

Technological Change and Convergence in Crops and Livestock Production

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Abstract

Data limitation on input allocation has limited agricultural economists in measuring sub-sector productivity growth in agriculture. However, recent developments allow now to estimate total factor productivity (TFP) growth for crops and livestock accounting for input-output allocation. This paper extends previous work on TFP measurement for livestock into ruminants and non-ruminant (pigs and poultry) productivity measurement, given the differences in productivity growth rates among these species. The results show the non-ruminant sector as more dynamic than the ruminant sector, with poultry driving most of the growth in that sub-sector. Given these rates of productivity growth, non-ruminant productivity in developing countries may be converging to the productivity levels of developed countries.

Key words: Total factor productivity, Malmquist index, livestock, ruminants, non-ruminants

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Production

Introduction

Productivity measurement in agriculture has captured the interest of economists for a long time. Most of the work on this topic has been focused on sector-wide productivity measurement, with less attention to the estimation of sub-sector productivity. This neglect is not because of lack of interest, but for reasons of data limitation. Because of this lack of information, sub-sector productivity has been usually measured by partial factor productivity (PFP). However, PFP is an imperfect measure of productivity, which sometimes can provide a misleading picture of performance.

A more accurate measure of productivity is total factor productivity (TFP) which accounts for all relevant factors and gives a more comprehensive assessment of productivity. However, TFP measurement has the problem of input allocation to specific activities in production. For example, how much time of labor can be allocated to crop production and how much to livestock production in a farm? Given the importance of this problem, the literature is extensive in this topic, but without a definite solution to it. To overcome this problem, Nin et al. (2003) proposed a directional Malmquist index that finesses unobserved input allocations across agricultural sectors. They use this methodology to generate multi-factor productivity at the sub-sector level, specifically for livestock and crops.

However, it has been observed that within livestock, there are different rates of productivity growth among different species (Delgado et al., 1999; Rae and Hertel, 2000;

Nin et al., 2004). Delgado et al. show that between 1982 and 1994, productivity for beef from cattle grew at 0.5, milk grew at 0.2, pork grew at 0.6, and poultry grew at 0.7 percent per year. Rae and Hertel show that in Asia the rate of productivity growth for non-ruminants (pigs and poultry) was higher than the rate of productivity growth in ruminants (cattle, sheep and goats). Therefore, there is the need for a disaggregate measure of TFP growth of livestock, since productivity growth for livestock species is different from each other.

In this paper we extend the work of Nin et al. (2003) disaggregating livestock into ruminant and non-ruminant (pigs and poultry) productivity measures. To produce these disaggregate livestock productivity measures we apply a directional Malmquist index using FAO data between 1961 and 2001 on inputs and outputs of crops and livestock production. Additionally, having produced these measures, we test for convergence using time series techniques. Section I of this paper presents a brief review of productivity measurement in agriculture and the problem of input/output allocation. Section II discusses the directional Malmquist index. Section III discusses the data used and section IV presents the results of productivity measurement and convergence tests.

Productivity Measurement

Total factor productivity measurement growth has developed in the last decades due to some key methodological contributions. Färe et al. (1994) implemented the Caves, Christensen and Diewert (1982) distance function approach to productivity measurement using non-parametric methods. They decompose the differences in efficiency into changes in efficiency (catching-up), and changes in the production frontier (technical

change). A world frontier is built based on the data from all of the countries in the sample, enabling the comparison of each country to that frontier. How much closer a country gets to the world frontier is called ‘catching-up’ and how much the world frontier shifts at each country’s observed input mix is called ‘technical change’ or ‘innovation’.” Countries cannot continue to “catch-up” indefinitely and at some point in time they will reach the frontier, at which time further growth will be determined only by the rate of innovation, or movement of the frontier itself.

The popularity of the Malmquist index approach has been growing in the last years, with multiple applications in various areas. Coelli and Rao (2003) present a review of the application to multi-country agriculture productivity comparison, with the majority of the research in agricultural productivity been focused on sector-wide (or national) level productivity. However, the availability of research in sub-sector productivity is limited, because of data availability on input allocation to individual activities. For example, the amount of labor and fertilizer may be known, but not how much has been allocated to each activity. Without this information, “imperfect” partial factor productivity measures such as “output per head of livestock” and “output per hectare of land” are used to measure sub-sector productivity (Rae and Hertel, 2000; Nin et al., 2004).

