Assessing livestock total factor productivity: A Malmquist Index approach

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Abstract

Traditionally, the measurement of livestock productivity has been focused on the use of partial factor productivity indicators. This study argues that the use of these indicators can provide a distorted assessment of the performance of the livestock sector. By applying a Malmquist index approach, we assessed the level and drivers of total factor productivity in a livestock production system in Africa. The approach was implemented in forty-one African countries using the cattle production system as an example. The results suggest that, in the African region, the productivity of the cattle production system might be decreasing rather than increasing, and the opportunities to foster productivity growth lie more in promoting changes in efficiency than in technology – a finding that contrasts with previous studies.

Key words: livestock total factor productivity; Malmquist index; technological change; technical efficiency

1. Introduction

Roughly one in nine people worldwide suffer from hunger, and most of them live in developing countries. While the proportion of people suffering from hunger in developing countries has decreased from 23% to 13% since 1990, the number of people without adequate access to food remains unacceptably high (United Nations 2016). Indeed, according to the FAO et al. (2017), after a prolonged decline in hunger numbers, the most recent estimates indicate that world hunger increased from 777 million in 2015 to 815 million in 2016. The food security situation has deteriorated above all in parts of sub-Saharan Africa, South-Eastern Asia and Western Asia, generally as a result of conflict, drought or floods.

By signing the UN 2030 Agenda for Sustainable Development, governments around the world have committed to end hunger and malnutrition over the next 15 years (United Nations 2016). The livestock sector is expected to play a key role in providing the world with adequate supplies of food. At the same time, the sector will face a new set of intersecting challenges. The increase in demand for livestock products will add pressure on ecosystems, and livestock producers will experience greater competition for capital, labour, land, water and energy (FAO 2018). Increasing productivity growth will be essential if the sector output can be expected to grow at a sufficiently rapid rate to meet the demands for food and raw material arising from population and income growth (Coelli & Rao 2005).
Thornton (2010), using partial factor productivity (PFP) indicators, reports that, from 1960 to 2000, carcass weights increased by about 30% for both chicken and beef cattle and 20% for pigs, while milk production per animal has increased by about 30% for cow’s milk, suggesting that global livestock productivity has increased substantially in the recent past. Herrero et al. (2014) indicate that there is a broad scope for increasing productivity at a very high resource-efficiency change in the African region because the yield of milk and meat per animal and per unit of land currently are low, highlighting that the opportunities for increasing livestock productivity in this region lie in rapid technological change.

Increasing partial productivity through factor substitution is a reasonable goal, although increasing total factor productivity (TFP), meaning the simultaneous productivity of several factors of production, will be a major challenge. As shown, livestock sector analyses have often used PFP indicators to measure productivity. These undoubtedly are valuable in providing a preliminary assessment of productivity levels, but these indicators can also present a distorted assessment of the performance of the livestock sector by not accounting for potential factor substitution.

To address this gap, a number of methodological options can be proposed, including the use of Cobb-Douglas, quadratic and translog functional forms (Coelli et al. 1998; Greene 2008). These models could be used to measure livestock productivity if a production system produces one output from one input. However, in most developing countries, livestock production systems generate multiple outputs from multiple inputs. For example, in African cattle production systems, a set of outputs (milk and meat) are simultaneously produced from a given combination of inputs (heads of cattle and land). Therefore, we opted for applying a non-parametric multiple-output multiple-input distance function approach such as the Malmquist index.

In this context, the aims of this study were twofold. First, to assess the level of total factor productivity of cattle production systems and, secondly, to decompose the drivers of TFP into technological change and efficiency change. The approach was implemented in 41 African countries, employing data from the Food and Agriculture Organization of the United Nations. The results of the analysis contrast with those of previous studies, suggesting that, in the African region, the productivity of the cattle production system might be decreasing rather than increasing and that the opportunities to foster productivity growth lie more in promoting changes in efficiency than in technology.

