

MANAGEMENT AND PRODUCTION

Scale economies and total factor productivity growth on poultry egg farms in Benin: a stochastic frontier approach

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ABSTRACT The study examines economies of scale and sources of total factor productivity growth on poultry farms producing table eggs in Benin Republic. We use panel data on commercial poultry farms from 2010 to 2018, and the flexible translog production functions to estimate a stochastic frontier and economies of scale. The results showed that there were significant economies of scale to be exploited, and the average productivity growth rate was decreasing of 5.09% over the study period. This deterioration was mainly because of

the decline of technical efficiency growth rate (2.16%) and technology growth rate (2.67%). Although the returns to scale (1.31) were increasing, their effects on productivity during the study period were negative (−0.74%). As implications, policy makers may encourage the increasing of the “size” of poultry farms and act on the sources of productivity growth identified in this study to increase the productivity of commercial poultry farms to meet the demand of table egg in Benin.

Key words: poultry, efficiency, technology, panel data, Benin

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INTRODUCTION

Productivity growth in agriculture has long been of interest to economists. It is the main explanatory element of the agricultural and economic growth of developed countries such as the United States, Japan, or the countries of the European Union (Nkamleu, 2004; Ludena, 2010). It contributes in particular to the increase of the income of the producers and the purchasing power of the consumers because of the decrease of the unit costs of production. It stimulates production and consumption and is therefore a major driver of economic growth and rising standards of living in the medium term (Douillet and Girard, 2013). It also enables farms to meet the nutritional needs of a rapidly growing human population (Nin-Pratt et al., 2012). In a simple way, total factor productivity (TFP) is defined as output per unit of inputs. It is the ratio of the aggregate index of

production to the aggregate index of factors of production and measures the efficiency of all factors of production. In other words, TFP is the part of production that is not explained by the quantity of inputs used. This is called a “residue” (Melaku et al., 2013). The importance and the economic role of total factor productivity may be measured in all sectors of a nation’s economy (Griliches, 1997). However, very few studies are done on total factor productivity in poultry farms in Benin. In addition, most studies did not use panel data.

Combary and Savadogo (2014) used stochastic frontier approach (SFA) to decompose total factor productivity growth and its sources in Burkina Faso cotton farms using panel data. Djimasra (2011) and Nkamleu (2004) analyzed also total factor productivity by decomposing the Malmquist productivity index using data envelopment analysis method. In the animal sector, Fleming et al. (2005) used the SFA and a specification of a translog production function to measure productivity changes in beef farms in southwest Victoria and Australia using panel data for the period 1995–2005. Empirical studies show that productivity is likely to change over time, and its growth is the result of improved technical and allocative efficiency, technical progress, and changes in returns to scale (RTS)

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(Fare et al., 1994; Kumbhakar and Lovell, 2000; Kumbhakar, 2006; Combarry and Savadogo, 2014).

In economic review, several methods are used to measure productivity and productivity growth. Nonparametric approaches and econometric techniques are the only ones that provide the sources of productivity growth. Moreover, in a stochastic environment such as agricultural sector in developing countries, where the data are heavily influenced by random variations, the econometric approach is the only one capable of estimating the sources of productivity growth (Coelli et al., 1998; Kumbhakar, 2006). Thus, the overall goal in this study was to evaluate total factor productivity growth and its sources in egg-producing poultry farms in Benin using the parametric approach of stochastic production frontier for an unbiased estimate.

The interest of this study on egg-producing poultry farms is based on the important issues that commercial poultry represents for the nutritional and economic growth and the reduction of poverty in Benin. This sector contributes about 5.7% to national gross domestic product and 14.8% to agricultural gross domestic product, and nearly 22% of the protein requirement coverage comes from poultry products (FAO, 2015; TDH, 2016). Commercial poultry farming is a major contributor and is growing, providing table eggs and meat for food. Egg production increased by 27% per year during the period 2012–2015 (FAO, 2015; TDH, 2016). However, this growth in production is more dependent on the expansion of commercial poultry farms (the number of poultry farmers has increased from 410 to 719 between 2010 and 2015) than productivity (TDH, 2016). Benin is still unable to meet its needs for animal protein consumption. Estimated at 12 kg per capita per year, the level of consumption of animal protein in Benin is below the minimum recommended consumption threshold set by Food and Agriculture Organization for developing countries (21 kg per inhabitant per year). In addition, the bulk of domestic meat production comes from traditional poultry farming. However, for several years, she has suffered the effects of avian pathologies. The mortality rate is close to 100% in case of pseudo-plague, and the level of productivity remains low (FAO, 2015). To make up for this deficit, the country is using massive imports of about 160,000 tons of poultry meat at a cost of more than 243 billion CFA francs (USDA, 2014). Thus, for a greater contribution of this sector to the overall objective of combating food and nutritional insecurity and to improve the living conditions of poultry farmers, the search for performance becomes a major concern at the level of commercial poultry farms. It is important to identify opportunities for improving total factor productivity for production growth of and income of poultry farmers in Benin.

Various studies have been conducted in the poultry sector in Benin (Chrysostome and Sodjinou, 2005; Houndonougbo, 2005; Sodjinou, 2011), but these studies focus on traditional poultry farming. On the commercial poultry farming, a few studies have been conducted (Fanou, 2006; TDH, 2010; FAO, 2015; TDH, 2016; Siéwé

et al., 2017). To our knowledge, none of these studies have addressed productivity in terms of total factor productivity growth, sources of productivity growth, and scale economies applied on commercial poultry farms.

The purpose of this study was two-fold: (i) highlight the existence and magnitude of scale economies effects on poultry eggs production in Benin and (ii) to examine the state and sources of total factor productivity growth (changes in technical, technological, allocative, and scale efficiency) on poultry eggs production in Benin. Apart from the introduction, this article has 4 sections.

DYNAMIC OF POULTRY EGG PRODUCTION IN BENIN

Commercial poultry farming has been marked since 2005 by an increase in egg production (Batonon et al., 2013). This emergence is driven by public actions, in particular the Project of Support for the Development of Modern Poultry Farming, which boosted production and encouraged the integration of several poultry farmers and private companies whose numbers are growing steadily (MAEP/PSDSA, 2017). Thus, the exhaustive censuses of commercial poultry farms carried out in 2005 and 2015 showed that the number of poultry farmers was increased. Indeed, this number increased from 425 in 2005 to 719 in 2015 (FAO, 2015; TDH, 2016). Commercial poultry farms are mainly located in southern Benin (78% of poultry farms) and in central Benin (16% of poultry farms). Table egg production is the main activity of these poultry farms (TDH, 2016; MAEP/PSDSA, 2017).

The actions undertaken by the public authorities have boosted the internal supply of table eggs in Benin; commercial poultry farms provide the bulk of the table eggs produced. The evolution of national production of table eggs during the period 2004 to 2017 is illustrated in Figure 1. After the dark periods of the sector marked by a drastic drop in egg production in 2008 and 2009, the actions undertaken in the sector have begun to bear fruit since 2010. Egg production since 2009 has increased dramatically. It increased from five 550 tons in 2009 to fifteen 500 tons in 2017 (FAOSTAT, 2019), an increase of 179% over the period from 2009 to 2017 and 78% of rate growth over the period 2004–2017. Despite this increase, the production of table eggs does not manage to satisfy the Beninese population demand of poultry eggs.

