What is driving livestock total factor productivity change? A persistent and transient efficiency analysis

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Abstract

Production and consumption of livestock products have increased substantially over the past decades, and a continuing growth is expected. These market trends could bring opportunities for economic and social development, however at the same time it can pose unintended food security, public health and environmental risks. Rising livestock productivity will be fundamental if the sector is to deliver on expectations. Increasing productivity through factor substitution is a feasible goal, however rising land, capital, and labour productivity simultaneously will be a major challenge. A better understanding of the level and drivers of livestock total factor productivity (TFP) has become a major topic in the sustainable development policy debate. Using a stochastic distance function approach, this paper aims to shed light on this issue by estimating TFP indicators of livestock production systems, and assessing the associated levels of persistent and transient efficiency. The results show that the level of livestock TFP continues to growth in most regions, however developing countries are not catching up in terms of efficiency change with developed countries.

1. Introduction

Over the past decades, production and consumption of livestock products increased substantially, with the sector becoming one of the fastest-growing in agriculture (FAO, 2017; World Bank, 2016). Continuing growth of the sector is expected, with demand for livestock products fueled by the one-billion increase in world population projected by 2030 and by a further decline in poverty, giving consumers greater access to animal proteins (OECD, 2016). Indeed by 2030 global milk and global meat production are expected to be 33% and 19% above the 2015-2017 base period, respectively (FAO, 2018). These market trends could bring opportunities for economic and social development. Animal food sources contribute to the global human diet with 33% of protein intake and 17% of calorie intake (Rosegrant et al., 2009). Livestock makes a major contribution to the global economy generating nearly 40% of total agricultural output in developed countries and 20% in developing countries (FAO, 2018). Furthermore, the sector employs at least 1.3 billion people worldwide and provides livelihoods for 600 million poor smallholder farmers in developing countries (Thornton et al., 2006).

However, at the same time the expansion of the sector can pose unintended food security, environmental, and public health risks. As the sector grows, competition over land to produce feed as opposed to food will increase (FAO, 2018). Currently, 33% of available arable land, is used to grow animal feed(Rae & Nayga, 2010). More than 70% of the infectious diseases can be traced back to animals (Jones et al., 2008), and rising livestock numbers will increase the probability of emerging zoonoses diseases (FAO, 2018). Agriculture uses approximately 70% of the available freshwater supply, and roughly 30% of global agricultural water goes on livestock production (Ran, Lannerstad, Herrero, Van Middelaar, & De Boer, 2016) Emissions from livestock supply chains account for about 14.5% of total anthropogenic emissions and although emission intensity is declining, a rise in production would lead to larger overall greenhouse gas levels (FAO, 2018).

As shown, the expansion of the sector could help to achieve some of the Agenda 2030 for Sustainable Development policy objectives, but at the same time create conflicts to accomplish others. Increasing livestock productivity will be fundamental to enhance the positive externalities while mitigate the negative outcomes (Pretty et al., 2001; Sterner, 2003). Rising partial productivity through factor substitution is a reasonable goal. Nevertheless, increasing total factor productivity (TFP), meaning expanding simultaneously the productivity of land, capital, labour, will be a major challenge (FAO, 2018). Global TFP has seldom been disentangled for the livestock sector. In cases where productivity was disaggregated, it was estimated by using partial factor productivity (PFP) indicators, such as land productivity, labour productivity or capital productivity. A straightforward estimation makes the use of PFP an appealing measurement of agricultural performance (Key, Mcbride, & Mosheim, 2008). However, they do not represent an accurate estimation of the performance of a sector (Ludena, Hertel, Preckel, Foster, & Nin, 2008) tending to overestimate or underestimate productivity growth (Nin, Arndt, Hertel, & Preckel, 2003).

A measurement of TFP introduced by Nin et al. (2003) allows for the estimation of sector-specific productivities by modifying a directional measure that does not require allocating all inputs across subsectors. Ludena et al. (2007) building on Nin et al.'s work estimated TFP growth indicators for crops, ruminants, and non-ruminant livestock. O'Donnell (2010) argued that Malmquist is not multiplicatively complete and is therefore not a reliable measure of TFP. An additional disaggregation method was introduced by Arnade and Jones (2011), unlike Nin et al.'s work, this estimation does not require input allocation, even in cases of joint production. Both approaches rely on output-oriented efficiency measures, but the Arnade and Jones's (2011) method is a multiple output-oriented measure, rather than a single one. Although this level of disaggregation allows the estimation of TFP for the two subsectors, it does not make it possible to analyze the productivity of each commodity individually.

By assembling a unique dataset composed of information from FAOSTAT, the International Labor Organization (ILO), the International Fertilizer Association (IFA), and complemented with data from Fuglie's (2015) database, this paper estimates country, regional and global level TFP indicators for ruminants, monogastrics, and crops, assessing the level of efficiency change per production system. The TFP estimation is derived from a stochastic directional output distance function (DODF) based on the O'Donnell (2008) index. Following Kumbhakar, Lien, and Hardaker's (2014) we split the error term into four components to incorporate different factors affecting the output-input relationship, such as country heterogeneity, persistent (time-invariant) technical efficiency, transient (time-varying) technical efficiency, and a random error.

The results show a high heterogeneity in TFP levels not only between production systems, but also among regions. In comparison to crops TFP productivity growth, ruminants and monogastrics are performing less well. Despite the positive levels of TFP for livestock production systems in many regions, the analysis shows that most developing economies are not catching up with developed economies in terms of efficiency change. Nevertheless, the wide differences in the level of persistence efficiency between developed and developing regions highlights a substantial opportunity for improvement in the transformation of inputs into outputs. However, in most developing regions average transient-efficiency was found to be above persistent-efficiency, suggesting that although short-term improvements have been made, adjustments may have not been enough to rise long-term efficiency.

This paper extends the existing literature in several directions. First, it provides the first global evidence on livestock production systems TFP levels using a stochastic distance function approach. Secondly, we study how this relationship varies between production systems and regions. Thirdly, differently from previous livestock TFP studies, we decomposed the error term into persistent and transient efficiency. To the best of our knowledge this is the first attempt in the literature to estimate global TFP indexes for livestock production systems using this approach. This is a particular relevant effort in the context of the Agenda 2030 for Sustainable Development, where indicators are the backbone of measuring progress, and countries will need to report changes in agricultural productivity (UN, 2016).

2. Analytical framework

The primary purpose of this article is to estimate country-level TFP indicators for crops, ruminants, and monogastrics at the global level (143 countries). In doing so, we follow Nin et al. (2003) and Ludena et al. (2007). Shephard, (1970) lays out the groundwork for the analysis of multi-output and multi-input technologies. Shephard's distance function approach is defined as the maximum radial expansion of the output vector y given input x, i.e., all the output of the production process is expanded by the same factor. This radial expansion can be a limitation for production processes that produce good and bad outputs, in which the interest lies in the expansion of the good output. This restriction leads to the work of Chambers, Chung and Färe (1996) and Chung, Färe and Grosskopf (1997) on developing the directional distance function which allows the expansion of the desirable output and the contraction of the undesirable. In this setting, inefficiency is defined as the distance between a specific observation and the efficient technology frontier. The directional output distance function (DODF) allows the expansion of an output vector while holding inputs fixed. Nin et al. (2003) built upon this work to measure subsector productivity. The modified framework seeks to expand the production of one specific output of the production process without either expanding other outputs or contracting inputs. The DODF is modeled as follow:

$$\vec{D}_0\left(\boldsymbol{x}, y_k, \boldsymbol{y}_j; \boldsymbol{g}\right) = sup\left\{\beta : \left[(y_k, \boldsymbol{y}_j) + \beta_g\right] \in P(x)\right\} \quad (1)$$

Where, y_k refers to a specific output that has been analyzed and y_j represents the other outputs, except k. $g = (g_y, -g_b)$ is the directional vector by which outputs are scaled, and the production technology is represented by the output set $P(x)$. The distance function is defined by simultaneously expanding output and contracting inputs. However, as mentioned before here $g_b = 0$, in order to obtain an output-oriented directional distance function, thus this can be interpreted as a special case of the directional distance function (Zelenyuk, 2014). This $\vec{D}_0\left(x, y_k, y_j; g\right)$ is a complete characterization of the P. The measurement of output expansion in the direction of output y_k is defined by setting g = $(y_k, 0)$, which implies that the objective is to maximize output $y_k. A$. Additionally, this framework makes use of the information regarding the utilization of specific inputs by sectors in order to allocate and constrain those by outputs. This is also a major reason for using a directional distance function. The estimation is expressed as:

$$\vec{D}_0\left(x, y_k, y_j; g = (y_k, 0)\right) = \beta_0 + \beta_1 labor_{it} + \beta_2 tractors_{it} + \beta_3 fertilizer_{it} + \beta_4 A_{it} + \beta_5 y_j + \varepsilon_{it} \quad (2)$$

Where k represents the vector of outputs for which efficiency is measured while j refers to the other outputs, A is the vector of allocable inputs, h is used to produce output k in country i, and β are the parameters to be estimated. Labor, tractors, and fertilizer are typical inputs used in crop and livestock production, which are not allocated.