2. Measuring productivity and efficiency

Productivity can be defined as the ratio of output to input. Often, the main objective of measuring productivity is to make inferences about the efficiency of a firm, industry, organisation, production system or sector. However, without some reference point of comparison, a productivity indicator by itself does not tell us how efficiently the firm performs. Thus, efficiency is a relative concept. Efficiency measures how well a firm performs relative to the maximum quantity of realisable output obtainable from a bundle of inputs under a given production technology. Therefore, improving efficiency means that higher levels of output can be achieved by using the same amount of inputs (Lall et al. 2002).

According to Benin (2016), there is a knowledge gap in understanding the drivers of agricultural productivity in Africa. Traditionally, the measurement of livestock productivity has been focused on the use of livestock partial factor productivity indicators to assess the relationship between output and input. Often, this indicator is built by computing the total quantity of output produced in relation to the number of animals or land used (Chilonda & Otte 2006). However, since the 1950s, the use of PFP indicators has been criticised since it can provide a distorted assessment of the performance of the livestock sector (Farrell 1957; Fabricant 1959). If output productivity per head
is increased by factor substitution, for example through more intensive feeding or the use of more capital, the level of PFP might appear to rise while the level of total factor productivity growth remains unchanged (Ludena et al. 2007).

In order to address this methodological gap, Caves et al. (1982) proposed to use the Malmquist index to measure TFP productivity under situations of multiple inputs and multiple outputs. Their work allowed them to measure productivity using distance functions under an input-oriented or an output-oriented approach. The former is useful under conditions in which we want to minimise the use of inputs when producing a fixed amount of output, while the latter is more appropriate in cases in which the output is to be maximised without changing the quantity of inputs.

Färe et al. (1994) further developed this index and applied it to measure productivity growth in industrialised countries. They calculated the four distance functions of the Malmquist index using non-parametric methods. Their technique consists in constructing a world production frontier based on all the countries and then comparing the relative position of them to the frontier. To determine the sources of growth, they divided the index into two components, efficiency change and technological change, which are measured between two periods in time.

Technological change captures sectoral changes in technology at the national level and is known as the “innovation” component. On the other hand, efficiency change is commonly described as the “catching-up” component, since it indicates how much closer or farther a subsector is to the production frontier. In other words, technological change represents the change in output that can be achieved at each level of input. Efficiency change relates to the capacity of a country to achieve its potential by using existing knowledge and technology. It can be understood as an indicator of the management of available resources and can be enhanced through education, training and managerial skills, market participation, policy reforms and changes in the macroeconomic environment (Lall et al. 2002; Nin-Pratt et al. 2012; Tirkaso & Hess 2018).

3. Livestock productivity in Africa

Livestock plays a catalytic role in helping rural households achieve their livelihood objectives. Increasing the output of livestock and non-livestock products plays a key role in food security and food supply through the provision of proteins, calories and fats. It can also provide inputs for production, such as manure, draught power and weed control. Furthermore, it is a source of disposable income and can serve as insurance for households. Increasing productivity levels can contribute to a decrease in the price of livestock products. Since these are price and income elastic, it will generate growth in the demand for them (ILCA/ILRAD 1988).

In Africa, the six largest categories of livestock are cattle, camels, chickens, goats, pigs and sheep. According to FAOSTAT (2017), in terms of stock there were more than 2 800 million heads of livestock in Africa in 2013. Chicken represented the largest category, with 62% of the stock population, followed by sheep and goats with a combined share of 25%, while cattle occupied the third place with 11%. However, in terms of net production value (PIN), we observe the opposite situation. Cattle meat and milk represented 48% of livestock PIN, goat and sheep products 20%, while chicken eggs and meat represented 15%.

