged as this will result in higher efficiency.

Findings from the performance analysis indicates that inefficiencies in Ghana's poultry industry may reflect insufficient technical skills (that has led to higher technical inefficiency), inadequate information on input prices (resulting to allocative inefficiency), and failures in input (especially feed) markets (resulting to cost and allocative inefficiency). Many of these factors, exogenous to the producer, are important constraints to efficiency improvements and will require the appropriate policy interventions to ease their effects on the overall performance and competitiveness of Ghana's chicken industry. Such interventions should, however, be targeted to specific farm groups given the wide disparity in the level and determinants of efficiency across efficiency measures, farm classes, geographic locations and chicken operations this study has shed light on.

6.2 Implications from the Demand for Chicken Feed

Commercial chicken producer in Ghana have three strategic options in managing their feed needs: purchase commercially prepared feed, produce own feed on-farm or use both own and commercial feed at varying proportions. Producers feed demand decisions are, however, constrained by a set of socio-demographic characteristics, market conditions, institutional considerations as well as other observable and unobservable motivating factors. Being able to identify potential sources of inefficiencies in chicken feed production is critical to enhancing producers' margin given that feed constitute the largest cost component in chicken production. The feed demand analyses provide useful insights into chicken producers feed choice behavior.

The findings from the study show that the decision of chicken producers in Ghana to produce own feed or purchase commercial feed are largely influenced by similar factors but with opposite effects. For example, the age of farm operator relates negatively with the probability to produce own feed in mixed operations but relates negatively with the probability of purchasing commercial feed in broiler and mixed operations. Similarly, while experienced broiler and mixed farm operators are more likely to produce their own feed, they are less likely to purchase commercial feed. Once the decision to produce own feed or purchase commercial feed has been made the quantity of self-prepared feed used is not affected by the age or experience of farm operator, however, the quantity of commercial feed used by layer farms increases with experience and reduces with the age of farm operator.

Because maize can form the bulk of poultry feed, farmers who produce maize were expected to be motivated to produce their own feed because of the perception that they can have better control over cost, quality and flexibility in feed formulation. The results from the analysis show that having a crop farm positively influence the probability of broiler producers using own feed. But once the decision to produce own feed has been made, having a crop farm reduces the quantity of own feed to produce by broiler farmers. It seems that promoting crop, specifically grain, production may not yield excepted direct short run benefits for the chicken industry due to the human food effect on animal feed demand. Grains may end up being used for home consumption which might be indirectly reducing food insecurity but not achieving the intended purpose for the poultry industry.

Large and medium sized layer farms are more likely to use own feed as well as produce more of the feed needs than small size farms. On the other hand, small-sized layer farms are more likely to purchase commercial feed but once the acquisition decision has been made large and medium-sized chicken farms tend to purchase more commercial feed than their small-sized counterparts. Many of the small farms producing their own feed did it manually. Aside the risk that small proportion ingredients, such as vitamins and minerals, may not mix evenly through the feed, manual mixing requiring lots of labor hours. Perhaps, the high labor requirement limits the production of own feed, giving the negative relationship between manual mixing and the other methods of own feed production (automated and toll mill).

There are considerable regional differences in the demand for commercial and self-prepared feed. These differences are somewhat ambiguous since no unique pattern of influence can be identified except that farms located in Brong-Ahafo and Northernmost Regions are more likely users of own feed than those in Ashanti Region but evidence to support the opposite in commercial feed use is weak. Maize price has a positive effect on own feed demand, indicating that in the event of maize price increases farmers may prefer producing their own feed to have better control over cost and quality.

Finally, it is observed that, in general, many of the variables that significantly affects the decision to produce own feed have opposite effects on the decision to purchase commercial feed. This would suggest that the factors that motivate the decision to produce own feed demotivate the decision to purchase commercial feed. For instance, the study finds that among other factors, the experience of farm operator, having a crop farm, farm location in a rural area, and farm size drive the decision to produce own feed but reduces the likelihood of purchasing commercial feed. On the other hand, age of farm operator and many regional dummies motivate the use of commercial feed but demotivates the using self-prepared feed.

Chapter 7 - References

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