Ludena et al. (2007) used a deterministic approach to estimate TFP indices; however, in this paper we estimate a stochastic DODF because we believe that the data noise for crop and livestock production is substantial. It is also important to separate random shocks from failures in the managerial process. Moreover, several authors have argued about the limitation and possible measurement error of FAO data (Fuglie, 2010, 2015; Nin et al., 2003; Trindade & Fulginiti, 2015). Thus, disentangling noise from technical inefficiency could produce a more accurate measurement of the performance of crop and livestock production for a country. Therefore, we follow Bogetoft and Otto (2011) and Kumbhakar and Lovell (2000) to estimate a parametric stochastic frontier. Therefore, $\vec{D}_0(x, y_k, y_j; g = (y_k, 0))$ is assumed to be 0 and the error term is addedε_i. We used Kumbhakar et al. (2014) and Colombi, Kumbhakar, Martini, and Vittadini (2014) models that split the error term into four components, namely: country heterogeneity that is disentangled from the inefficiency component (Greene, 2005a, 2005b), short-run (time-varying) inefficiency, persistent (time-invariant) technical inefficiency and random shocks; thus $\varepsilon_i = \mu_i + v_{it} - \eta_i - u_{it}$. To satisfy the translation property, Equation 1 can be expressed as:

$$\vec{D}_0(x, y_k, y_j; g) - \beta = \vec{D}_0(x, y_k + \beta g_y, y_j; g) \tag{3}$$

This estimation takes the following form:

$$-\beta_i = \vec{D}_0(\boldsymbol{x}, y_i, \boldsymbol{y}_j; 1{,}0) + \mu_i + v_{it} - \eta_i - u_{it} \tag{4}$$

Where, μ_i and v_{it} are country effect and noise terms, μ_i captures random country effects, accounting for cross-country heterogeneity, ensuring that the production system diversity and also policies are considered in the estimations. v_{it} is the typical noise component. $\eta_i > \mathbf{0}$ and $u_{it} > \mathbf{0}$ are persistent technical inefficiency and time-varying inefficiency components. Kumbhakar et al (2014) argued that this model accounts for factors that have permanent or time-invariant effects on a country's inefficiency. The time-varying component assumes a period-based efficiency that does not depend on the previous period, i.e., the countries' farmers learn over time, which allows for the improvement of their managerial skills, thus decreasing inefficiency in the production process (Lien, Kumbhakar, & Alem, 2018). In crop and livestock production permanent/time-invariant inefficiency is the product of inputs or policies that preclude farmers from being fully efficient, for instance, agricultural soil characteristics, existing animal breeds, or regulatory regime.

The production technology is specified by a Cobb–Douglas (CD) production frontier, because it satisfies non-negativity and monotonicity globally and allows for an econometric decomposition (O'Donnell, 2016; 2014). The CD is closed in both inputs and outputs are strongly disposable (Färe & Primont 1995). A similar specification was applied by Mathijs and Swinnen (2001) and Latruffe et al. (2004), and Lachaud, Bravo-Ureta, and Ludena (2017). The use of the CD comes with the cost of imposing assumptions, such as Hicks-neutral technical changes and constant production elasticity (Coelli & Rao, 2005).

To estimate country TFP change, we start with a basic definition that the TFP of a decision-making unit (DMU) is the ratio of an aggregate output over an aggregate input (O'Donnell, 2008), the formal expression of the TFP for country i in period t is defined as follows:

$$TFP_{it} = \frac{Q_{it}}{X_{it}} \tag{4}$$

where $Q_{it} \equiv Q(y_{it})$ is an aggregate output term, $X_{it} \equiv X(x_{it})$ is an aggregate input term, and $Q(.)$ and $X(.)$ are non-negative, non-decreasing, and linearly homogeneous (O'Donnell, 2012).

The measurement of the changes TFP in a DMU i in period t compared to the performance of DMU h in period s is defined by the follow index:

$$TFPI_{hsit} = \frac{TFP_{it}}{TFP_{hs}} = \frac{QI_{hsit}}{XI_{hsit}} \tag{5}$$

where $QI_{hsit} = Q_{it}/Q_{hs}$ and $XI_{hsit} = X_{it}/X_{hs}$ are output and input quantity indices. A multiplicative complex TFP index can be decomposed in a measure of technical changes and efficiency change[1], and is formally expressed as follow:

$$TFP_{hs,it} = \frac{TFP_{it}}{TFP_{hs}} = \left(\frac{TFP_t^*}{TFP_s^*}\right)\left(\frac{TFPE_{st}}{TFPE_{hs}}\right),$$

$$TFPE_{it} = \frac{TFP_{it}}{TFP_t} \tag{6}$$

In the previous equation the ratio TFP_t^*/TFP_s^* measures the change in the maximum TFP possibly using the available technology periods s and t, which represent a measure of technical changes, and TFP_t^* is the maximum attainable TFP at time t (O'Donnell, 2012). The overall productive efficiency of DMU is defined as the ratio of $TFPE_{st}/TFPE_{hs.}$

As specified in Kumbhakar et al. (2014) the estimation of equation 3 involves four steps, in the first step a random panel data model is used to and estimate $\hat{\beta}$, θ_i and ε_{it}. In the second step, we estimate the value of u_{it} based the predict value of ε_{it} from step 1.

$$\varepsilon_{it} = v_{it} + E(u_{it}) \tag{7}$$

In equation 7, v_{it} is assumed to iid $N(0, \sigma_v^2)$ and u_{it} is iid $N^+(0, \sigma^2)$ which allows the estimation of SF by using a standard procedure, what following Jondrow, Knox Lovell, Materov and Schmidt's (1982) turn in the prediction of the time-varying residual technical inefficiency components $\hat{u}_{it}$, which can be used to estimate the residual technical efficiency, $RTE = exp(-\hat{u}_{it})$.

In the third step, a similar procedure as step 2, is followed to estimate η_i. This step relies on the best linear predictor of θ_i of step 1. By using similar normality assumption for μ_i and η_i equation 8 is estimated:

$$\theta_i = \mu_i + \eta_i + E(\eta_i) \tag{8}$$

In this equation the standard normal-half normal SF model for cross-sectional is used to estimate the persistent technical inefficiency component η_i (based on Jondrow et al. (1982) estimator). Thus, the persistent technical efficiency measure (PTE) is obtained from $PTE = exp(-\hat{\eta}_i)$. In the

[1] Although a multiplicate complex index can be decomposed in in several indexes (Bravo-ureta & Donnell, 2018; Njuki et al., 2018; O'Donnell, 2010, 2016), we exclusively focus on technical changes and efficiency change.

final step, the overall technical efficiency is the product of time-invariant component and residual component, i.e., $OTE = PTE * RTE$

3. Data

Global TFP studies rely on data from FAO and are sometimes supplemented with country-level data or other databases. The FAO's data is constructed through different systems of data collection which can vary across countries. This could potentially introduce errors in the data aggregation process, and subsequently influence the measurement of crop and livestock TFP changes. Furthermore, available data is often the result of aggregated input information; for instance, labor information represents the labor used at country-level, thus it is not possible to identify how much labor is used in each subsector. Additionally, in some cases, the data is the product of joint production, i.e., a production unit could produce crops and livestock without keeping a separate accounting system. Ideally, it would be valuable to have input data related to each output, but this kind of data does not exist on a global level. Therefore, this TFP analysis is based on a global panel dataset of livestock and crops related outputs and inputs built using FAOSTAT (FAO, 2019)2019. The dataset includes country-level information for 143 countries (see annex 1) over a 23-year period from 1992 to 2014. Our analysis considers aggregated outputs and specific and non-specific allocable inputs.

The estimations considered three aggregate outputs: crops, ruminants, and monogastrics. Gross production values at constant international US dollars (2004–2006) make up the output data for crops, ruminants, and monogastric. This approach makes it possible to measure changes in output over time and not just an increase in output as result of a price change effect. The estimation of the gross production values is based on "international commodity prices." These prices were derived using a Geary-Khamis formula for the agricultural sector. This method assigns a unique weighted average price for each commodity across countries.

Inputs were allocated in the following order: ruminant's stocks to ruminants, and monogastrics stocks to monogastrics. Land in crops' cultivation to crops, and land in pastures to ruminants. Labor, fertilizer, and machinery were treated as non-allocated inputs. Feed was also treated as a non-allocated input. The quantity of animal stock is based on live animal information from FAO. In order to avoid zeros among livestock species, ruminants were converted to a standardized cattle unit and monogastrics to a standardized pig unit using FAO guidelines for the preparation of livestock reviews (FAO, 2011). Ruminants included the following species: buffalo, camel, cattle, goat, and sheep. Monogastrics encompasses: chicken, duck, pig, geese, turkey, and rabbit.