Partial Factor Productivity (PFP) measures productivity in terms of a specific input. Some of the most common measures of PFP are yield and labor productivity. PFP is a simple, intuitive, and frequently used measure, but with some problems. For example, is high labor productivity always desirable? What are the appropriate measures of output and labor? According to Zepeda (2001), PFP may be misleading, and with no clear indication on how it changes. For example, land and labor productivity may increase by

use of tractors, fertilizer or output mix. Total Factor Productivity (TFP) is a measure that accounts for all relevant factors, and hence offers a more comprehensive picture.

The most reasonable way of finessing the differences between sector-wide TFP and commodity-specific PFP measures involves the estimation of input allocations to specific commodities. The research on this problem is extensive, and various methods have been proposed, without a definite answer to this problem because of the limitations of these methods. Given these limitations, Nin et al. (2003) propose an alternative approach to the measurement of commodity-specific efficiency and productivity. They calculate crops and livestock productivity growth using directional distance functions, adapting a directional efficiency measure to focus on a single commodity at a time, not requiring the allocation of all inputs to specific outputs. Distance functions are used to estimate a Malmquist index to measure productivity growth in an output-specific direction (e.g. crops or livestock). In this paper we extend Nin et al.'s work estimating productivity growth for ruminants and non-ruminants (pigs and poultry), since the productivity for these livestock sub-sectors are expected to be different from each other (Delgado et al. 1999; Rae and Hertel, 2000).

Directional Malmquist Index

The Malmquist index is based on the idea of a function that measures the distance from a given input/output vector to the technically efficient frontier along a particular direction defined by the relative levels of the alternate outputs. The Shephard's output distance function is defined as the reciprocal of the maximum proportional expansion of output vector y given input x , seeking to increase all outputs simultaneously. Färe et al.

show that the Shephard's distance function can be computed as the solution to a linear programming problem, with the model exhibiting constant returns to scale.

In contrast to the Shephard's output distance function, the directional distance function allows the expansion of output in a specified direction (Chambers, Chung and Färe, 1996 and 1998; Chung, Färe and Grosskopf, 1997; Färe and Grosskopf, 2000). Stated as a linear programming problem, the directional distance measure is:

$$\bar{D}(\mathbf{x}, \mathbf{y}; \mathbf{g}_x, \mathbf{g}_y) = \max_{z^k, \beta} \beta \quad (1)$$

subject to

$$\sum_{k=1}^N z^k y_j^k \geq y_j^{k*} + \beta g_{yj} \quad j = 1, \dots, J$$

$$\sum_{k=1}^N z^k x_h^k \geq x_h^{k*} - \beta g_{xh} \quad h = 1, \dots, H$$

$$z^k \geq 0 \quad k = 1, \dots, N$$

where k is the set of countries (k^* is a particular country), j is the set of outputs, h is the set of inputs, z^k is the weight of the k th country data, $\mathbf{g}_y$ and $\mathbf{g}_x$ determine the direction in which D is defined, and g_{yj} and g_{xh} denote the j th and h th components of $\mathbf{g}_y$ and $\mathbf{g}_x$, respectively. The distance function is defined simultaneously as the contraction of inputs and the expansion of output ($-\mathbf{g}_x \mathbf{g}_y$), which in the case of an output oriented measure, we have that $\mathbf{g}_x = 0$.

However, as shown by Nin et al, the distance to the frontier might change depending on the direction in which is measured. For example, country A might be closer to the frontier than country B when measured using Shephard's distance, but country B

might be closer to the frontier if measured output's 1 direction. As shown by Färe and Grosskopf (1996), the Shephard's distance function is a special case of the directional distance function.

Nin et al. (2003) take advantage of information on input allocation by introducing specific input constraints for allocated inputs, modifying the directional distance function measure in (1). The modified problem is:

$$D_0(\mathbf{x}, y_i, \mathbf{y}_{-i}; g = (y_i, \mathbf{0})) = \max_{z^k, \beta_i^{k*}} \beta_i^{k*} \quad (2)$$

subject to

$$\sum_{k=1}^N z^k y_{-i}^k \geq y_{-i}^{k*} \quad -i \in j \text{ and } j = 1, 2, \dots, J$$

$$\sum_{k=1}^N z^k y_{-i}^k \geq y_i^{k*} (1 + \beta_i^{k*}) \quad i \in j \text{ and } i \notin -i$$

$$\sum_{k=1}^N z^k x_{hj}^k \leq x_{hj}^{k*} \quad h \in A$$

$$\sum_{k=1}^N z^k y_h^k \leq y_h^k \quad h \notin A$$

$$z^k \geq 0 \quad k = 1, \dots, N$$

where A is the set of allocatable inputs, x_{hj}^k is the level of the allocatable input h used to produce output j of firm k and y_i^{k*} is the particular output for which efficiency is being measured.