Thus, to ensure national food security, the Beninese Government has designed a Strategic Plan for Agricultural Sector Development. The main objective of this policy was “to improve the Beninese agriculture performance to enable it to ensure sustainable food sovereignty, food and nutritional security and to contribute to the economic and social development of Benin’s men and women to achieve the Sustainable Development Goals. In this dynamic, poultry production, especially the production of table eggs, is chosen by the Beninese State as one of the key sectors to receive more attention.

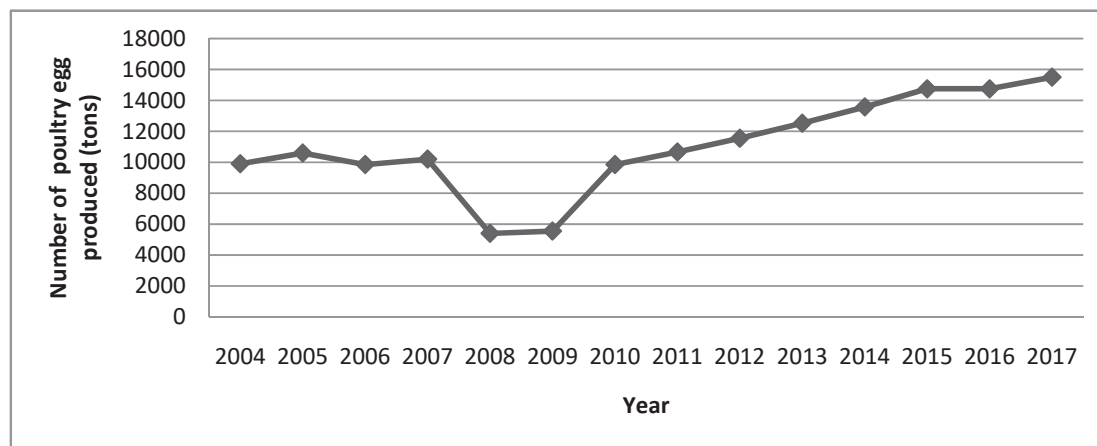


Figure 1. Dynamic of eggs production in Benin from 2004 to 2017 (source: FAOSTAT, 2019).

To achieve its operationalization, the Strategic Plan for Agricultural Sector Development has been endowed with a National Agricultural Investment Plan which includes 4 framework programs including the “Program Development of Livestock” which aimed inter alia to increase the production of table eggs from 13,093 tons in 2015 to 25,000 tons in 2021. This is an ambition that requires efforts in connection with farms producing table eggs. To achieve this, it is important to improve the performance of these farms in terms of quantitative production (MAEP/PSDSA, 2017).

MATERIALS AND METHODS

Description of the Study Areas

The study was conducted in the Republic of Benin, a coastal country in West Africa with a land area of 114,763 km², bordered by Nigeria (to the East), Togo (to the West), Niger and Burkina-Faso (to the North), and the Atlantic Ocean (to the South). It is subdivided into 12 provinces, which are further subdivided into 77 districts. The study covered southern and central of Benin. The south of Benin is chosen more than 75% of the poultry farming were located in this region. This region includes the provinces of Atlantic, Littoral, Oueme, Plateau, Mono, and Couffo (Onibon and Sodegla, 2005; TDH, 2010; FAO, 2015; TDH, 2016). In addition, most small and large poultry farming are located in southern Benin (FAO, 2015). The center of Benin is the second largest region in terms of commercial poultry farming and includes the provinces of Zou and Collines. According to previous references, more than 15% of poultry farms were located in this region. These 2 regions accounted for 90% of commercial poultry farms in Benin. The study area is presented by Figure 2.

Data and Source

The data used are unbalanced panel data covering the period 2010–2018 on commercial poultry farms.

The panel database was designed from secondary and primary data. Secondary data were collected by the Ministry of Agriculture, livestock, and Fisheries in the case the Milk and Meat Support Project in years 2010 and 2015. The primary data were collected in 2018 during the research project “Youth engagement in agribusiness and rural economic activities in Africa” implemented by the International Institute of Tropical Agriculture. The database of year 2015 was used as the sampling frame to draw a representative sample for the year 2018. This database included 600 egg-producing poultry farms in the study area (TDH, 2016).

Multiple sampling techniques were used in the research area to collect data in 2018. The primary sampling units were the province, and the ultimate sampling units were egg-producing poultry farmers. The first stage involved purposive sampling of the areas based on the population of egg producers. The second stage involved a simple random selection of egg producers from the sampling frame of the year 2015. The sample size was determined using the formula (Cochran, 1963) in Equation (1).

$$n = \frac{Z_{0.95}^2 P(1-P)}{e^2} \quad (1)$$

In Equation (1), $n=354$ is the sample size without the finite population correction factor, Z^2 (3.5416) is the abscissa of the normal curve that cuts off an area α (0.05) at the tails ($1-\alpha$ equals the desired confidence level and is 95%), e is the desired level of precision, p is the estimated proportion of an attribute that is present in the population, and p is $1-p$. The value for Z is found in statistical tables which contain the area under the normal curve. Assume there is a large population but that we do not know the variability in the proportion that will adopt the practice; therefore, assume $P = 0.5$ (maximum variability).

Applying the finite population correction factor, results in the actual sample size n , computed as in Equation (2).