Land corresponds to the agricultural area in thousands of hectares as classified by FAO. Unlike Fuglie (2010; 2015), we do not account for soil quality since we intend to capture soil quality effects through the persistent inefficiency component. However, this represents a limitation in our study; adjusting for quality could also generate TFP that accounts for changes in the quality of the input used in the production process (Craig, Pardey, & Roseboom, 1997). Cropland is arable land either planted with permanent and arable land, and pasture is equal to the area under permanent pasture; both are measured in thousands of hectares. A limitation with the use of the data on pastureland is that we assume that the area reported by FAO is being fully used, which is not always the case. More accurate observations could be obtained from spatial information analysis that estimate land under-used for animal production. However, these datasets are based on a specific time period year, not allowing for time series dynamic analysis.

Labor units are defined as the number of economically active adults in agriculture, and the data was obtained from the International Labor Organization. Fertilizer represents the quantity of metric tons of N, P2O5, K2O used every year, and the data was obtained from the International Fertilizer Association and complemented the data from Fuglie (2015). Machinery is an aggregation of total metric horse-power, 4-wheel tractors, harvester-threshers, and milking machines, based on Fuglie's (2015) database.

Feed constitutes a major input both for ruminants and monogastrics; however, the data available does not allow to desegregate its allocation. One alternative is to use FAO (2017) livestock biophysical model, to assess the share of feed used per system. In this model the calculation quantity of feed used is related to the specific diet needs of different species. However feed used is the result of a constrained-optimization production function based on the input own price, other inputs' price, capital availability, and output prices, rather than a biological optimization function alone. Based on this rational we preferred to treat feed as a non-allocable input associated to the livestock component of the model.

4. Results and discussion

The aim of this study is to estimate TFP indicators for ruminants, monogastrics, and crops, assessing the level of efficiency change per production system. Three independent models are estimated – a model for ruminants, monogastrics, and crops. We estimate three separate distance functions while the value of the directional vector is the same across models. In the first model, the vector is extended to the direction of crops, while holding ruminants and monogastrics fixed. Then, the directional vector is expanded towards the other two outputs. At first, we test for the correlation of the error terms across the equations. In so doing we estimate a seemingly unrelated regression.

To test for zero contemporaneous covariance between the errors of the different equations we used the Brausch and Pagan test (Cameron & Trivedi, 2005), which shows a chi-square test statistic of 6.32 and a p-value larger than 0.10; the null hypothesis of independence cannot be rejected. Therefore, estimating independent equations produce more efficient results than the estimation of a seemingly unrelated regression. As Greene (2007) indicates, in a case where a section of the regressors in one equation are a subset of those in another there is no efficiency to be gained.

To estimate TFP growth per region we used weighted output values from each of the countries listed per region, as done by Trindade and Fulginiti (2015). Since we estimate TFP for three outputs, the weight values vary accordingly. The TFP estimation is affected by the short-run fluctuations in outputs or inputs derived from weather, political or economic shocks. In order to smooth these effects we use a Prescott filter (Hodrick & Prescott, 1997), setting the smoothing parameter λ to 6.25 (Ravn & Uhlig, 2002). A similar procedure in the estimation of TFP analysis has been applied by Fuglie (2008) and Baráth and Fertő (2017).

4.1 Total Factor Productivity Growth

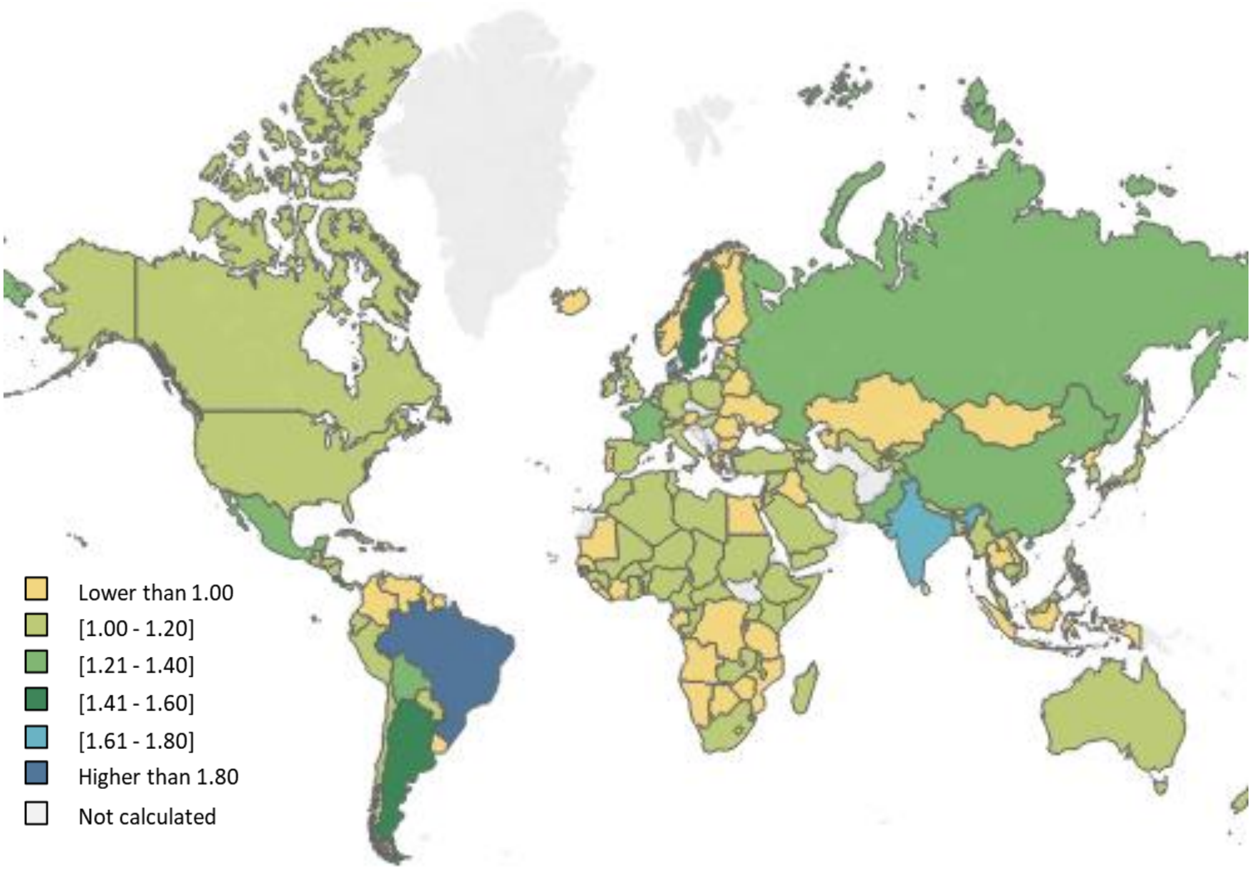
This study assesses livestock production systems TFP levels per country over the period 1992-2014. These indexes compare the production variables in a particular year with the variable of Albania in 1992, as done by Njuki, Bravo-ureta and O'Donnell, (2018). The detail results of TFP indexes per production system and country are presented in annex 1. We employed the TFP level of crops as benchmark to compare the performance of ruminants and monogastrics livestock production systems. Although TFP indexes are estimated for each of the 143 countries, results are presented by region (table 1).

Table 1. TFP growth per production system by region (1992-2014)

Region	Ruminants			Monogastrics			Crops		
	TFP	TC	EC	TFP	TC	EC	TFP	TC	EC
Industrialized economies	1.072	1.031	1.021	1.041	1.068	1.033	1.213	1.236	1.041
Economies in transition	1.043	1.031	0.948	1.047	1.068	1.027	1.029	1.236	0.960
Asia	1.084	1.031	1.083	1.134	1.068	2.876	1.172	1.236	1.002
Middle East and Northern Africa	1.030	1.031	1.044	1.094	1.068	1.427	1.119	1.236	1.185
Sub-Saharan Africa	1.012	1.031	0.996	0.995	1.068	1.140	1.026	1.236	1.020
Central America and the Caribbean	1.046	1.031	1.026	1.024	1.068	0.965	1.092	1.236	0.857
South America	1.231	1.031	0.912	1.002	1.068	1.143	1.620	1.236	0.936
Global weighted average	1.057	1.031	1.006	1.080	1.068	1.350	1.136	1.236	1.005

Source: Authors

As shown in table 1, TFP indexes varies between regions, and among production systems. This is not surprising if we consider the influence of domestic policies in the performance of the sector, and that the results might be reflecting the limiting factor of production involved in each production system, tending ruminants to be more land intensive, monogastric more capital intensive, and crops more labour intensive. The global index suggest that all regions have experienced a positive growth for ruminants, monogastrics, and crops. However, in comparison



to crops TFP productivity growth, ruminants and monogastrics have performed less well.