Nin et al. argue that there are two features that distinguish their measure from the general directional distance measure. The first is that the direction of expansion of outputs and contraction of inputs increases only the i th output while holding all other outputs and all inputs constant. The second is that physical inputs that can be allocated to

other outputs are treated as different inputs. That is, allocatable inputs are constrained individually by output, and inputs that are not allocable are constrained in aggregate. For example, land in pasture is a livestock input and cropland is a crops input.

Using the modified distance function, the product-specific directional Malmquist index is defined as:

$$DM(t, t+1) = \left[\frac{(1 + \bar{D}_0^t(x^t, y_i^t, y_{-i}^t; y_i^t, \mathbf{0}))}{(1 + \bar{D}_0^t(x^{t+1}, y_i^{t+1}, y_{-i}^{t+1}; y_i^{t+1}, \mathbf{0}))} \cdot \frac{(1 + \bar{D}_0^{t+1}(x^t, y_i^t, y_{-i}^t; y_i^t, \mathbf{0}))}{(1 + \bar{D}_0^t(x^{t+1}, y_i^{t+1}, y_{-i}^{t+1}; y_i^{t+1}, \mathbf{0}))} \right]^{0.5} \quad (3)$$

The directional Malmquist index indicates increase in productivity if its value is greater than one. As with the general Malmquist index, this measure can be decomposed into an efficiency component and a technical change component.

$$DEFF(t, t+1) = \frac{(1 + \bar{D}_0^t(x^t, y_i^t, y_{-i}^t; y_i^t, \mathbf{0}))}{(1 + \bar{D}_0^t(x^{t+1}, y_i^{t+1}, y_{-i}^{t+1}; y_i^{t+1}, \mathbf{0}))} \quad (4)$$

and

$$DTECH(t, t+1) = \left[\frac{(1 + \bar{D}_0^{t+1}(x^t, y_i^t, y_{-i}^t; y_i^t, \mathbf{0}))}{(1 + \bar{D}_0^t(x^t, y_i^t, y_{-i}^t; y_i^t, \mathbf{0}))} \cdot \frac{(1 + \bar{D}_0^{t+1}(x^{t+1}, y_i^{t+1}, y_{-i}^{t+1}; y_i^{t+1}, \mathbf{0}))}{(1 + \bar{D}_0^t(x^{t+1}, y_i^{t+1}, y_{-i}^{t+1}; y_i^{t+1}, \mathbf{0}))} \right]^{0.5} \quad (5)$$

However, there are two limitations of the directional Malmquist Index. The first is the case where the distance function takes on the value of -1, in which case the Malmquist index is not well defined. This may happen when for example the LP problem in y_2 direction is not feasible because technical progress has occurred allowing production of more y_1 and y_2 than was possible in period t . The second is that there might be a

reallocation factor bias in the measure, that is, movement of unallocated inputs from one activity to the other rather than technical growth.

Data

Data for inputs and outputs was collected principally from FAOSTAT 2004 (unless noted) and covered a period of 40 years from 1961 to 2001. There are two datasets, one for the estimation of ruminants and non-ruminants measures and a second dataset for the disaggregation of non-ruminants into pigs and poultry. The data for the first dataset is of 130 countries considering three outputs (crops, ruminants and non-ruminants), and nine inputs (feed, animal stock, pasture, land under crops, fertilizer, tractors, milking machines, harvesters and threshers, and labor). The second dataset contains 119 countries¹ and considers four outputs (crops, ruminants, pigs and poultry), and the same nine inputs as the first dataset, with the exception that non-ruminant animal stock is now split into pigs and poultry stock.