As a result of its valuable contribution to the livestock sector, in increase in cattle productivity is vital to meet the needs of the growing population, as well as to become an instrument to reduce rural poverty. In 2006, the Comprehensive African Agriculture Development Programme (CAADP) incorporated productivity targets for cattle (Nouala et al. 2012). The annual rate of growth in output for meat and milk should be 2.5% and 4.9% respectively (NEPAD 2006). Nevertheless, several constraints have been identified as deterrents to higher productivity levels.
There are deficiencies to overcome in the technical aspect, such as feed supply, infrastructure, animal health and genetics. Furthermore, African countries are well known for their policy and institutional entanglements. Bias towards urban consumers, excessive regulations, lack of research, weak institutions and policy instruments, lack of planning and poor statistical data are major limitations that need to be addressed (Meltzer 1995; AU-IBAR 2010).

There are not many studies in Africa that focus on measuring TFP growth and monitoring the component of growth in the cattle sector per se. Lusigi and Thirtle (1997) measured agriculture TFP growth in Africa, including livestock. They found that productivity growth averaged 1.27% per year, and their results revealed that the key driver of productivity changes was efficiency change. In contrast, several studies support technological change as the greatest contributor to livestock TFP growth in Africa and in developing countries. Coelli and Rao (2005) found that the African continent experienced an average expansion in TFP of 0.6% per year. Technological and efficiency change presented progress, with the former making a higher contribution.

Nin et al. (2003) found that the TFP growth of agriculture in developing countries was at 1.3%, with technological change as the main promoter of growth (1.6%), while efficiency change experienced a reduction of 0.3%. Rae et al. (2006) calculated TFP growth for the livestock sector in China and found that technological change was the leading component of productivity gains. In the milk sector it experienced an annual growth of 5.6%, while efficiency change regressed by 4.7%. Beef presented a gain of 4.4% in technological change, while efficiency change increased by only 0.01%.

4. Methodology

In this study, we measured TFP using the distance function of the Malmquist index approach proposed by Färe et al. (1994). This method is based on the construction of a piece-wise linear production function for each year in the sample (Coelli & Rao 2005). The basic idea underlying this approach involves the radial proportional contraction or expansion of an output-input relationship, depending on whether we are specifying an output- or input-oriented distance function (Coelli et al. 1998). This approach was selected since it allows for the description of a multiple-input, multiple-output production function without the need to specify a behavioural objective. In addition, the methodology allows for a comparison between countries with similar input and output mixes (Coelli & Rao 2005).

The Malmquist TFP index measures the change in TFP between two data points by calculating the ratio of the distances of each data point relative to a common technology (Lissitsa et al. 2007). Considering that cattle producers in most countries tend to expand their level of output given determined levels of input, we decided to use an output-oriented Malmquist TFP approach. The change in the output-oriented Malmquist TFP index can be written as in equation (1), which is the geometric mean of two TFP indices.

\[
m_o(x_{t+1}, y_{t+1}, x_t, y_t) = \left[ \frac{b_t^o(x_{t+1}, y_{t+1})}{b_t^o(x_t, y_t)} \times \frac{b_{t+1}^o(x_{t+1}, y_{t+1})}{b_{t+1}^o(x_t, y_t)} \right]^{\frac{1}{2}} \quad (1)
\]

In the first term inside the bracket, technology in period \( t \) is used as reference technology; in the second term inside the bracket, the technology of period \( t+1 \) is used as reference technology. A value of \( m_o \) greater than one indicates TFP progress from period \( t \) to period \( t+1 \). In contrast, a value of less than one indicates TFP regress. The Malmquist TFP index can be decomposed to highlight what sources account for TFP growth. An equivalent way of writing the above equation is
as in equation (2), in which the first ratio outside the brackets is called efficiency change and the term inside the brackets is the technological change.

\[
m_e(x_{t+1},y_{t+1},x_t,y_t) = \frac{D^0_t(x_{t+1},y_{t+1})}{D^0_t(x_t,y_t)} \left[ \frac{D^0_t(x_{t+1},y_{t+1})}{D^0_{t+1}(x_{t+1},y_{t+1})} \right]^{\frac{1}{2}} \]

(2)

The efficiency change component compares the distances of two observations, \((x_t,y_t)\) and \((x_{t+1},y_{t+1})\), to the corresponding production frontiers, \(S^t\) and \(S^{t+1}\). It measures whether production is catching up with or falling behind the production frontier. The technological change term captures changes in technology at the national level.