Figure 1. Global TFP growth index for ruminants (1992-2014)

The global TFP for ruminants suggest that all regions have experienced a positive TFP growth with an aggregate global index of 1.05%. Nevertheless, as shown in figure 1, there are differences between economic regions and countries. Among regions South America (1.23%) and Asia (1.08%) exhibited the highest level of TFP growth, and Sub-Sahara Africa (1.01%) the lowest. Within the South American region, Brazil (2.26%) followed by Argentina (1.59%) displayed a particularly high TFP index. Among Asian countries, India (1.66%) followed by Pakistan (1.30%) showed the highest TFP level.

Rungsuriyawiboon and Wang (2009) found similar TFP growth levels while analyzing a similar group of countries. These results are aligned with previous studies, showing that India have experienced a significant growth in TFP for ruminants during the last decades (Nin et al., 2003: Bosworth & Collins, 2008; Dias Avila & Evenson, 2010;). During this period, India's agricultural sector went through a significant reform that boosted TFP growth (Nin Pratt, Yu, & Fan, 2008).

However, recent studies claims that further productivity growth in the livestock sector could be jeopardized by a weak link between research and technology transfer and the lack of support from extension services (Rathod, Chander, & Bardhan, 2018; Abed & Acosta, 2018).

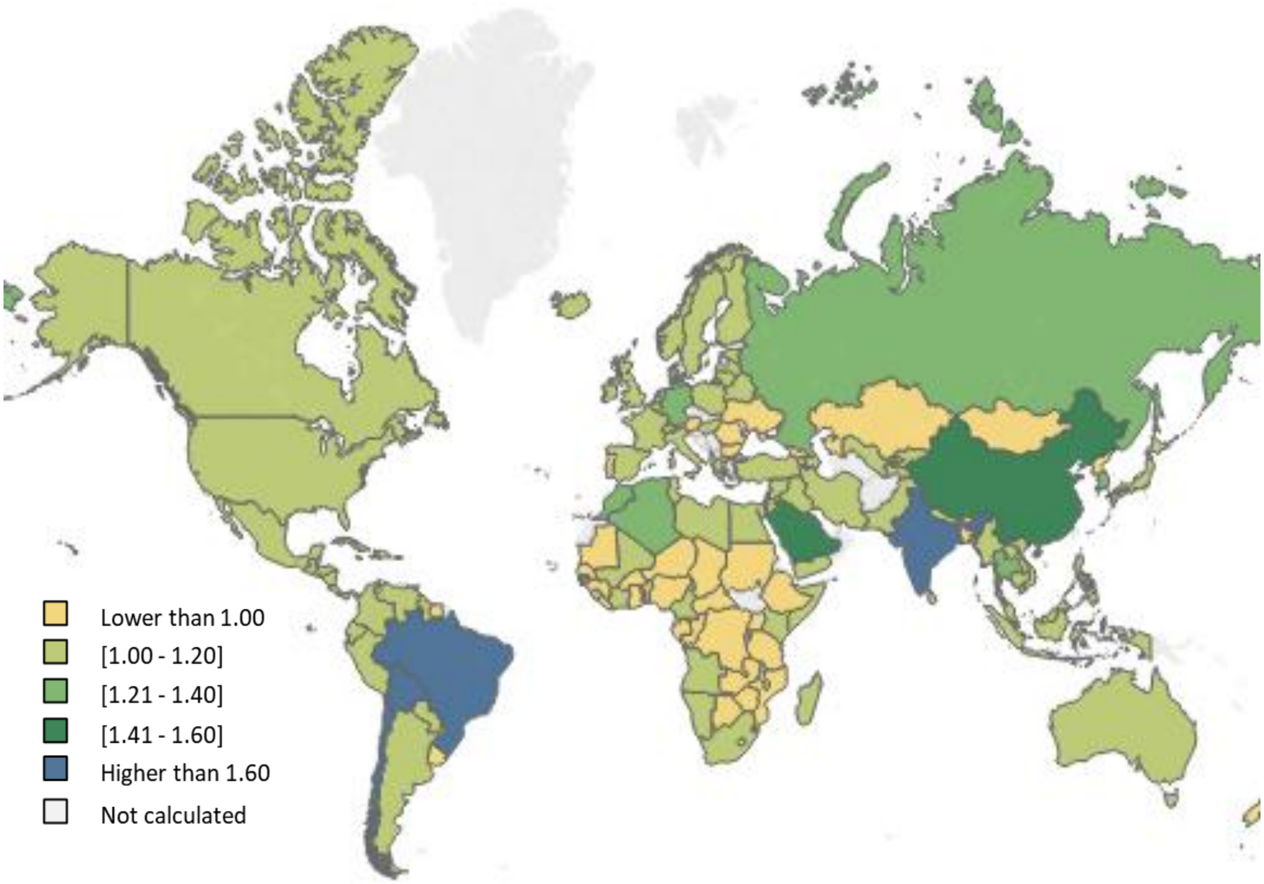


Figure 2. Global TFP growth index for Monogastrics (1992-2014)

Figure 2, illustrates the global livestock TFP index for monogastrics. The results indicate that monogastric production systems experienced an aggregate TFP growth of 1.08%. All regions but Sub-Saharan Africa has shown a positive growth during the period of analysis. As in the case of ruminants, there are also differences between economic regions and countries. Asia (1.13%) showed the highest level of TFP growth, being India (2.03%) and China (1.43%) the countries that recorded the highest level of growth. By contrast Sub-Sahara Africa (0.99) reported the lowest TFP aggregate levels for monogastrics, with 27 out of 40 countries included in this group, having a TFP growth level below 1%.

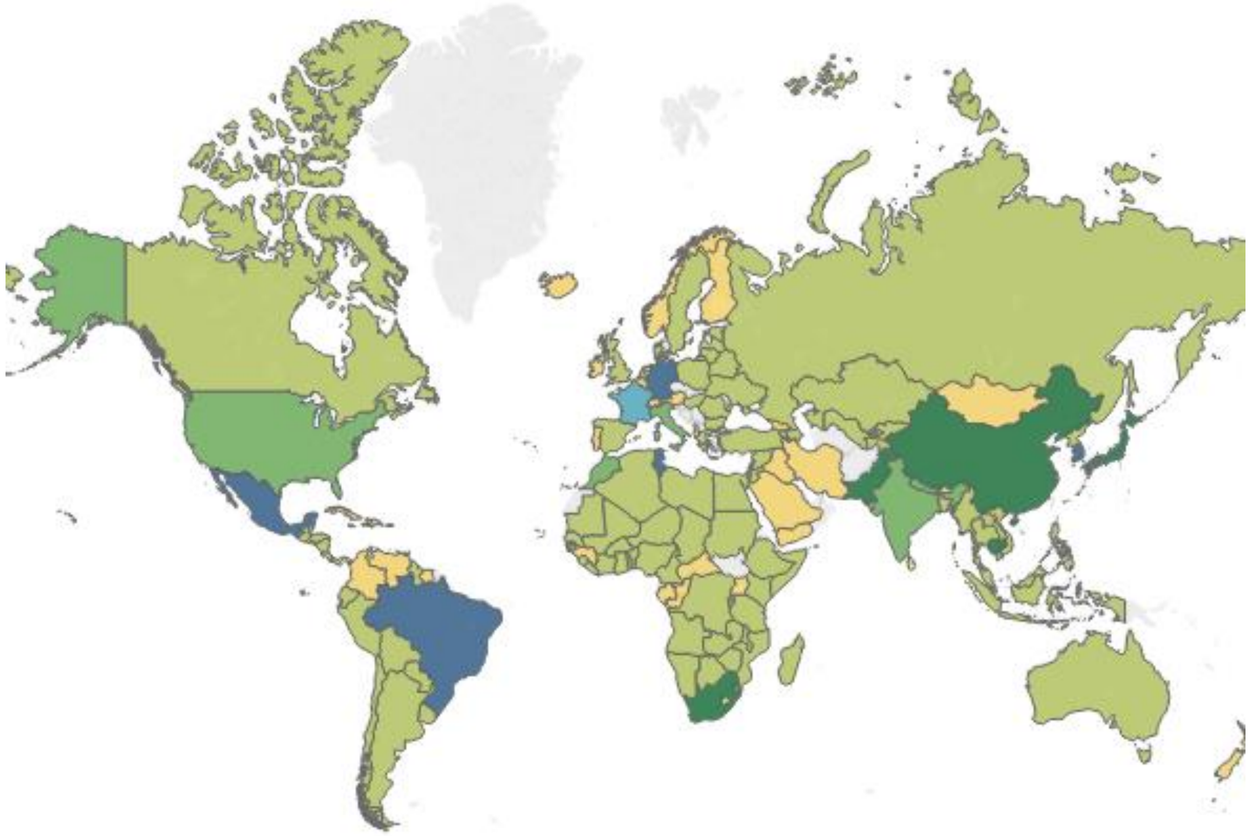


Figure 3. Global TFP growth index for crops (1992-2014)

Crops reported the highest TFP growth, among production systems with an average global index of 1.13%. As shown in Figure 3, among regions South America (1.62%) followed by Industrialized economies (1.21%) showed the highest level of TFP growth, and Sub-Sahara Africa (1.02%) the lowest. Within the two best preforming regions, Brazil (3.19%) and Germany (3.60%) presented a particularly high TFP index. Within the Sub-Saharan Africa region, 12 out of 40 countries included in this group, showed a TFP productivity growth below 1%. These results are consistent with the TFP values reported by Trindade and Fulginiti (2015).