Nin et al. (2003) note that there are two limitations with these data. First, it has limited information on prices, and second, it does not allocate input usage to activities in agriculture. As mentioned by Zepeda (2001), this is of particular importance when allocation is skewed to a small group of producers or crops such that reallocation could greatly improve agricultural output. Because of this reason, the data from FAO can take full advantage of the product-specific distance measure developed by Nin et al. This allows the estimation of productivity growth by sector given the inputs used and the output of all other sectors given these data limitations.

¹ Bangladesh, Iran, Iraq, Jordan, Libya, Mauritania, Saudi Arabia, Sudan, Syria, and Yemen were eliminated from this second dataset because of zero output value in pig's production.

Nin et al. used the FAO dataset and assumed that three of the inputs were allocatable. Feed, animal stock and pasture are assigned to livestock production, and land under crops is assigned to crops. Inputs that are not allocated are labor, fertilizer and tractors. For the ruminant/non-ruminant disaggregation, we assume five allocatable inputs: land under crops to crops, ruminant stock and milking machines to ruminants, non-ruminant stock to non-ruminants. Feed is allocated to livestock but cannot be allocated between ruminants and non-ruminants. All other inputs remain unallocatable among outputs. For the pigs/poultry disaggregation we assume the same input allocation, with the difference that we allocate pigs and poultry stock to pigs and poultry, respectively. Description of inputs and outputs used are:

Outputs

The quantity of crop production is in millions of 1990 international dollars. FAO's crop production index estimated for each country is scaled using the value of crop output for 1990 from the Economic Research Service, USDA. The quantity of livestock production is in millions of 1990 international dollars. Output aggregates for ruminants, non-ruminants, pigs and poultry are built using international prices from Rao (1993, table 5.3). The 1990 output series were extended to cover the 1961-2001 period using the FAO production index. Livestock production is in millions of 1990 international dollars. Production indices for ruminants, non-ruminants, pigs and poultry were estimated using the same methodology as FAO (1986), and using data from Rao (1993).

Inputs

Fertilizer

Quantity of nitrogen, phosphorus, and potassium (N, P, K) in metric tons of plant nutrient consumed in agriculture by a country.

Labor

The total economically active population in agriculture (in thousands), engaged in or seeking work in agriculture, hunting, fishing, or forestry, whether as employers, own-account workers, salaried employees or unpaid workers assisting in the operation of a family farm or business. This measure of agricultural labor input, also used in other cross country studies is an uncorrected measure, that does not account for hours worked or labor quality (education, age, experience, etc.).

Land

It is expressed in 1,000 Hectares, and includes: Land under crops is the land under temporary crops (doubled-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens, land temporarily fallow (less than five years), land cultivated with permanent crops such as flowering shrubs (coffee), fruit trees, nut trees, and vines but excludes land under trees grown for wood or timber. Pasture land includes land used permanently (five years or more) for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land).

Machinery

There are three types of machinery used as inputs: Tractors, harvesters and threshers and milking machines, expressed as the total number in use. Tractors refer to total number of wheel and crawler tractors (excluding garden tractors) used in agriculture. We do not

make any allowance to the horsepower of the tractors. Harvesters and threshers refer to the number of self-propelled machines that reap and thresh in one operation. Milking machines refer to the total number of installations consisting of several units, each composed of a pail, a pulsator and four-teat cups and liners.

Animal Stock

Animal stock is the number of cattle, sheep, goat, pigs, chicken, turkeys, ducks and geese expressed in livestock unit (LU) equivalent. Given the variability of body sizes of the main animal species across geographical regions, animal units are standardized for comparisons across the world. Carcass weight statistics from 2000 are used to generate conversion factors for several regions around the globe, and used to convert stock quantities into livestock units using OECD cattle as the unit measure. Cattle, sheep and goat stock were aggregated to form ruminant stock, and chicken, turkeys, ducks and geese were aggregated to form poultry stock.

Feed

The amount of feed is expressed in metric tons of total protein supplied to livestock per year. Amounts of edible commodities (cereals, bran, oilseeds, oilcakes, fruits, vegetables, roots and tubers, pulses, molasses, animal fat, fish, meat meal, whey, milk, and other animal products from FAOSTAT food balance sheets) fed to livestock during the reference period, are transformed into protein quantities using information of feed protein content for each commodity.