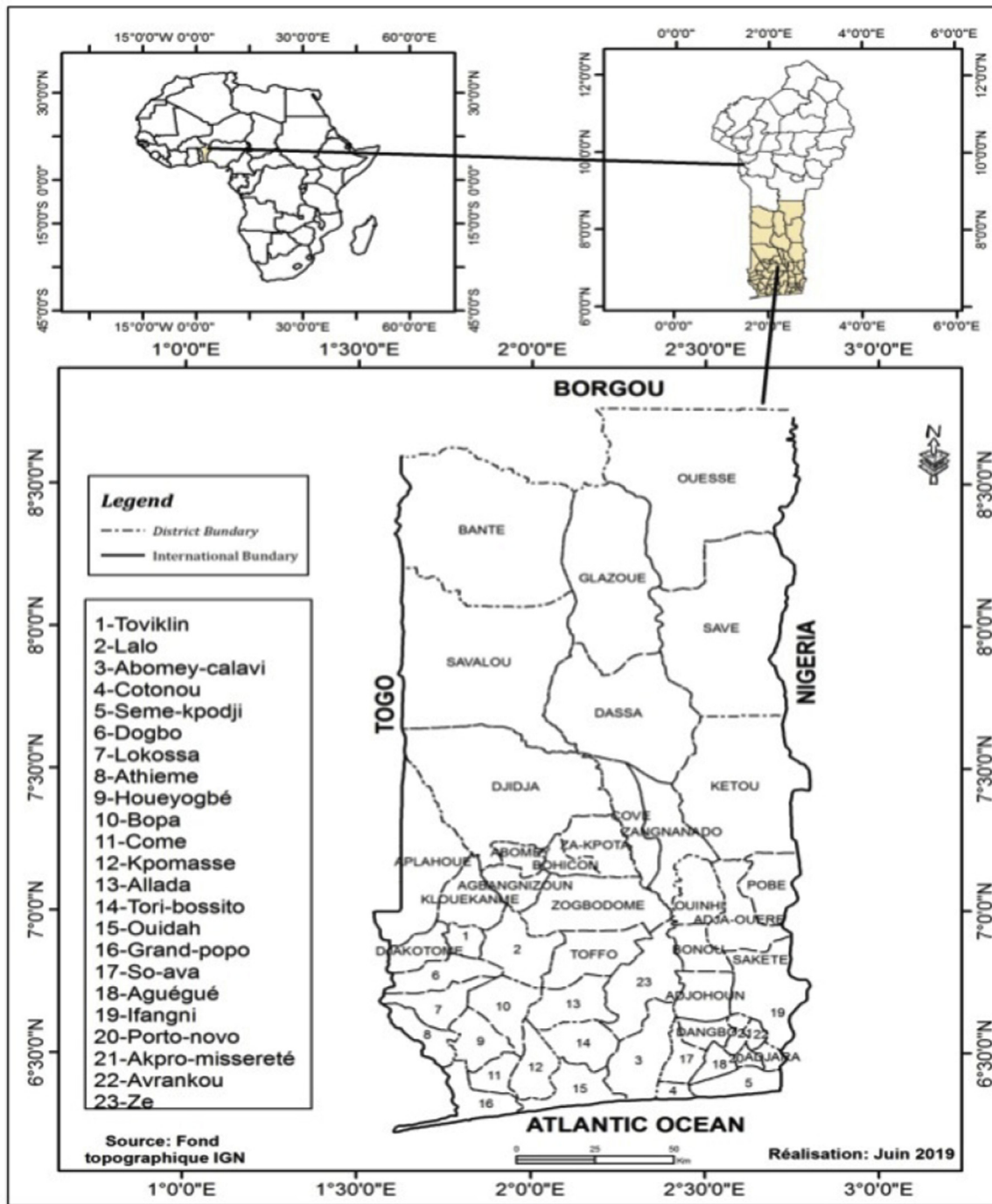


Figure 2. Study area. Source: National Geographic Institute topographic background.

$$n = \frac{n_0 N}{n_0 + (N - 1)} \quad (2)$$

n is the actual sample size, and N is the population size.

Using this formula and effect design applying, 214 egg-producing poultry farmers were surveyed. During year 2018, data were collected using questionnaires, and the missing data for 2010 and 2015 were filled by the presence of management tools (diary notebook, customer account, and stock cards) available to the majority of poultry farms. These data concerned information on

the prices of the inputs used and the socioeconomic characteristics of poultry farmers (number of years of experience, access to veterinary services, access to agricultural credit, existence of input supply, or sales contracts).

The panel database designed covers a total of 470 observations, including 88 in 2010, 214 in 2015, and 168 in 2018. This led to the construction of an unbalanced panel database which nevertheless offers advantages. Indeed, the use of an unbalanced panel data reduces considerably the risk of simultaneity bias, whereas this risk is very high in the case of a balanced panel data (Marschark and Andrews, 1944; Marion, 2009).

Data contain sociodemographic characteristics of poultry farms, numbers of egg produced, and inputs. Inputs included number of day-old chicks purchased, the quantity of feed intake, veterinary treatments and care costs, labor force, heating chicks costs, transport and water costs depreciation of infrastructures, and materials and equipment used. Prices of inputs (day-old chicks, food, water, energy, etc.) and products (eggs, chickens, and droppings) were also collected.

Descriptive statistics were used to analyze the characteristics of the explanatory variables introduced in the econometric estimation model, whereas the stochastic frontier production function was used to decompose total factor productivity growth into its sources. The STATA software was used for descriptive statistics and econometric estimation.

Theoretical Framework

Productivity and productivity growth can be measured using different techniques. Diewert (1992) has shown that productivity change can be calculated using a productivity index method (Fisher, 1922; Törnqvist, 1936). Fisher and Törnqvist productivity indices require information on quantities and prices, as well as assumptions about the technology structure and the behavior of producers, but neither requires an econometric estimate. The productivity change can also be calculated using the Divisia index, which is a nonparametric approach. Finally, it can be estimated using econometric techniques (Kumbhakar, 2006).

The disadvantage of the index and Divisia index calculation techniques is that they do not provide sources of productivity growth, unlike nonparametric and econometric techniques. Although nonparametric and econometric techniques are able to measure productivity change and its sources, only the econometric approach is capable of doing so in a stochastic environment. For this study, therefore, we have chosen to use econometric techniques to estimate the magnitude of the productivity change and then to decompose the estimated productivity change into its different sources. According to the theory, productivity is affected by the presence of inefficiency. It should also affect productivity growth (Kumbhakar, 2006). Early econometric models of productivity change analysis ignored the contribution of efficiency change. The change in productivity has been broken down into technical change and economies of scale. However, if inefficiency exists, the change in efficiency makes an independent contribution to the change in productivity. If the efficiency change is omitted from the analysis, its omission leads to an erroneous estimate of the productivity change at its sources. As a consequence, it is desirable to integrate the possibility of efficiency into the econometric models of productivity and productivity evolution (Kumbhakar, 2006). Therefore, the production frontier approach with technical inefficiencies incorporated is preferred in this study. It served as a basis for the decomposition of productivity using a

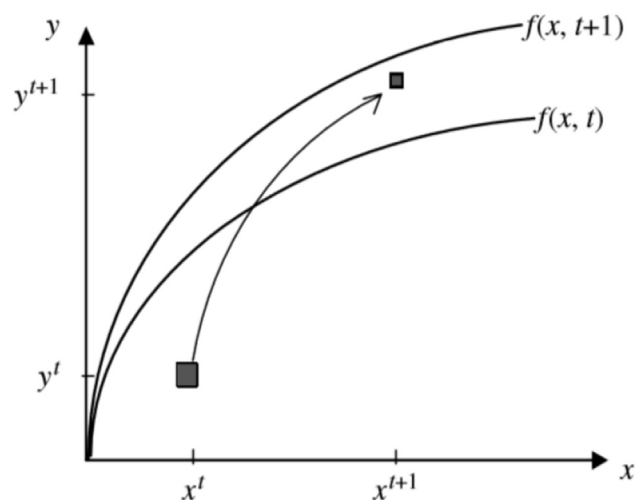


Figure 3. Primal approach of estimating and decomposing the change in productivity. Source: Kumbhakar, 2006.

production function (primal approach) of Kumbhakar (2006) and Kumbhakar et al. (2015).

The scopes of Figure 3 have illustrated the general structure of the primal approach in which a single input is used to produce a single output. Suppose for a producer at the moment t , the production plan is given by the input–output combination (x^t, y^t) , and the production frontier is $f(x, t)$. The productivity of this combination of input–output is defined by the ratio between output and input, that is, y^t/x^t which can be easily measured from input and output data. Note that, $y^t < f(x^t, t)$ which means that the production plan is technically inefficient. Technical efficiency is defined as $y^t/f(x^t, t)$, which is at most equal to unity. Because the production frontier $f(x, t)$ is not known, measurement of technical efficiency requires estimation of the boundary. In addition, productivity is reduced in case of technical inefficiency, that is, $y^t/x^t < f(x^t, t)/x^t$. Similarly, the more efficient a firm is, the higher its productivity, *ceteris paribus*. Suppose the producer extends the production plan of (x^t, y^t) to (x^{t+1}, y^{t+1}) and a technical progress intervenes between the period t and $t + 1$. This would imply that $f(x, t + 1) > f(x, t)$. By ignoring the noises, it is clear that production is technically inefficient at each of the 2 periods because $y^t < f(x^t, t)$ and $y^{t+1} < f(x^{t+1}, t + 1)$ and that technical efficiency has improved over the period t to the period $t + 1$, because $[y^t/f(x^t, t)] < [y^{t+1}/f(x^{t+1}, t + 1)]$. It is also clear that there is a productivity gain because $(y^{t+1}/x^{t+1}) > (y^t/x^t)$. The estimated rate of productivity growth can then be decomposed into RTS, technical change, and technical efficiency change.