The Sub-Saharan African region calls the attention. As observed, for all production system, the level of TFP growth in Sub-Saharan African is lower than the level accomplished in other regions. This situation is striking if we consider that during the coming decade the expected population and income rise in this region will be translated in an increased demand for food products. These low levels of TFP growth rate in all production systems, suggest that the quantities expected to supply the increase in demand from these countries might be marginally satisfied from domestic production systems. Similar low TFP rates have been reported by several studies, including Nin et al. (2003), Ludena et al. (2007), Alene (2010), Fuglie (2008, 2010, 2015) for this region.

4.2 Efficiency change

The contribution of efficiency change to TFP varies among production system and regions. As shown in table 1, the worldwide contribution of efficiency change to TFP is 1.00% for ruminants, 1.35% for monogastrics, and 1.00% for crops. The highest level of efficiency change have been observed in Asia for both for ruminants (1.83%) and monogastrics (2.87%). So far, most livestock productivity studies (Nin et al., 2003; Ludena, 2007; Abed & Acosta, 2018) have split the level of TFP into technical change and efficiency change. Unlike previous studies, to better understand its drivers, this study goes one step further decomposing the level of efficiency change into two different components, persistent (time-invariant) and transient (time-variant) efficiency. Figures 4, 5 and 6 depicts the levels of transient and persistent efficiency for ruminants, monogastrics, and crops across regions. In overall the level of persistent efficiency tends to be lower for monogastrics than for ruminants.

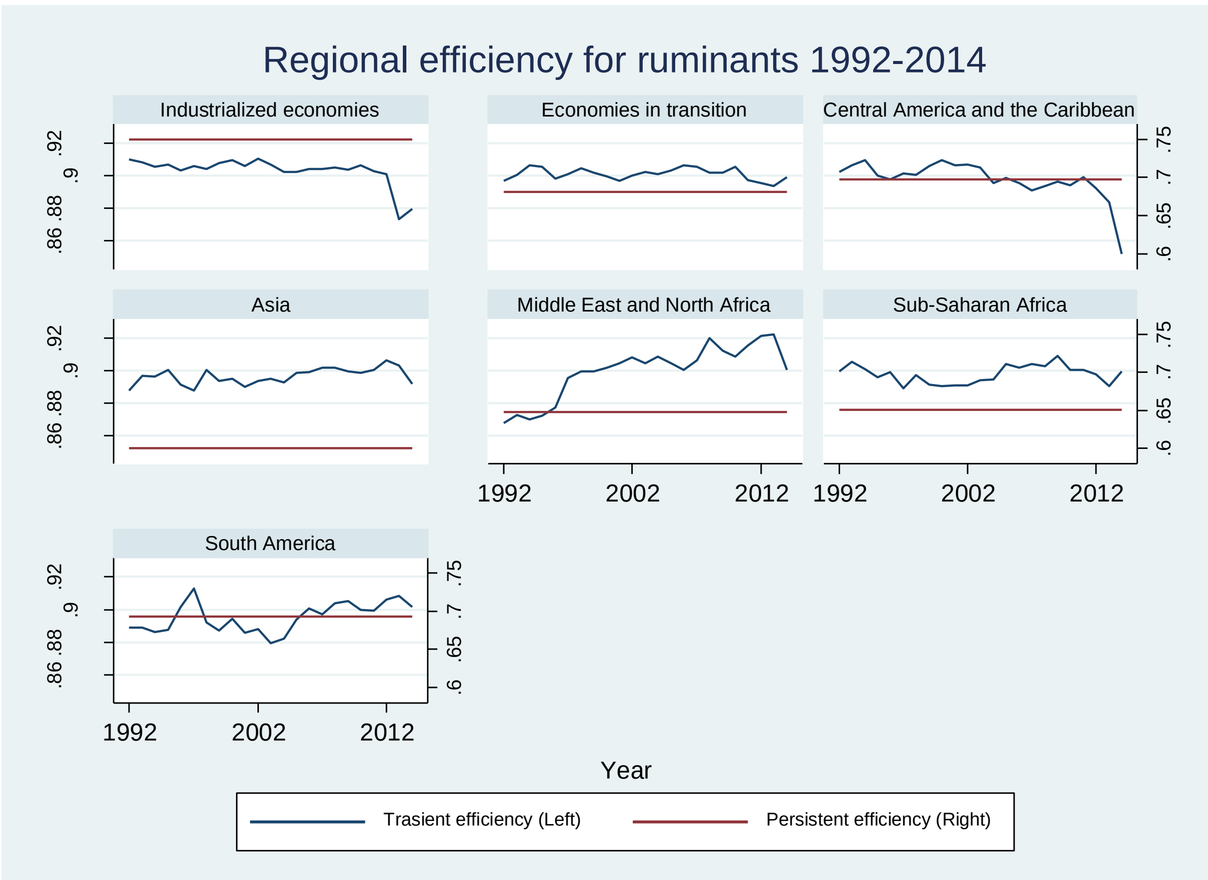


Figure 4. Ruminants' persistent and transient efficiency (1992 – 2014).

Global levels of transient and persistent efficiencies for ruminants are estimated at 0.89 and 0.61, respectively (Figure 4). This result highlight a major opportunity to raise the level of efficiency by nearly 40% if persistent efficiency is improved. As shown in figure 4, industrialized countries show the highest level of persistent efficiency (0.75). On the other hand, Asia (0.6) followed by Sub-Saharan Africa (0.65) displayed the lowest level of persistent efficiency. This figure suggest, that there is a substantial scope for improvement on the transformation of inputs into outputs. The low level of persistent efficiency implies that some structural changes are needed in order to develop the true potential of the sector.

The fact that in most developing regions transient-efficiency was found to be on average above persistent-efficiency during the full period of analysis, suggest that although short-term improvements have been made, adjustments may have not been sufficient to increase the overall level of persistent efficiency.