5. Data

The study uses panel data information from FAOSTAT for 41 African countries from 1993 to 2013. As output variables, we employed total meat cattle and total cow milk production per country. The former refers to meat of bovine animals, whether fresh, chilled or frozen, with bone in, for which common trade names are beef and veal, while the latter corresponds to raw whole fresh cow’s milk containing all its constituents. As input variables, we used cattle stocks and permanent pastures and meadows as a proxy of capital and land respectively. Cattle stocks are the total bovine animals regardless of age, sex or purpose for which raised, expressed in number of head. Permanent meadows and pastures refer to the land used permanently to grow herbaceous forage crops, either cultivated or growing wild.

We report the descriptive statistics of the variables of interest in Table 1. The data reflects the substantial variation among countries in the sample. The average number of stock is 4 670 495 head, and the maximum value of the sample exceeds it by a factor of nine. An analogous situation presents when analysing the quantity of milk produced. The mean is 426 039 tonnes, but with a standard deviation of 734 119 tonnes. However, a comprehensive analysis of the livestock sector in Africa necessarily requires the study of nations that may have a heterogenous set of outputs and inputs.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inputs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stock (head)</td>
<td>4 670 495</td>
<td>7 353 464</td>
<td>36 109</td>
<td>40 731 233</td>
</tr>
<tr>
<td>Land (1 000 hectares)</td>
<td>16 535</td>
<td>18 808</td>
<td>247</td>
<td>83 859</td>
</tr>
<tr>
<td><strong>Outputs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meat (tonnes)</td>
<td>86 200</td>
<td>128 883</td>
<td>1 034</td>
<td>674 346</td>
</tr>
<tr>
<td>Milk (tonnes)</td>
<td>426 039</td>
<td>734 119</td>
<td>806</td>
<td>2 875 730</td>
</tr>
</tbody>
</table>

6. Results and discussion

The results show that, in the 21-year period, the average level of cattle TFP grew at an average annual rate of 1.4% in the selected African countries. However, in the period from 2003 and 2013, the TFP decreased 0.6% on average (Table 2). This result contrasts with the findings of previous studies, which have suggested that livestock productivity growth is increasing (Nin et al. 2007; Thornton 2010).

<table>
<thead>
<tr>
<th>Years</th>
<th>Total factor productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993-1998</td>
<td>0.3</td>
</tr>
<tr>
<td>1998-2003</td>
<td>2.4</td>
</tr>
<tr>
<td>2003-2008</td>
<td>1.6</td>
</tr>
<tr>
<td>2008-2013</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Table 3 shows the results of TFP and its components in the analysed period. A detailed cross-country analysis indicates that 80% presented growth and 20% experienced a decrease in TFP. Mali has the highest progress (4.6%), while Côte d’Ivoire presents the largest regress (-1.7%). When focusing on technological change, 100% of the countries presented an increase. For efficiency change, we observed gains in only 29% of the cases, regression in 56% of the countries, and no change at all in 15% of them. Consequently, 71% of the countries show an increase in technological change coupled with a decrease or no change in efficiency change.

<table>
<thead>
<tr>
<th>Country</th>
<th>Efficiency change</th>
<th>Technological change</th>
<th>TFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.999</td>
<td>1.014</td>
<td>1.014</td>
</tr>
</tbody>
</table>

The decomposition of TFP into efficiency change and technological change indicates that the former presents an annual contraction of 0.1%, while the latter grows at an annual rate of 1.4%. As
shown, more than half of the countries in the study present gains in technological change, together with a decrease in efficiency change. These results suggest that, while total factor productivity has improved in most countries over the past few years, efforts in technological change have not been accompanied by efforts in efficiency change, hence limiting the full potential of the sector. However as indicated by Hornstein and Krussel (1996), the adoption of technology could lead to a temporary decrease in productivity due to the lack of knowledge on the use of newly introduced resources.