Decomposition of Total Factor Productivity By imposing the same production technology and assuming that there is only 1 output, the production function can be represented by $y_{it} = f(x_{1it}, \dots, x_{Jit})$, where $f(\cdot)$ is the production technology, y_{it} is the output of the i^{th} farm ($i = 1, \dots, N$) in the period t , ($t = 1, \dots, T$), and x is the vector of J inputs. Thus, the production function can be represented by:

$$y_{it} = f(x_{it}, t) \exp(-\mu_{it})$$

where, $\mu_{it} \geq 0$ is the technical inefficiency which measures the proportion by which actual production is less than the maximum possible output $f(x, t)$. It is defined in this case by $y_{it}/f(x_{it}, t) = \exp(-\mu_{it}) \leq 1$. The time trend variable t in (1) represents a technical change (a change in the production function over time).

When input quantities change, the change in productivity is measured by what is commonly known as the change in TFP. As input quantities change, productivity growth is measured by what is commonly referred to as the change in TFP (or the Divisia index of productivity change), and is defined as:

$$TFP = \dot{y} - \dot{x} \equiv \dot{y} - \sum_j S_j^a \dot{x}_j,$$

where, $S_j^a \dot{x}_j = w_j x_j / C^a$ and $C^a = \sum_j w_j x_j$, w_j being the price of the input. x_j

By totally differentiating (1) and using the definition of TFP in (2), we obtain the decomposition of TFP as follows:

$$\begin{aligned} PTF &= TC - \frac{\partial \mu}{\partial t} + \sum_j \left(\frac{f_j x_j}{f} - S_j^a \right) \dot{x}_j \\ &= (RTS - 1) \sum_j \lambda_j \dot{x}_j + TC + TEC + \sum_j \left\{ \lambda_j - S_j^a \right\} \dot{x}_j, \end{aligned} \quad (3)$$

where, $TC = \frac{\partial \ln f(x, t)}{\partial t}$, $TEC = -\frac{\partial \mu}{\partial t}$, and $RTS = \sum_j \frac{\partial \ln y}{\partial \ln x_j} = \sum_j \frac{\partial \ln f(\cdot)}{\partial \ln x_j} = \sum_j f_j(\cdot) x_j / f(\cdot) \equiv \sum_j \varepsilon_j$ is the measure of the returns of scale. Finally, $\lambda_j = \left\{ f_j x_j / \sum_k f_k x_k \right\} = \varepsilon_j / RTS$, whereas f_j is the marginal product of the input x_j .

The relationship in (3) decomposes total factor productivity growth into 4 sources or components:

- (i) The first term of the right $(RTS - 1) \sum_j \lambda_j \dot{x}_j$ is the return to scale component which materializes a weighted effect of the RTS. It captures the effect of an increase in the amount of factors on total productivity. When RTS are constant ($RTS = 1$), this term has no effect on total factor productivity. On the other hand, we observe an increase in the total factor productivity when the returns of scale are increasing $RTS > 1$ and a decrease when the returns of scale $RTS < 1$ are decreasing.
- (ii) The second term of the right $TC = \frac{\partial \ln f(x, t)}{\partial t}$ is the technological change (TC). This is the rate of technical progress that represents the shift of the production frontier over time. If $TC = 0$, there is lack of technical progress. If $TC > 0$, there is technical progress, and if $TC < 0$, there is technological regression.
- (iii) The third component $TEC = -\frac{\partial \mu}{\partial t}$ is the change in technical efficiency (TEC) over time. It represents

the rate at which the unit of production approaches or moves away from the production frontier. When, $TEC = 0$, the level of technical efficiency does not change. If $TEC < 0$, there is a loss of technical efficiency, and if $TEC > 0$, there is a gain in technical efficiency.

- (iv) The last term $\sum \{ \lambda_j - S_j^a \} \dot{x}_j$ is the component of the price effect. This latter component captures either the price differentials of the inputs relative to the value of their marginal products, that is, $w_j \neq p f_j$, or the difference between the marginal rate of technical substitution and the price ratio of inputs ($f_j / f_k \neq w_j / w_k$). Thus, this latter component can be removed from the analysis if it is assumed that the production units are allocatively efficient.

Econometric Model Specification Stochastic frontier model was developed (independently) by Aigner et al. (1977) and Meeusen and Vanden Broeck (1977). Pitt and Lee (1981) and Schmidt and Sickles (1984) developed an extension of this model for panel data. Since then, several improvements have been proposed, such as that of Battese and Coelli (1992), in which technical inefficiency is modeled so as to vary over time.

The present study used total factor productivity decomposition approach of Kumbhakar et al. (2015) with panel data considering a stochastic production frontier model specified as follows:

$$y_{it} = f(x_{it}, t; \beta) \exp(v_{it} - \mu_{it}), \quad i = 1, 2, \dots, N, \quad t = 1, 2, \dots, T \quad (4)$$

where, y_{it} is the output of the i^{th} poultry farm at year t ; x_{it} is a vector of the inputs of the i^{th} poultry farm during the t^{th} year; β is a vector of unknown parameters; and v_{it} is the random error term. It is assumed to be independently distributed $N(0,1)$ and independent of technical inefficiencies μ_{it} .

The model can be estimated simultaneously by the maximum likelihood method and adapts to the variable technical efficiency over time. It is specified in such a way that all time-invariant effects, such as unobserved heterogeneity, are captured by α_i (the individual specific component of the production units) and the technical inefficiency that varies freely over time with $N(\mu_{it}, \sigma_\mu^2)$.

Statement of Hypothesis Because the parametric SFA requires a particular functional form, the following hypotheses are considered for investigation. (A): $H_0: \beta_{jk} = 0$, the coefficients of the second-order variable in the translog model are zero to become the Cobb-Douglas model; (B): $H_0: \lambda = 0$ inefficiency effects are absent from the model. Therefore, the variance of the inefficiency term is zero, and deviations of the observed output from the frontier output are entirely because of pure noise effect. On the other hand, if $\lambda > 0$, then technical inefficiency is present in the data, and deviations from the frontier output are as a result of technical inefficiency and pure noise. The results of the hypothesis A showed that the translog functional form is preferred and more adapted to the available data. The empirical model of

stochastic production frontier with an output and five inputs as part of this study is specified with a translog form such as:

$$\begin{aligned} \ln y_{it} = & \alpha_i + \sum_{k=1}^5 \beta_k \ln x_{kit} + \beta_\tau T \\ & + \frac{1}{2} \left\{ \sum_{k=1}^5 \sum_{j=1}^5 \beta_{kj} \ln x_{kit} \ln x_{jit} + \beta_{\tau\tau} T^2 \right\} \\ & + \sum_{k=1}^5 \beta_{k\tau} \ln x_{kit} T + v_{it} - \mu_{it} \end{aligned} \tag{5}$$

$(i = 1, 2, \dots, 470; t = 1, 2, 3)$

Dependent Variable

Y_{it} is the only output which represents the total number of eggs produced during a cycle.