Total Factor Productivity Growth Results

The results of our TFP calculations are summarized here. Given the number of countries and annual observations, the amount of output is very extensive; hence we have decided to be selective in the results that we present in this paper. The average general and directional Malmquist indexes are reported in Table 1. For comparison purposes, we report only those countries for which the LP problem for the ruminant/non-ruminant disaggregation was feasible for all years. The first three columns report the Malmquist index for agriculture and the directional measures for crops and livestock as measured in Nin et al. 2003. The next four columns report the general and directional Malmquist indices, disaggregating livestock into ruminants and non-ruminants. The last five columns report the Malmquist indices disaggregating non-ruminants into pigs and poultry. The lower part of table 1 displays weighted productivity growth measures for aggregate regions around the world.

A total of 18 countries and 16 weighted regions are presented in table 1. Of the 18 countries, 11 of them are from Africa, 3 from Latin America, 2 from Europe, 1 from Asia and 1 from the Middle East. Using the general Malmquist index we have that 12 countries show a positive average productivity growth rate in agriculture. However, as we disaggregate agriculture into crops and livestock for these 12 countries, we observe that although the agricultural sector has a positive growth rate, some of the sub-sectors display average negative productivity growth rates. Those are the cases of Cuba, Iran, Mozambique, Sierra Leone, Sudan and Zambia. For example, in Zambia the average productivity growth rate in agriculture was 0.38%, but as we disaggregate into crops and

livestock sectors, crops' productivity rate declined (-0.61%), while livestock displays productivity gains (0.97%).

In general, most of the countries in the sample display largest average productivity growth gains in livestock than in crops. From all 18 countries, 16 display average productivity growth gains in livestock, with China as the country with the best average productivity growth gain (3.66%). For crops however, only 9 countries display productivity growth gains. Both Spain and Austria, the two developed countries in the sample, show the largest productivity growth gains for crops with 2.62 and 2.53 percent, respectively.

As we further disaggregate livestock into ruminants and non-ruminants, most of the countries display productivity gains in non-ruminant production, compared to ruminant productivity gains. In ruminant production, China is the country with the best average productivity growth gain at 2.87%. For non-ruminants, Brazil displays the largest average productivity growth gain at 4.33%. From all 18 countries, only 3 display average productivity decline in non-ruminant production compared to 7 in ruminant production. Before, only 2 countries displayed productivity declines in livestock. As in the case when we disaggregated agriculture into crops and livestock, we observe that for some countries with positive average growth rate in livestock, one of the sub-sectors may display average negative productivity growth rates. For example, in Zambia livestock grew at an average rate of 0.97%. However, as non-ruminant productivity grew at an average of 0.99% per year, ruminant average productivity declined at 0.71%.

It is worth noticing that in almost all cases, the average productivity growth rate of livestock falls between the productivity growth rates of ruminants and non-ruminants.

This shows that livestock productivity growth rate is driven by one sector, with the other dragging the productivity rate down. However, there are some exceptions where we have that the average productivity growth rate of livestock is either larger or smaller than both productivity measures for ruminants and non-ruminants. For example, for Brazil the average livestock productivity growth rate is smaller (1.04%) compared to the ruminant and non-ruminant measures (1.20% and 4.33%, respectively).

These differences may be due to the way productivity growth is measured using the directional Malmquist index. In the aggregate productivity measures, we estimate output expansion with two outputs (crops and livestock), as compared to three outputs (crops, ruminants and non-ruminants). Output of the livestock sub-sectors may be able to expand on different terms when disaggregated as compared when aggregated, due to input and output composition when the other outputs are fixed. This denotes the risk of aggregating outputs or inputs as mentioned by Preckel, Akridge and Boland (1997).

As for the agriculture and crop measures, they are consistent with the more disaggregate measures. For agriculture only two out of the 18 countries (Cuba and Sudan) present a sign reversal in the average productivity growth rate. For crops, three countries present sign reversal (Iran, Sierra Leone and Sudan). This change in measures may be also due to the fact that the input and output composition has changed in the data used to estimate these measures.

Table 2 displays the two components of productivity growth (efficiency and technical change) in agriculture and the three agricultural sub-sectors. At first glance all countries in our sample have positive average technical change between 1961 and 2001. This denotes that there have been shifts in the production frontier, and that technical

change has been an important component of productivity growth. The largest technical change gains overall are on the non-ruminant sector, with 10 countries displaying average technical gains above 2%. China is the country with the largest average technical gain over the period with 5.39%.