Various authors (Olson 1996; Park et al. 2015; Veiderpass 2015) agree that this phenomenon has occurred partly because foreign aid cooperation has focused on the promotion of modern technologies, rather than on strengthening the capacity of local extension services to provide technical assistance. According to Lall et al. (2002), the extent to which countries are able to adopt and apply technology depends predominantly on policies and institutions. Therefore, policies oriented to promote changes in productivity should aim to better balance the adoption of existing technologies and the efficient use of the available resources, given the particularities of different production systems and farmers (Meltzer 1995; Omore et al. 2009; Coker et al. 2015).

Tchale (2009) and Benin et al. (2011) emphasise the importance of extension services to reap out the benefits of newly introduced technologies. Formal education plays a significant role in reinforcing this process. Bravo-Ureta and Pinheiro (1997) found that having four and more years of schooling has a positive effect on the technical efficiency of farmers. They conclude that education not only allows farmers to better comprehend and implement information received from extension agents, but may also lead to lower risk-aversion towards the adoption of new technologies.

Education and access to information for capacity building undoubtedly are crucial to improve TFP changes in African countries. Nevertheless, policies should cover a broader spectrum of areas in the interest of achieving higher gains in technical efficiency, and thus the largest positive impact on productivity. In this sense, researchers highlight the role of markets, trade policies and the macroeconomic environment to generate incentives that may lead to a relative increase in the intensification of production.

Nin-Pratt et al. (2012) mention that an open economy increases the technical efficiency of a sector through a larger amount of imports. These put pressure on the domestic market, forcing farmers to become more efficient in the use of the available resources to remain competitive. Brummer et al. (2006) add to this by concluding that farmers facing market distortions such as price control or isolation from domestic markets will not apply the best production techniques and will direct their efforts to more lucrative activities than production. According to Tchale (2009), the rate of increase in input costs with respect to output prices can also decrease the investment by farmers. Consequently, this will affect their supply response, which will translate into lower levels of commercialisation. This reduction in market participation will have a significantly negative impact on farmers’ technical efficiency (Bachewe et al. 2017; Tirkaso & Hess 2018).

6. Conclusions

Governments around the world have committed to end hunger by 2030. The cattle sector is expected to play a key role in providing the world with adequate supplies of animal-source foods. Increasing growth in productivity will be essential if the sector output can be expected to grow at a sufficiently rapid rate to meet the expected increase in the demand for beef and milk. Previous studies suggest that cattle productivity is increasing, and that further opportunities exist to foster productivity growth by promoting rapid technological change. This paper highlights that increasing partial productivity through factor substitution is a reasonable goal, but increasing total factor productivity will be a major challenge.
The measurement of livestock productivity has traditionally been focused on the use of partial factor productivity indicators. This study argues that the use of these indicators can provide distorted assessment of the performance of the livestock sector. We assessed the level and drivers of total factor productivity in cattle production systems in Africa applying the Malmquist TFP index approach. The results show that, in the selected African countries, the average rate of cattle TFP is growing at a rate of 1.4 % per year. The decomposition of total factor productivity into efficiency change and technological change indicates that the former presented an annual contraction of 0.1%, while the latter grew at an annual rate of 1.4%.

The results of the analysis indicate that, while total factor productivity has improved in most countries over the past few years, efforts in technological change have not been accompanied by efforts in efficiency change, hence limiting the full potential of the sector. The findings suggest that the level of TFP growth in cattle production system in Africa in recent years has been decreasing rather than increasing, and that the opportunities to foster productivity growth might lie in promoting changes in the efficiency of use of resources, rather than changes in technology alone.

References


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