Explanatory Variables

- X1 = Farm size (number of day-old chicks purchased)
 - X2 = Labor input (in man-days)
 - X3 = Total feed intake (kg)
 - X4 = Cost of drug and medication (FCFA)
 - X5 = Other capital (Depreciation of equipment and buildings used) in FCFA
- $t =$ year (2010, 2015 and 2018). This is the time trend variable. It is included to capture the technical change that may affect the location of the production frontier.

The parameters of the frontier production are estimated by the maximum likelihood method using the method described by Kumbhakar et al. (2015) in “A practitioner’s guide to stochastic frontier analysis” with the STATA software. The results of these estimates make it possible to obtain the variances of the errors: $\sigma^2 = \sigma_v^2 + \sigma_\mu^2$ and $\gamma = \frac{\sigma_\mu^2}{\sigma_v^2 + \sigma_\mu^2}$. The composition of total factor productivity procedure described previously allows estimation of TFP and its sources. The empirical application of this model in the poultry sector has necessitated the existence of panel data on egg-producing poultry farms in Benin.

Method of Determining the Returns to Scale With a Translog Function The RTS are defined as the sum of the elasticities of the factors used in the production of a good. The elasticity of a factor measures the percentage of increase in output that can be expected (all things being equal) of the 1% point increase in that factor. Factor elasticities and RTS are usually measures that depend on the amount of factors and the level of production. As part of a translog production function, as defined in equation 5, the RTS are calculated as follows:

$$\epsilon^p(x) = \sum_{j=1}^n \epsilon_j^p(x_j); \tag{6}$$

with $\epsilon_j^p(x_j) = \frac{x_j}{f((x,t))} \frac{\partial f}{\partial x_j}(x, t)$ which represents the elasticity of the production of the x_j .

Depending on the value of the scale efficiencies, 3 cases can be distinguished:

- a) if, $\epsilon^p(x) = 1$, the RTS are constant (an identical increase in all factors leads to a similar increase in production)
- b) if, $\epsilon^p(x) < 1$, RTS are decreasing (an identical increase in all factors leads to a smaller increase in production);
- c) if, $\epsilon^p(x) > 1$, RTS are increasing (an identical increase in all factors leads to a greater increase in production).

The value of the RTS is an important factor since increasing RTS push the increase of the “size” of the companies (concentration), whereas decreasing returns of scale push rather to the development of small units (atomization). When RTS are constant, there is no incentive to increase or decrease size.

Diagnostic Tests on Data Multicollinearity was tested with variance inflation factor. The results showed the existence of multicollinearity. The correction was made by a combination of 2 highly correlated variables, and ridge and weighted regression was also used to deal the multicollinearity. The Breusch-Pagan test was used to detect the presence of heteroskedasticity. The results of tests showed the presence of heteroskedasticity. Then, we used weighted least squares method to deal with heteroskedasticity. This technique is a more advanced method, which is appropriate to the available data and made it possible to correct the individual coefficients of the variables in the model.

RESULTS AND DISCUSSION

Descriptive Statistics of Production Factors Included in the Econometric Model

The descriptive statistics for the quantitative variables included in the stochastic frontier model are presented in Table 1. The result indicated that the mean egg production in the study area is 19,906 tons egg during the period. The mean number of day-old chicks kept by the producers was 1,089 which the minimum was 40 and the maximum was 12,000. This implies that the average egg production in the south and the center of Benin is the medium scale category given the classification of FAO (2015) and TDH (2016). Their classification showed that small-scale farm contains <1,000 birds, medium scale farms had between 1,000 and <5,000 birds, and large scale-scale poultry farm starts from 5,000 birds. The average feeds and feed supplements used by the farmers to feed the chicks until the end of the laying hen stage were 56,059.4 kg, whereas the average labor use (wage and family labor) was 1,278 man-days for a production

Table 1. Summary statistics of output and input variables (N 470).¹

Variable	Variables name	Mean	Standard error	Minimum	Maximum
Output					
Y1	Total number of eggs produced (in tons)	19.906	29.366	0.243	267.626
Inputs					
X1	Farm size	1,089	1,497	40	12,000
X2	Total feed intake (kg)	56,059.4	77,754.66	1,319.5	556,823.7
X3	Labor (Man-day)	1,277.629	912.5945	256.875	7,088.438
X4	Cost of drug and medication (FCFA ²)	203,571.4	270,656.3	2,500	1,748,600
X5	Other capital (FCFA)	908,608.9	2,095,026	18,710	11,593,700

¹Source: Survey during 2010–2018.

²1 euro=650 FCFA.

cycle. Disaggregated, the mean of the family labor use was 108 man-days, whereas the hired labor use was 1,170 man-days. Thus, poultry egg production use mainly hired labor. Similarly, the costs of veterinary care and veterinary products for hen health were on the average 203,571 FCFA. Farmers use veterinary and para-veterinary agents to provide this care to poultry to reduce the mortality rate and to increase or to maintain the rate of spawning. Better, a poultry egg farm needed about 908,609 FCFA per cycle to depreciate the infrastructure and production equipment.

These descriptive analyses do not allow to assess the contribution of each factor of production to the achievement of the production objectives nor the productive performance of the poultry farms during the study period. Only an econometric estimate of the production frontier was used to assess the productivity status of this sector and to isolate the probable sources of its growth.

Testing of Hypothesis

Some specification tests have been performed, imposing different restrictions on the parameters of translog technology. Likelihood ratio (LR) tests allowed verifying whether the restrictions were valid or not as defined in equation (5). The hypothesis tests carried out concerned (A) the functional form and (B) the presence of inefficiency. The results of these 2 LR tests are shown in Table 2. The first LR test in Table 2 is a test of the functional form of Cobb-Douglas with respect to the functional form of the translog. The result indicated that the translog form is more suitable in this empirical analysis. The second LR showed that there was presence of technical inefficiency effects in egg production in the study.

Table 2. Hypothesis test for model specification.^{1,2}

Null hypothesis (H0)	LogL _{H1} (unrestricted model)	LogL _{H0} (restricted model)	Statistiques LR	Critical value	Decision
(A) H0: Cobb-Douglas model is adequate ($\beta_{kj} = \beta_{ka} = \beta_{\tau\tau} = 0, k, j = 1, 2, 3, 4, 5$)	27,51	-2,43	59,88	32,67	Rejet of H0
B. H0: Lack of inefficiency ($\mu = 0$)	-2,77	27,51	39,16	3,84	Rejet of H0

¹Source: Author's computation.

²LR = 2(LogL_{H1}-LogL_{H0}) with LogL_{H1} = unrestricted model and LogL_{H0} = restricted model. Abbreviation: LR, likelihood ratio.

Analysis of Econometric Estimates

The estimation results of the production frontier parameters with incorporated technical inefficiency effects were presented in Table 3. The likelihood ratio test showed that the model is globally significant at 1% level. The production factors retained in the stochastic frontier model explained significantly at 1% level the poultry egg production in Benin. The coefficients of the variables were mostly significant at 1 and 5% level.

The need for a specification that incorporates technical inefficiency into the analysis of the production frontier is perceived by the random term σ_u^2 . The estimation results showed that this parameter was significantly different from zero at 1% level. This means the presence of technical inefficiencies related to technical errors in poultry farms. In addition, the value of $\gamma = 0.37$ indicates that 37% of the deviations from the production frontier were because of technical inefficiency of the producers. Thus, the specification in terms of stochastic production frontier to represent the technology of poultry egg farms is appropriate.