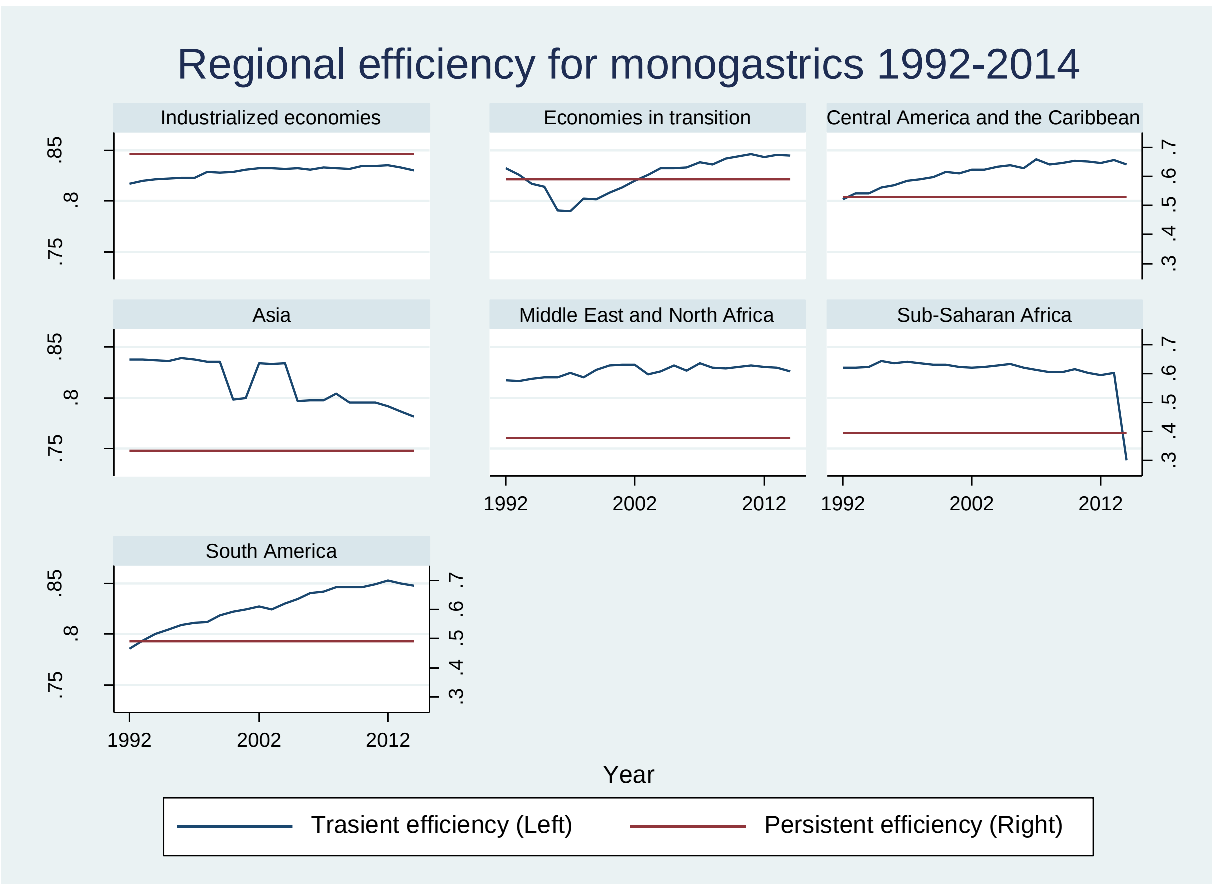


Figure 5. Monogastrics' persistent and transient efficiency (1992–2014).

In regards to monogastrics, global levels of transient and persistent efficiencies are estimated at 0.82 and 0.48, respectively (Figure 5). This result highlight opportunities to raise the level of efficiency by nearly 50% if persistent efficiency is improved. Figure 5, points out the heterogeneity in the level of persistent efficiency between regions, showing a higher efficiency gap in developing and transition economies than in developed economies. In comparison to ruminants, the level of persistent efficiency of monogastric production systems seems to be slightly lower. Regarding transient efficiency the figure shows that while in most developing regions the level of transient efficiency is increasing in the Sub-Sahara African region is decreasing. This result is consistent with previous results, suggesting that monogastric production systems in these regions are not catching up with changes in efficiency in other regions.

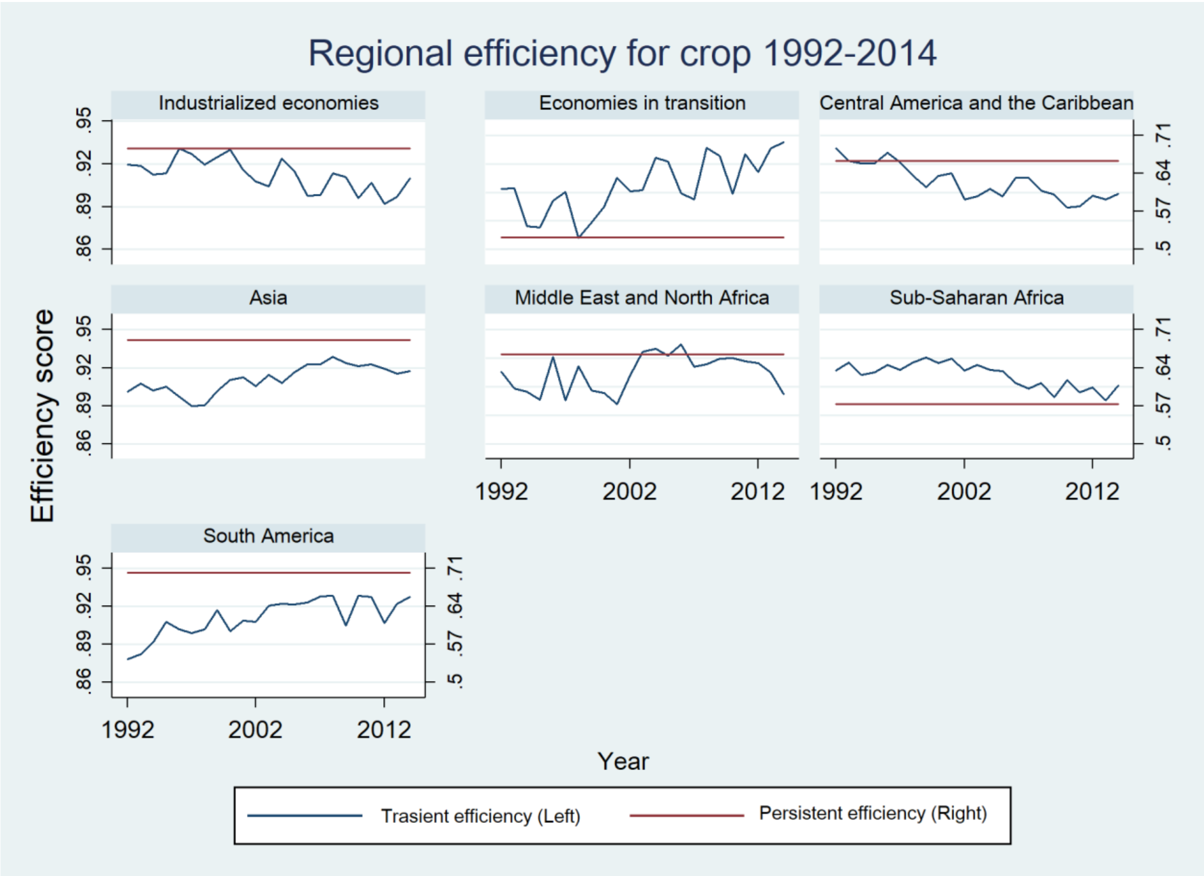


Figure 6. Crops' persistent and transient efficiency (1992–2014)

Worldwide levels of transient and persistent efficiencies for crops are estimated at 0.90 and 0.62, respectively (Figure 6). This implies that crops production faces less long term-structural problems than ruminants and monogastrics. At the regional level, the structural problems that preclude individual countries of achieving their full potential are not as significant for the industrialized countries and South America. However, more attention is needed for countries included in Economies in transition, Central America and the Caribbean, Middle East and North Africa and Sub-Saharan Africa. As is shown in Figure 6, the countries included in these groups are producing below their efficient frontier.

5. Conclusions

Driven by population growth, rising incomes and rapid urbanization, the production and consumption of livestock products have increased substantially over the past decades. Continuing growth of the sector is expected, with demand for livestock products fueled by the two-billion increase in world population and a further decline in poverty. These market trends could bring opportunities for economic and social development, however at the same time it can pose unintended food security, public health and environmental risks. Rising livestock productivity will be fundamental if the sector is to deliver on expectations. Increasing productivity through factor substitution is a feasible goal, however rising land, capital, and labour productivity simultaneously will be a major challenge. Using a stochastic distance function approach, this paper shed light on this issue by estimating TFP indicators of livestock production systems, and assessing the associated levels of persistent and transient efficiency. To conduct this study we assembled a unique dataset composed of information from FAOSTAT, the International Labor Organization (ILO), the International Fertilizer Association (IFA), and complemented with data from Fuglie's (2015) database.

The results show a high heterogeneity in livestock TFP levels, not only between production systems but among regions. In comparison to crops TFP productivity growth, ruminants and monogastrics are performing less well. The global TFP average index suggest that livestock production systems have experienced a positive TFP growth of 1.05% for ruminants, and 1.08% for monogastrics. Despite the positives levels of TFP growth, recent studies claims that further productivity growth in the livestock sector could be jeopardized by a weak link between research and technology transfer. From the overall TFP analysis, the Sub-Saharan African region calls the attention. The level of TFP growth in Sub-Saharan Africa for all production system is lower than the level accomplished in other regions. This situation is striking if consider the expected increase in demand for animal source foods during the coming decades. This result has important policy implications, suggesting that the increment in consumption of animal-source foods in this region might be only marginally satisfied from domestic production systems.

The efficiency change analysis shows that most developing economies are not catching up with developed economies in terms of efficiency change. Nevertheless, the wide differences in the level of persistence efficiency between developed and developing regions highlights a substantial opportunity for improvement in the transformation of inputs into outputs. Global levels of persistent efficiency for ruminants and monogastrics are estimated at 0.61 and 0.48 respectively. These result present an area to improve in 40% for ruminants and 50% for monogastrics the transformation of inputs into outputs, if the level of persistent efficiency is improved. However, the fact that in most developing regions transient-efficiency was found to be above persistent-efficiency, indicate that although short-term improvements have been made, adjustments may have not been enough to rise long-term efficiency. These results suggest that economic factors beyond production processes at the farm gate might be playing a major role in determining long-term efficiency change. The analysis points out the attention to one particular region, Sub-Sahara Africa, where the level of TFP remains not only among the lowest in the word, but the level of efficiency change in livestock production systems seems to be decreasing rather than increasing.