However, we observe that this is not the case for technical efficiency. Every country displays on average a negative change in efficiency in at least one sub-sector. Only a few countries display efficiency gains over the period. Spain and Guatemala have efficiency gains in agriculture and crops. The European countries in the sample are two of the four countries with efficiency gains in crop production. An important case is ruminant production in China, with large efficiency gains of close to 2% per year, the opposite of the numbers in non-ruminant production for that same country.

These efficiency losses are due to the nature of the directional Malmquist index, which is based on a cumulative frontier. That denotes that technical change is always positive, and for negative efficiency changes, countries are not keeping up with technology. One case with large efficiency losses is Cuba, with average negative gains for crops (-7.94%), ruminants (-3.02) and non-ruminants (-3.48%). In 1989, with the collapse of the Soviet Union, \$6 billion dollars in subsidies vanished almost overnight. According to Zepeda (2003) GDP shrank by 25% between 1989 and 1991, oil imports fell by 50%, availability of fertilizer and pesticides decreased by 70%, and other imports fell by 30%. After these changes, all agricultural sectors decreased. For ruminants the decrease may be due to the government policies towards tractor substitution, due to the oil shortages, with animal traction. Additionally, sales of beef is prohibited, and anyone caught illegally slaughtering cattle could spend up to 20 years in prison. For non-

ruminants, especially for poultry production, the loss of foreign exchange to import feed has driven down production levels, with many poultry production units remaining idle because of the lack of feed.

As we further disaggregate non-ruminants into pigs and poultry, we focus on four countries in our sample (Guatemala, Mozambique, Zambia and Zimbabwe) which display complete productivity information for all agricultural sub-sectors (where information is available for all years in the sample). For these countries we observe that poultry is the sector driving the growth in non-ruminant productivity growth. The average productivity gains are larger in poultry than in pig production for Guatemala (3.86% vs. 0.68%), Mozambique (3.78% vs. 2.72%), Zambia (3.02% vs. 0.28%), and Zimbabwe (2.42% vs. -0.40%). Except for Mozambique, the average productivity changes in the aggregate non-ruminant sector falls between the two disaggregate measures of pigs and poultry.

Figure 1 displays the cumulative directional Malmquist index for livestock and its sub-sectors for Guatemala, Zambia, and Zimbabwe. The black line denotes the cumulative Malmquist index for livestock, the two red lines the cumulative index for ruminants and non-ruminants and the three blue lines the disaggregation for ruminants, pigs and poultry. These graphs demonstrate the importance of disaggregating the measures, first of livestock into ruminants and non-ruminants, and then of non-ruminants into pigs and poultry. For example, in the case of Guatemala we have that as we disaggregate into ruminants and non-ruminants, is the non-ruminant sector the one with the largest productivity growth. This information is completely missed by the aggregate livestock measure. The same can be said for the disaggregation of non-ruminants. We observe that the poultry sector is the driving sub-sector in this case, compared to pigs.

To better illustrate how productivity changes in crops, ruminants and non-ruminants (pigs and poultry) have evolved over time, we discuss the case China, and how productivity is influenced by changes in policy towards agriculture, macroeconomic changes and political events. In China, between 1955 and 1977 agriculture was centrally planned, with farmers organized into collective farms and communes. This period was characterized by grain shortages, with limited market activity. Farmers were forced to sell their products at relative low prices, and cattle could not be owned or controlled by individuals. Most collectives abandoned raising beef and kept cattle only for draft purposes. The results of these policies for this period were that productivity growth stagnated or declined (Figure 2).

In 1978 rural reforms were established, which allowed family farms to pursue profit-maximizing strategies once they have fulfilled production quotas. Livestock production was helped by policies that included increasing procurement prices, market deregulation, enhancing the feed industry, providing better breeds, and setting up a network of technical and veterinary assistance (USDA, 1998). In ruminant production, the last 20 years have been of transformation from traditional draft/beef cattle raising into more efficient beef cattle operations. Expansion of beef cattle productivity have depended on finding new sources of low cost feed such as ammoniated feed in farming regions. This technology significantly increased the efficiency of non-grain feed and greatly accelerated the conversion of draft to beef cattle raising. A new “beef belt” emerged in the North China Plains, where rural labor and production of feed grains is abundant. During this period ruminant productivity grew at a rate of 6.5 percent per year, with a cumulative growth of 300% between 1978 and 2000.