Elasticity of Production and Returns to Scale

The contribution of each factor of production to the productivity of the poultry farms is appreciated through their elasticity of production. The output elasticities of inputs used were presented in Table 4. The results revealed that feed was the first factor that caused the increase in egg production in poultry farms. An increase in the amount of food (feed and food supplements) of 1% induces an increase of 0.80% in the quantity of eggs produced. Labor was the second factor contributing to the increase in egg production. A 1% increase in the quantity of labor caused a growth of 0.18% in the quantities of

Table 3. Maximum likelihood estimates of translog mean output function (“Half-Normal Stochastic Production Frontier” of [Kumbhakar et al. \[2015\]](#)).¹

Variables	Coefficients	Ecart-type	t test
Dependent Variable e (1Y): Number of egg produced			
Constance	-22.86 ²	7.38	-3.10
IX1 (Farm size)	-5.48 ³	2.41	-2.27
IX2 (feed intake)	5.88 ³	2.54	2.32
IX3 (Labor)	2.60 ³	1.23	2.12
IX4 (Cost of drug and medication)	0.15	1.06	0.15
IX5 (Other capital)	-0.63	0.57	-1.11
t (temps: année)	0.54	0.58	0.95
tt (temps x temps)	-0.02	0.04	-0.52
IX12 (Farm size × Farm size)	-1.23 ²	0.45	-2.74
IX22 (feed intake × feed intake)	-1.39 ³	0.66	-2.12
IX32 (Labor × Labor)	-0.27 ²	0.07	-3.83
IX42 (Cost of drug and medication × Cost of drug and medication)	-0.34 ³	0.17	-1.99
IX52 (Other capital × Other capital)	-0.02	0.03	-0.58
IX1IX2 (Farm size × feed intake)	1.11 ³	0.54	2.06
IX1IX3 (Farm size × Labor)	0.43	0.29	1.48
IX1IX4 (Farm size × Cost of drug and medication)	-0.09	0.22	-0.40
IX1IX5 (Farm size × Other capital)	-0.01	0.13	-0.05
IX2IX3 (feed intake × Labor)	-0.35	0.27	-1.30
IX2IX4 (feed intake × Cost of drug and medication)	0.43 ⁴	0.26	1.68
IX2IX5 (feed intake × Other capital)	-0.02	0.13	-0.18
IX3IX4 (Labor × Cost of drug and medication)	-0.10	0.09	-1.17
IX3IX5 (Labor × Other capital)	0.11 ³	0.04	2.66
IX4IX5 (Cost of drug and medication × Other capital)	0.05	0.05	0.90
tIX1 (Time × Farm size)	0.12	0.13	0.88
tIX2 (Time × feed intake)	-0.07	0.13	-0.53
tIX3 (Time × Labor)	-0.01	0.04	-0.27
tIX4 (Temps × Cost of drug and medication)	0.003	0.05	0.08
tIX5 (Time × Other capital)	-0.04 ³	0.02	-1.96
SIZE (SIZE = 1 if number of day-old chicks is ≤ 1,000; 2 if day-old chicks is > 1,000 and ≤ 5,000 and 3 if > 5,000)	-0.47 ²	0.14	-3.23
Variance of parameters			
σ_u^2	-2.16 ²	0.42	-5.09
σ_v^2	-3.63 ²	0.15	-23.35
$\gamma = \frac{\sigma_\mu^2}{\sigma_\mu^2 + \sigma_v^2}$	0.37		
Likelihood log		10,970.17	
LR test		27.51 ¹	
Number of observations		467	

Abbreviation: LR, likelihood ratio.

¹Source: Author’s computation.

²1% level of significance.

³5% level of significance.

⁴10% level of significance.

eggs produced. The size of the farm (number of day-old chicks) was the third factor affecting the increase in table egg production. A 1% increase in the number of chicks resulted in egg production growth of 0.17%. Similarly, costs and veterinary care influence the increase in production, but their effects are almost nil (0.003). Finally, the fixed costs related to infrastructure and production equipment also lead to a growth in production (0.15%).

On average, the scale efficiency (RTS) characterizing the production technology of commercial poultry egg production was increasing (1.31 > 1). An increase of all factors of production of 1% causes on average a growth of the production of 1.31% (Table 4). Thus, opportunities for economies of scale to be exploited exist in poultry egg farms in Benin.

The state of scale returns in this sector is comparable to that found by some authors in the livestock sector. Indeed, [Kumbhakar et al. \(2009\)](#) found a return to scale around 1.14 for Norwegian dairy farms over the period

1993–2006. [Brümmer et al. \(2002\)](#) found a return to scale around 1.08 and 1.10 for German, Dutch, and Polish dairy farms over the period 1991–1994. [Newman and Matthews \(2006\)](#) found constant RTS on Irish dairy farms, whereas [Karagiannis et al. \(2004\)](#) found an increase in RTS (1.31) for UK farms. In general, the livestock sector offers opportunities for economies of scale that farmers can exploit to increase their productivity.

Total Factor Productivity and Its Components

Total factor productivity growth and its 3 sources identified in poultry egg farms in Benin were presented in Table 5. The results showed that the rate of total factor productivity growth declined of -5 57% on average and per year on poultry egg production in Benin over the period 2010 to 2018. These results are contrary to those found by some authors in the

Table 4. Elasticity of production and returns to scale.¹

Inputs	Mean	Standard error	Minimum	Maximum
Farm size (X1)	0.17	0.25	-1.44	1.15
Alimentation (X2)	0.80	0.25	0.08	1.78
Input labor (X3)	0.18	0.15	-0.35	1.08
Cost of drug and medication(X4)	0.003	0.12	-0.42	0.42
Autre capital (X5)	0.16	0.08	-0.07	0.42
RTS	1.31	0.12	0.98	2.03

¹Source: Author's computation.

Abbreviation: RTS, returns to scale.

livestock sector. Singbo and Larue (2015) estimated total factor productivity growth at 8.8% on Quebec dairy farms over the period 2001–2010. Kumbhakar and Lien (2009) found that the change in TFP was 3% per year between 1993 and 2006 for Norwegian dairy farming. In Finland, Sipiläinen (2007) found that total factor productivity increased on average by 0.15% per year on dairy farms. Newman and Matthews (2006) estimated productivity change at 1.2% per year, whereas Karagiannis et al. (2004) estimated it at 0.97% for UK ranches.

The decline in productivity growth observed on poultry farms was because of 3 main sources (Table 5). Technical progress contributed negatively to total factor productivity growth (on average -2.67% per year). The results are consistent with those obtained in the studies by Ludena et al. (2005) on the productivity growth of non-ruminants (pigs and poultry) in Burkina Faso but are contrary to the results of Kumbhakar et al. (2009) in the Norwegian dairy farming sector; Sipiläinen (2007) on Finnish dairy farms for the period 1989–2000, and Newman and Matthews (2006) on Irish dairy farms for the period 1984–2000. The negative contribution of technical progress on poultry egg production in Benin is explained by inaccessibility of poultry producers to new technologies as inputs and production materials (l'aviculteur, 2017). In Benin, commercial production systems use hybrid birds specially bred either for meat or for egg production. The introduction of improved, exotic, and genetic material is an important first step in the growth and development of the commercial poultry sector. However, the greater productive potential cannot be attained without complementary inputs of specially compounded concentrate feeds and improved housing, management, and veterinary care (Chatterjee, 2015). But, in Benin, there are few new technologies developed in this direction, and the few existing ones are little known to producers (l'aviculteur, 2017).