This paper extends the existing literature in several directions. First, it provides the first global evidence on livestock production systems TFP levels using a stochastic distance function approach. Secondly, we study how this relationship varies between production systems and regions. Thirdly, differently from previous livestock TFP studies, in order to better understand the drivers of efficiency change we decomposed the error term into persistent and transient efficiency. To the best of our knowledge this is the first attempt in the literature to estimate TFP for livestock production systems using this approach.

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Annex 1

Table 1.1 Growth rate (%) for industrialized economies, 1992- 2014

Country	Crops			Ruminants			Monogastrics		
	TFP%	TC%	EC%	TFP%	TC%	EC%	TFP%	TC%	EC%
Australia	0.997	1.236	0.981	0.998	1.031	1.051	1.002	1.068	1.021
Austria	0.986	1.236	1.093	0.970	1.031	0.968	0.984	1.068	1.074
Belgium-Luxembourg	0.986	1.236	1.243	0.999	1.031	1.076	1.165	1.068	1.264
Canada	1.045	1.236	1.027	1.143	1.031	1.079	1.025	1.068	1.112
Denmark	1.009	1.236	1.048	1.675	1.031	1.071	1.241	1.068	1.273
Finland	0.983	1.236	0.796	0.978	1.031	1.097	1.151	1.068	0.983
France	1.669	1.236	1.189	1.206	1.031	1.051	1.001	1.068	1.096
Germany	3.600	1.236	1.144	1.001	1.031	1.028	1.220	1.068	1.129
Greece	1.001	1.236	1.200	0.969	1.031	1.095	1.044	1.068	0.570
Iceland	0.971	1.236	0.221	0.966	1.031	1.069	0.999	1.068	0.581
Ireland	0.978	1.236	0.784	0.998	1.031	1.079	1.014	1.068	0.994
Israel	1.064	1.236	1.243	0.987	1.031	1.077	1.027	1.068	1.323
Italy	1.209	1.236	1.239	1.129	1.031	1.062	1.077	1.068	0.922
Japan	1.591	1.236	1.166	0.999	1.031	0.020	0.997	1.068	0.726
Netherlands	1.027	1.236	1.249	1.079	1.031	1.096	1.010	1.068	1.253
New Zealand	0.978	1.236	1.142	1.023	1.031	1.045	0.977	1.068	1.023
Norway	0.968	1.236	0.710	0.979	1.031	1.082	0.997	1.068	1.018
Portugal	0.979	1.236	1.053	0.967	1.031	1.089	0.976	1.068	0.928
South Africa	1.515	1.236	0.987	1.005	1.031	1.059	1.040	1.068	1.111
Spain	1.056	1.236	1.177	1.004	1.031	1.007	1.029	1.068	1.055
Sweden	1.081	1.236	0.911	1.508	1.031	1.082	1.001	1.068	1.089
Switzerland	0.994	1.236	1.057	1.013	1.031	1.064	0.996	1.068	0.989
United Kingdom	1.058	1.236	1.122	1.126	1.031	1.070	1.003	1.068	1.165
USA	1.368	1.236	1.192	1.008	1.031	1.092	1.013	1.068	1.088
Average	1.213	1.236	1.041	1.072	1.031	1.021	1.041	1.068	1.033

Table 1.2 Growth rate (%) for economies in transition, 1992- 2014

Country	Crops			Ruminants			Monogastrics		
	TFP%	TC%	EC%	TFP	TC%	EC%	TFP%	TC%	EC%
Albania	1.044	1.236	1.098	1.026	1.031	0.954	1.027	1.068	0.968
Bulgaria	1.000	1.236	1.189	0.927	1.031	0.914	0.989	1.068	1.003
Czechoslovakia, former	1.046	1.236	1.010	1.167	1.031	0.923	1.167	1.068	1.509
Hungary	1.061	1.236	1.307	1.025	1.031	0.945	1.168	1.068	1.282
Poland	1.002	1.236	1.278	1.204	1.031	0.973	1.003	1.068	0.924
Romania	1.022	1.236	1.220	0.989	1.031	0.976	0.967	1.068	0.715
Yugoslav SFR	0.981	1.236	1.133	1.032	1.031	0.958	0.967	1.068	1.238
Estonia	0.999	1.236	0.595	0.985	1.031	0.910	1.008	1.068	1.309
Latvia	1.029	1.236	0.682	1.027	1.031	0.911	1.011	1.068	1.159
Lithuania	1.058	1.236	0.789	1.129	1.031	0.956	1.052	1.068	1.428
Armenia	1.022	1.236	0.971	0.992	1.031	0.969	0.985	1.068	0.992
Azerbaijan	1.013	1.236	0.846	1.033	1.031	0.979	1.054	1.068	0.806
Georgia	0.984	1.236	0.776	0.976	1.031	0.955	0.969	1.068	1.025

Kyrgyzstan	1.039	1.236	0.834	1.049	1.031	0.919	1.009	1.068	0.699
Tajikistan	1.020	1.236	0.929	0.996	1.031	0.888	1.079	1.068	0.138
Uzbekistan	1.094	1.236	1.089	1.147	1.031	0.967	1.203	1.068	0.747
Belarus	0.997	1.236	0.927	0.989	1.031	0.992	1.066	1.068	1.391
Kazakhstan	1.035	1.236	0.641	0.988	1.031	0.967	0.982	1.068	0.967
Russian Federation	1.121	1.236	0.963	1.215	1.031	0.968	1.259	1.068	1.012
Ukraine	1.013	1.236	0.925	0.962	1.031	0.926	0.981	1.068	1.228
Average	1.029	1.236	0.960	1.043	1.031	0.948	1.047	1.068	1.027

Table 1.3 Growth rate (%) for Asian countries, 1992- 2014

Country	Crops			Ruminants			Monogastrics		
	TFP%	TC%	EC%	TFP%	TC%	EC%	TFP%	TC%	EC%
Bangladesh	1.093	1.236	1.001	1.010	1.031	1.006	0.983	1.068	0.935
Bhutan	0.978	1.236	0.991	0.972	1.031	1.124	0.968	1.068	0.859
Cambodia	1.438	1.236	1.005	1.006	1.031	1.046	1.003	1.068	2.597
China, mainland	1.423	1.236	1.009	1.273	1.031	1.121	1.438	1.068	4.147
Democratic People's Republic of Korea	0.999	1.236	0.995	0.968	1.031	1.108	0.990	1.068	3.255
India	1.256	1.236	0.999	1.664	1.031	1.071	2.038	1.068	1.332
Indonesia	0.995	1.236	1.004	0.971	1.031	1.035	1.002	1.068	2.596
Lao People's Democratic Republic	1.022	1.236	0.999	0.981	1.031	1.068	1.024	1.068	1.863
Malaysia	1.090	1.236	1.004	1.010	1.031	1.043	1.015	1.068	6.231
Mongolia	0.986	1.236	0.977	0.975	1.031	1.140	0.969	1.068	0.658
Myanmar	1.094	1.236	1.047	1.152	1.031	1.119	1.086	1.068	3.357
Nepal	1.278	1.236	1.000	1.122	1.031	1.082	1.090	1.068	0.709
Pakistan	1.538	1.236	0.992	1.309	1.031	1.028	1.043	1.068	1.045
Philippines	1.021	1.236	1.011	1.002	1.031	1.058	1.025	1.068	4.125
Republic of Korea	1.853	1.236	1.004	1.154	1.031	1.142	1.401	1.068	5.940
Singapore	0.985	1.236	1.011	-	-	-	1.193	1.068	3.255
Sri Lanka	0.975	1.236	0.983	0.950	1.031	1.044	1.009	1.068	4.270
Thailand	1.146	1.236	1.008	0.987	1.031	1.138	1.235	1.068	3.781
Viet Nam	1.092	1.236	1.001	1.001	1.031	1.112	1.030	1.068	3.695
Average	1.172	1.236	1.002	1.084	1.031	1.083	1.134	1.068	2.876

Table 1.4 Growth rate (%) for Middle East and Northern African countries, 1992- 2014

Country	Crops			Ruminants			Monogastrics		
	TFP%	TC%	EC%	TFP%	TC%	EC%	TFP%	TC%	EC%
Algeria	1.076	1.236	0.990	1.036	1.031	1.056	1.242	1.068	0.974
Egypt	1.071	1.236	1.454	-	-	-	1.028	1.068	1.609
Iran (Islamic Republic of)	0.992	1.236	1.286	1.024	1.031	1.009	1.013	1.068	1.240
Iraq	0.985	1.236	1.169	0.978	1.031	1.011	1.090	1.068	0.591
Jordan	0.997	1.236	1.367	1.041	1.031	1.103	1.003	1.068	2.954
Lebanon	0.988	1.236	1.480	1.019	1.031	1.071	1.006	1.068	2.213
Libya	1.032	1.236	1.072	1.013	1.031	1.057	1.059	1.068	1.936
Morocco	1.387	1.236	1.112	1.032	1.031	1.012	1.297	1.068	1.304