In the case of hog production, since the mid 1980s the production structure has been changing towards more specialized and commercial production units. Shorter production times and increased slaughter rates have led to an increase in the average carcass weight from 49 kilograms per head in 1978 to 77 kilograms in 1997 (USDA, 1998). Specialized firms and modern firms have become important pork producers, which by 1996 had a share of 20 percent of production compared to 5 percent in 1985. These facilities have a higher feed conversion ratio compared to the backyard system which is the dominant production system. Between 1980 and 2000, productivity grew at a rate of 5.4% per year, with a cumulative growth of 150% between 1978 and 2000.

Before 1980, China's focus was on the production of red meat (pork, beef, and mutton). But this changed with the concerns of feed shortages and the concept of China's grain self-sufficiency. Policies were made to encourage the expansion of poultry production, because chickens, ducks and geese are more efficient feed converters than hogs, cattle and sheep. Most poultry is produced by households using traditional production techniques, accounting for half of total poultry output by the mid 1990s. An increasing number of households have adopted more modern production techniques, with the availability of modern hatcheries from where to obtain chicks and feed mills. Right now, large-scale poultry facilities are located near large urban areas, producing 10 percent of poultry output. These policy changes towards the pork and poultry have positively affected productivity growth in the non-ruminant sector. In the period from 1980 to 2000, poultry productivity grew at a rate of 7 percent per year, with a cumulative growth of 780 percent in that period.

Testing for Productivity Convergence

Productivity convergence occurs in a given sample when the less developed economies tend to grow faster than their developed neighbors, therefore reducing the technology gap between them. Divergence occurs when the more developed grow faster, increasing the gap with their less developed neighbors. The concept of convergence traces back to the standard neoclassical growth model (Solow, 1956) that predicts that technological change is an exogenous process that can be transferable from developed to developing countries. This model allows for differences between countries to be transitory, allowing them to converge in the long run.

More recent, the endogenous growth theory (Romer, 1986; Lucas, 1988) considers technological change as an endogenous process, which would reflect structural differences across countries. This model allows for productivity growth (and income) to differ permanently across countries, arguing that there will not be convergence between developed and developing countries.

To test convergence the most used are the cross section and time series approaches. The cross section approach takes advantage of the tendency of developing economies to grow faster relatively to the more developed economies. The time series approach (Bernard and Durlauf 1995; Bernard and Jones, 1996) is based on the properties of the productivity growth series. In this case, there is convergence if the productivity differences across countries tend to zero, as the forecasting horizon tends to infinity. That is, there is productivity equality across countries or regions. Convergence is tested in this approach using the augmented Dickey-Fuller (ADF) and cointegration tests.

In this study convergence is tested using the efficiency times series produced from the Malmquist index, based on a frontier production function approach (Cornwell and Watcher, 1999). The advantage of using this approach is that identifies production inefficiencies by observed departures from the maximum output. These efficiency levels can be interpreted as the county's ability to absorb technological innovations, and improvements may represent productivity catch-up to the frontier by technology diffusion.

The methodology first takes the efficiency level time series for each country, which are the empirical representation of the frontier technology for the set of countries, and tests if they are stationary or non-stationary. That is, it tests the null hypothesis that each series has a unit root $I(1)$. If we reject the null hypothesis, the series are stationary. These unit root tests are the basis for the test for convergence.

As pointed out by Cornwell and Watcher the interpretation of the unit root tests become somewhat problematic because the efficiency series are bounded between zero and one. Hence, the series can never really diverge to infinity, which the presence of a unit root would suggest. However, failure to reject the null hypothesis can be interpreted as a sign of persistence of the series, and they can be treated as "if" they were $I(1)$.

For the countries that have a unit root, we determine if the country level efficiencies are cointegrated between pair of countries. If a linear combination of two or more non-stationary $I(1)$ series is stationary $I(0)$, then these series are said to be cointegrated. Failure to reject the cointegration null for a set of countries would indicate a long time relationship in the diffusion of technology between those countries.

In this paper we focus on the cointegration tests for crops, ruminants and non-ruminants for Brazil, China and the most relevant regional aggregations. North America and Australia/New Zealand are not included explicitly in this analysis (although they are included in the region Developed) because their efficiency series were stationary and could not be included in the convergence tests. Table 3 contains the results of the cointegration tests for each pair of countries/regions. For crops, the results show that Brazil and China show convergence with developed countries. That might denote technology diffusion of crop production technology to these two countries. There is also convergence of Sub-Saharan Africa to other regions such as Asia, Latin America and the former USSR.