The change in technical efficiency also had negative effects on the loss of TFP during the period 2010–2018 (at a rate of -2.16% per annum). The negative contribution

of the technical efficiency change for the period is because of the low professionalism of poultry producers in this economic sector and result in inadequate capacity-building programs to equip poultry farmers with proven techniques for efficient and rewarding poultry production culminating from optimal utilization of resources (Etuah, 2014). Poultry farms are managed by different socioprofessional groups who have generally not received any specific training on production systems and the management of a poultry farm. The majority of them have received no support from the government. They are generally trained on the economic activity with the support of some NGOs incidentally. There is also lack of policy initiative to focus attention on developing poultry industry. Since 2005, there has been a single program specific to commercial poultry farming, which actions have been more oriented toward access to credit (FAO, 2015). These reasons justify the negative effect of technical efficiency on the contribution of productivity growth on poultry farms in Benin. This result corroborates that found by Ludena et al. (2005) who found a negative contribution of technical efficiency change on productivity growth in non-ruminants (pigs and poultry) sector for many Africa countries. Combarry and Savadogo (2014) showed also a decrease in the rate of growth of technical efficiency (0.38%) in the cotton farms of Burkina Faso. However, this result is contrary to those of Coelli and Rao (2003); Thirtle et al. (1995) who found that technical efficiency contributes positively to total factor productivity on farms in developing countries.

The RTS also have a negative effect on TFP growth (-0.74). This result showed that poultry farms are unable to exploit existing economies of scale in the commercial poultry sector in Benin. The negative contribution of scale component on the productivity growth of poultry farms in Benin is explained by the strong dominance of small poultry farms in the sector (FAO, 2015; TDH, 2016), which are at a disadvantage in facing high feed and transport costs, limited access to vaccines and veterinary services, and shortage of credit (Chatterjee,

Table 5. Total factor productivity growth and its sources (%).¹

Variable	Mean	Standard error	Minimum	Maximum
Scale component effect	-0.74	18.41	-119	43.55
Technological change	-2.67	4.05	-27.26	8.76
Technical efficiency change	-2.16	0.10	-2.31	-2.08
Total factor productivity	-5.57	18.69	-113.6	34.01

¹Source: Author's computation.

2015). However, the scale and intensity of production are significantly higher in large poultry farms offering economies of scale, possibilities for specialization, and division of labor between the different stages of the production process, leading to the automation of operations and labor savings (Chatterjee, 2015). The results for negative contribution of scale component on total factor productivity growth are somewhat similar to the findings of Combarry and Savadogo (2014), where the scale component had a negative effect on TFP growth of the cotton farms in Burkina Faso. The finding is however different from Kumbhakar et al. (2009), Brümmer et al. (2002), and Sipiläinen (2007), where scale component contribute positively to TFP growth in animal sector.

CONCLUSION AND POLITICAL IMPLICATIONS

This article focuses on the total factor productivity growth analysis, technological change, technical efficiency change, and the role of scale efficiencies in poultry egg farms in Benin. The study uses a SFA with unbalanced panel data. A specification of translog production function is more adapted to the data and allows decomposing the TFP over the period from 2010 to 2018. The econometric estimations results show that the RTS of the production technology in the poultry egg farms are increasing (1.31) over the study period. This implies that on average, farms have not fully exploit economies of scale. In addition, the TFP see a decrease of 5.57%. This decrease in productivity is because of a loss of technical efficiency change (2.16%), technological change (2.67%), and the effects of RTS (0.74%) over the 2010 to 2018 period. Although there are economies of scale in this sector, they are not exploited for productivity improvement.

The results obtained provide very important information to guide efforts to improve the productivity of poultry farms to contribute to food security and poverty reduction. Thus, the following recommendations were made based on the results obtained. Because technical progress has a negative effect on TFP growth, it is necessary to generate and to transfer to producers stronger technologies on production inputs (day-old chicks, feeds, vaccines, etc.), and to invest in livestock research and development, especially in commercial poultry production by the National Institute of Agricultural Research, Universities. Also, because of the negative contribution of technical efficiency, the government and development partners, extension and veterinary services, and NGOs should develop policies to improve technical efficiency by advisory support, access to production factors, and better use of inputs. To allow poultry farms to exploit the existing economies of scale in the sector, the government should establish policies to encourage the increase in the size of poultry farms through access to production inputs (day-old chicks, feeds, vaccines, etc.) and access to adapted credits. Finally, Benin government should

implement economy-wide and policies that promote productivity growth in commercial poultry. These policies should be included within a livestock development framework that helps increase efficiency, generation and transfer technology, implement best livestock practices, and provide access to credit, market opportunities, and inputs. These policies must be accompanied by the implementation of strategies to limit imports of eggs and meat, to encourage local production of day-old chicks, and to improve the living conditions of professional poultry farmers.

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REFERENCES

- Aigner, D. J., C. A. K. Lovell, and P. Schmidt. 1977. Formulation and estimation of stochastic frontier production function models. *J. Econom.* 6:21–37.
- Batonon, D. I., F. Houndonougbo, C. A. A. M. Chrysostome, G. Duteurtre, D. Bastianelli, and P. Lescoat. 2013. La filière œuf au Sud-Bénin: organisation, contraintes et perspectives. *Dixième Journées de la Recherche Avicole et Palmipèdes à Foie Gras*, La Rochelle, France.
- Battese, G. E., and T. J. Coelli. 1992. Frontier production functions, technical efficiency and panel data: with application to Paddy farmers in India. *J. Productivity Anal.* 3.
- Brummer, B., T. Glauben, and G. Thijssen. 2002. Decomposition of productivity growth using distance functions: the case of dairy farms in three European countries. *Am. J. Agric. Econ.* 84:628–644.
- Chatterjee, R. N., and U. Rajkumar. 2015. An overview of poultry production in India. *Indian J. Anim. Health* 54:89–108.
- Chrysostome, C., and E. Sodjinou. 2005. Diagnostic de la filière des volailles et étude d'impacts de la phase 1 du Programme d'Appui au Développement de l'Aviculture Villageoise dans les Départements du Mono et de la Donga (Bénin). + annexes, Cotonou, Bénin, p. 123.
- Cochran, W. G. 1963. *Sampling Techniques*, 2nd ed. John Wiley and Sons, Inc, New York, NY.
- Coelli, T. 1998. A Guide to DEAP Version 2.1: A Data Envelopment Analysis (Computer) Program. Centre for Efficiency and Productivity Analysis, Department of Econometrics, University of New England, Armidale, NSW 2351, Australia. Copeland (1937).
- Coelli, T. J., and D. S. P. Rao. 2003. "Total Factor Productivity Growth in Agriculture: A Malmquist Index Analysis of 93 Countries, 1980-2000", CEPA Working Paper Series No. 02/2003. School of Economics, University of Queensland, Australia.
- Combarry, O. S., and K. Savadogo. 2014. Les sources de croissance de la productivité globale des facteurs dans les exploitations cotonnières du Burkina Faso. *Revue d'économie du développement* 22:61–82.
- Diewert, W. E. 1992. The measurement of productivity. *Bull. Econ. Res.* 44:163–198.
- Djimasa, N. 2011. Décomposition de l'indice de productivité de Malmquist: une application sur un échantillon des pays africains producteurs de coton, LEO Working Papers/DR LEO 413.