Saudi Arabia	0.981	1.236	1.076	1.020	1.031	0.979	1.458	1.068	1.938
Sudan (former)	1.056	1.236	0.935	1.010	1.031	1.006	0.982	1.068	0.531
Syrian Arab Republic	1.068	1.236	1.227	1.001	1.031	1.111	1.003	1.068	1.457
Tunisia	1.875	1.236	1.141	1.023	1.031	1.062	1.031	1.068	0.968
Turkey	1.165	1.236	1.305	1.185	1.031	1.079	1.106	1.068	1.027
Yemen	0.987	1.236	0.974	1.011	1.031	1.014	1.002	1.068	1.229
Average	1.119	1.236	1.185	1.030	1.031	1.044	1.094	1.068	1.427

Table 1.5 Growth rate (%) for Sub-Saharan African countries, 1992- 2014

Country	Crops			Ruminants			Monogastrics		
	TFP%	TC%	EC%	TFP%	TC%	EC%	TFP%	TC%	EC%
Angola	1.042	1.236	1.165	0.974	1.031	0.942	0.998	1.068	0.996
Benin	1.162	1.236	1.286	1.023	1.031	0.970	1.019	1.068	1.334
Botswana	1.024	1.236	0.563	0.987	1.031	1.046	0.983	1.068	0.865
Burkina Faso	1.013	1.236	0.843	1.018	1.031	1.024	0.988	1.068	0.662
Burundi	0.997	1.236	1.228	0.983	1.031	1.037	0.984	1.068	0.884
Cabo Verde	0.998	1.236	0.832	0.999	1.031	0.974	0.990	1.068	1.803
Cameroon	1.029	1.236	1.237	1.080	1.031	0.952	1.005	1.068	1.902
Central African Republic	0.984	1.236	1.058	0.996	1.031	0.989	0.957	1.068	1.259
Chad	1.049	1.236	0.936	0.999	1.031	1.025	0.955	1.068	0.395
Congo	0.994	1.236	1.144	1.012	1.031	1.044	0.965	1.068	2.466
Cote d'Ivoire	1.020	1.236	1.295	0.979	1.031	1.022	0.998	1.068	2.031
Democratic Republic of the Congo	0.997	1.236	1.198	0.991	1.031	0.986	0.985	1.068	1.930
Ethiopia	1.096	1.236	0.936	1.179	1.031	0.956	0.977	1.068	0.501
Gabon	0.981	1.236	1.165	0.962	1.031	0.972	0.977	1.068	2.119
Gambia	1.009	1.236	0.803	1.011	1.031	1.015	0.933	1.068	0.944
Ghana	1.006	1.236	1.303	1.104	1.031	1.055	0.967	1.068	2.004
Guinea	0.993	1.236	1.087	1.078	1.031	1.036	0.942	1.068	0.362
Guinea-Bissau	0.993	1.236	1.056	0.986	1.031	0.981	0.952	1.068	2.001
Kenya	1.045	1.236	1.035	1.025	1.031	0.925	1.062	1.068	0.658
Lesotho	0.990	1.236	0.636	0.983	1.031	1.023	0.975	1.068	0.653
Liberia	1.101	1.236	1.112	0.972	1.031	0.957	0.964	1.068	1.794
Madagascar	1.052	1.236	1.197	1.142	1.031	1.054	1.132	1.068	1.581
Malawi	1.028	1.236	1.279	1.010	1.031	1.048	1.020	1.068	0.521
Mali	1.010	1.236	0.980	1.038	1.031	0.987	1.022	1.068	0.846
Mauritania	1.004	1.236	0.596	0.982	1.031	0.963	0.957	1.068	0.302
Mozambique	1.015	1.236	0.920	0.974	1.031	0.977	0.972	1.068	1.114
Namibia	1.007	1.236	0.776	0.973	1.031	0.960	1.082	1.068	0.314
Niger	1.054	1.236	0.762	1.020	1.031	1.073	0.973	1.068	0.766
Nigeria	1.204	1.236	1.324	1.016	1.031	1.038	0.973	1.068	0.976
Rwanda	0.996	1.236	1.286	1.001	1.031	1.004	1.000	1.068	1.844
Senegal	1.019	1.236	0.897	0.984	1.031	0.943	0.954	1.068	0.725
Sierra Leone	1.031	1.236	1.161	0.990	1.031	0.980	1.001	1.068	0.884
Somalia	1.025	1.236	0.598	1.025	1.031	0.960	1.004	1.068	0.244

Swaziland	1.023	1.236	1.084	1.002	1.031	1.061	1.187	1.068	0.818
Togo	0.992	1.236	1.089	0.991	1.031	1.041	1.004	1.068	1.563
Uganda	0.969	1.236	1.164	0.997	1.031	1.017	0.984	1.068	1.202
United Republic of Tanzania	1.013	1.236	1.055	0.985	1.031	0.935	0.985	1.068	0.636
Zambia	1.038	1.236	0.882	1.019	1.031	0.923	0.984	1.068	1.444
Zimbabwe	1.010	1.236	0.812	0.993	1.031	0.961	0.987	1.068	1.121
Average	1.026	1.236	1.020	1.012	1.031	0.996	0.995	1.068	1.140

Table 1.6 Growth rate (%) for Central America and Caribbean countries, 1992- 2014

Country	Crops			Ruminants			Monogastrics		
	%TFPI	%TC	%TEC	%TFPI	%TC	%TEC	%TFPI	%TC	%TEC
Belize	0.980	1.236	0.980	0.974	1.031	1.057	0.991	1.068	1.048
Costa Rica	1.122	1.236	1.039	1.552	1.031	1.048	1.190	1.068	1.161
Cuba	0.980	1.236	0.856	1.091	1.031	1.042	1.052	1.068	0.501
Dominican Republic	1.011	1.236	0.917	0.982	1.031	1.044	0.991	1.068	1.290
El Salvador	0.964	1.236	0.799	1.012	1.031	1.004	0.997	1.068	1.287
Guatemala	1.017	1.236	0.934	1.064	1.031	0.951	1.010	1.068	0.922
Guyana	1.021	1.236	0.865	0.977	1.031	1.067	1.041	1.068	0.475
Haiti	1.047	1.236	0.801	1.023	1.031	1.043	1.035	1.068	0.766
Honduras	1.011	1.236	0.835	1.023	1.031	1.044	1.044	1.068	0.809
Jamaica	0.960	1.236	0.883	0.949	1.031	1.038	0.985	1.068	1.393
Mexico	2.525	1.236	0.885	1.248	1.031	1.001	1.035	1.068	0.778
Nicaragua	1.001	1.236	0.721	1.008	1.031	0.962	1.022	1.068	0.727
Panama	0.957	1.236	0.773	0.973	1.031	1.011	1.018	1.068	1.143
Puerto Rico	0.959	1.236	0.799	0.977	1.031	1.027	0.962	1.068	1.465
Suriname	0.968	1.236	0.909	0.933	1.031	1.060	0.985	1.068	0.674
Trinidad and Tobago	0.945	1.236	0.720	0.949	1.031	1.023	1.019	1.068	1.003
Average	1.092	1.236	0.857	1.046	1.031	1.026	1,024	1.068	0.965

Table 1.7 Growth rate (%) for South American countries, 1992- 2014

Country	Crops			Ruminants			Monogastrics		
	TFP%	TC%	EC%	TFP%	TC%	EC%	TFP%	TC%	EC%
Argentina	1.118	1.236	1.009	1.596	1.031	0.962	1.183	1.068	1.102
Bolivia (Plurinational State of)	1.168	1.236	0.838	1.390	1.031	0.913	2.474	1.068	0.847
Brazil	6.720	1.236	0.994	2.266	1.031	0.917	3.197	1.068	1.469
Chile	1.066	1.236	1.029	1.025	1.031	0.868	2.545	1.068	1.847
Colombia	0.976	1.236	1.009	0.983	1.031	0.798	1.000	1.068	1.289
Ecuador	1.016	1.236	0.950	1.036	1.031	0.871	1.033	1.068	0.994
Paraguay	1.134	1.236	0.918	1.061	1.031	0.944	1.007	1.068	1.082
Peru	1.029	1.236	0.917	1.006	1.031	0.901	1.076	1.068	1.518
Uruguay	0.999	1.236	0.864	0.981	1.031	0.932	0.987	1.068	0.673
Venezuela (Bolivarian Republic of)	0.974	1.236	0.831	0.969	1.031	1.010	1.002	1.068	1.143
Average	1.620	1.236	0.936	1.231	1.031	0.912	1.550	1.068	1.196