- Orleans Economics Laboratory/Laboratoire d'Economie d'Orleans (LEO), University of Orleans.
- Douillet, M., and P. Girard. 2013. Productivité agricole: des motifs d'inquiétude? (I) Les concepts. Accessed Sept. 2019. <http://www.fondation-farm.org/spip.php?article873>.
- Etuah, S. 2014. Cost efficiency and economies of scale in broiler production in Ghana. A case study of the Ashanti Region. Thesis Diss. Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.
- Fanou, U. 2006. Revue du secteur avicole du Bénin. Division de la Production et de la Santé Animales de la FAO. Centre d'Urgence pour les Maladies Animales Transfrontalières Unité de Socio-économie, production et Biodiversité. FAO, Rome, Italy, p. 36.
- FAO. 2015. Secteur Avicole Bénin. Revues nationales de l'élevage de la division de la production et de la santé animales de la FAO. No. 10. FAO, Rome, Italy, p. 74.
- FAOSTAT. 2019. Livestock Primary. Accessed Mar. 2019. <http://www.fao.org/faostat/fr/#data/QL>.
- Färe, R., and D. Primont. 1995. Multi-Output Production and Duality: Theory and Applications. Kluwer Academic Publishers, Boston, MA.
- Fisher, I. 1922. The Making of Index Numbers. Houghton Mifflin, Boston, MA.
- Fleming, E., R., T. Villano, Farrell, and P. Fleming. 2005. Efficiency and Productivity Analysis. Report on the Australian Sheep CRC Benchmarking Sub-Project, Armidale, Australia.
- Griliches, Z. 1997. Education, human capital, and growth: a personal perspective. *J. Labor Econ.* 15:S330-S344.
- Houndonougbo, M. F. 2005. Micro credit impact on family poultry system: a case study of two regions in Benin. Master of Science thesis. RVAU- FSA/UAC, Copenhagen, Denmark, p. 70.
- Karagiannis, G., P. Midmore, and V. Tzouvelekas. 2004. Parametric decomposition of output growth using a stochastic input distance function. *Am. J. Agric. Econ.* 86:1044-1057.
- Kumbhakar, S. 2000. Estimation and decomposition of productivity change when production is not efficient: a panel data approach. *Econometric Rev.* 19:312-320.
- Kumbhakar, S. C. 2006. Productivity and efficiency measurement using parametric econometric methods. Pages 21-61 in Transparency, governance, and markets. M. Bagella, L. Becchetti and I. Hasan, eds. Elsevier, Oxford, UK.
- Kumbhakar, S. C., E. G. Tsionas, and T. Sipilainen. 2009. Joint estimation of technology choice and technical efficiency: an application to organic and conventional dairy farming'. *J. Productivity Anal.* 31:151-161.
- Kumbhakar, S. C., H. J. Wang, and A. Horncastle. 2015. A Practitioners Guide to Stochastic Frontier Analysis Using Stata. Cambridge University Press, Cambridge, UK.
- L'aviculteur. 2017. Bulletin d'Information de l'UNAP-Bénin N°084 de juillet 2017, vers la mise en place d'un centre de services d'intérêts communs aux acteurs. UNAP-BENIN, Cotonou, Benin.
- Ludena, C. E. 2010. Agricultural Productivity Growth, Efficiency Change and Technical Progress in Latin American and the Caribbean. IDB Working Papers No.61. Accessed Aug. 2019. <http://www.iadb.org/res/publications/pubfiles/pubIDB-WP-186.pdf>.
- Ministère de l'Agriculture, de l'Élevage et de la Pêche (MAEP) 2017. Plan Stratégique de Développement du Secteur Agricole (PSDSA) 2025 et Plan National d'Investissements Agricoles et de Sécurité Alimentaire et Nutritionnelle (PNIASAN, 2017 - 2021) au Bénin, 2017, 139, document stratégique. MAEP, Cotonou, Benin.
- Marion, D. 2009. Formulation et estimation des modèles de mesure de la productivité totale des facteurs: une étude sur un panel d'entreprises turques. *Revue D'économie Politique* 2009/6 119:945-982.
- Marschak, J., and W. H. Andrews. 1944. Random simultaneous equations and the theory of production. *Econometrica* 12:143-205.
- Meeusen, W., and J. Van Den Broeck. 1977. Efficiency estimation from Cobb-Douglas production functions with composed error. *Int. Econ. Rev.* 18:435-444.
- Melaku, T. A. 2013. Total factor productivity and technical efficiency in the Ethiopian Manufacturing sector. In EDRI Working Paper 010. Addis Ababa. Ethiopian Development Research Institute.
- Newman, C., and A. Matthews. 2006. The productivity performance of Irish dairy farms: a multiple output distance function approach. *J. Productivity Anal.* 26:191205.
- Nin-Pratt, A. M. Johnson, and B. Yu. 2012. Improved Performance of Agriculture in Africa South of the Sahara: Taking off or Bouncing Back. IFPRI Discussion Paper No.01224. International Food Policy Research Institute, Washington, DC.
- Nkamleu, G. B. 2004. L'échec de la croissance de la productivité agricole en Afrique Francophone. *Economie Rurale* 279:55-67. Janvier-Février.
- Onibon, P., and H. Sodegla. 2005. Etude de la sous-filière « aviculture moderne » au Bénin, p. 141. Rapport final.
- Pitt, M. M., and L. Lee. 1981. The measurement and sources of technical efficiency in the Indonesian weaving industry. *J. Development Econ.* 9:43-64.
- Schmidt, P., and R. C. Sickles. 1984. Production frontiers and panel data. *J. Business Econ. Stat.* 2:367-374.
- Siéwé Pougoué, E. B., I. Manu, I. Labiyi Adédédji, and T. Bokossa. 2019. Technical efficacy of laying hen farms in Southern Benin. *Rev. Elev. Med. Vet. Pays Trop.* 72:23-32.
- Singbo, A., and Larue. 2015. Scale economies, technical efficiency and the sources of total factor productivity growth of Quebec dairy farms. *Can. J. Agric. Econ.* 25.
- Sipiläinen, T. 2007. Sources of productivity growth on Finnish dairy farms - application of an input distance function. *Food Econ. - Acta Agriculturae Scandinavica, Section C* 4:65-76.
- Sodjinou, E. 2011. Poultry-based Intervention as Tool for Poverty Reduction and Gender Empowerment: Empirical Evidence from Benin. Institute of Food and Resource Economics, University of Copenhagen.
- TDH Expertise. 2010. Pratiques de biosécurité dans la filière avicole commerciale au Bénin Enquête de référence. Rapport final. MAEP, Cotonou, Benin, p. 98.
- TDH Expertise. 2016. Etude de la filière avicole au Bénin: géoréférencement et recensement exhaustifs des cheptels moderne et traditionnel. Rapport final. MAEP, Cotonou, Benin, p. 116.
- Thirtle, C., D. Hadley, and R. F. Townsend. 1995. Policy-induced Innovation in Sub-Saharan African agriculture: a Multilateral Malmquist productivity index approach. *Development Policy Rev.* 13:323-342.
- Törnqvist, L. 1936. The Bank of Finland's consumption price index. *Bank Finland Monthly Bull.* 10:1-8.
- United States Department of Agriculture (USDA). 2014. Foreign Agricultural Service: Benin: Agricultural Situation, *GAIN Report*. USDA, Washington, DC.