For ruminants, most of the developing regions (China included) show convergence with the world average, although none show convergence with the developed countries. So given the productivity growth rates that we have presented in this paper, there may be divergence between developed and developing countries in ruminant production. For non-ruminants, we observe that there is convergence of former USSR and Latin America to developed countries, and in the case of Latin America to Western Europe. Sub-Saharan Africa shows signs of convergence to various regions, including Europe, Asia and Latin America. These results may suggest that for developing countries, the growth in non-ruminant production is taking them to catch up with developed countries.

Summary and Conclusions

This paper has tried to extend previous work of sub-sector productivity growth and shed some light of productivity differences in livestock across countries and regions. We used a directional Malmquist Index and apply it to estimate total factor productivity measures for crops and livestock (ruminants, pigs and poultry). The directional Malmquist index finesses the differences between partial factor productivity and total factor productivity, and adapts a directional efficiency measure to focus on a single commodity at a time, not requiring the allocation of all inputs to specific outputs.

Using this measure, total factor productivity and product-specific productivity are estimated for a group of 116 developed and developing countries. The results of this study showed how productivity measures in livestock are different from each other, when disaggregated between ruminants and non-ruminants. In most of the countries in our sample, non-ruminant (especially poultry productivity) growth has driven the increase in productivity in livestock, with ruminant productivity lagging behind. The results also show that developed countries have had a larger productivity growth in crops and ruminant production than developing countries. However, developing countries show a much larger productivity growth in non-ruminant (pigs and poultry) production.

These measures are consistent to what Nin et al. (2003) found on their study, with developed countries having a higher productivity growth in crops, and developing countries having a larger productivity growth in livestock. Additionally, the results show some degree of convergence between developing and developed countries in crops and non-ruminant production, but not for ruminant production. The results of this paper are a

valuable addition to the agriculture productivity measurement literature, as it expands total factor productivity measurement to include disaggregated measures of livestock.

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Table 1. Annual Productivity Growth Rate for Aggregate and Disaggregate TFP Measures (1961-2001)

Country/Region	Aggregate			Disaggregate Livestock				Disaggregate Non-Ruminants				
	Agriculture	Crops	Livestock	Agriculture	Crops	Ruminants	Non-Ruminants	Agriculture	Crops	Ruminants	Pigs	Poultry
Angola	-1.22	-1.55	0.36	-1.34	-1.55	-0.16	0.07	-0.41	-0.42	0*	-0.23*	4.95*
Austria	1.27	2.53	1.72	0.84	2.28	0.55	1.47	1.80	4.2*	1.03*	1.3*	1.02*
Brazil	0.68	0.65	1.04	0.81	0.79	1.20	4.33	0.74	0.86	1.51	2.07*	5.7*
Burkina	-0.98	0.97	-2.84	-0.56	1.12	-0.72	-1.49	-0.59	-1.4*	-0.7	-0.5.	-3.1*
China	0.80	0.71	3.66	1.00	0.75	2.87	3.39	2.15	-0.1*	16.8	4.19	8.25
Cuba	0.99	-0.43	0.97	-0.74	-4.66	-2.17	0.31	-0.90	-15.8*	-2.3	1.57*	0.0
Guatemala	1.24	1.34	0.79	1.10	1.31	0.56	3.43	0.87	1.56	-1.0	0.68	3.86
Guinea Bissau	-0.97	-1.05	-2.56	-0.54	-0.82	-0.88	-1.64	0.94	-4.61*	3.0*	1.38	-6.2*
Iran	0.35	-0.55	0.72	0.64	1.17	0.60	2.02	n.a.	n.a.	n.a.	n.a.	n.a.
Madagascar	-0.35	-0.60	0.34	-0.25	-0.44	0.00	0.62	-0.27	-1.31*	1.0*	1.68*	0.21
Morocco	1.20	0.68	1.52	0.78	0.66	0.79	1.76	3.77	3.72*	-1.3*	0.02*	4.35*
Mozambique	-0.19	-0.22	0.36	-0.23	-0.20	-0.72	0.47	0.12	0.26	0.43	2.72	3.78
Sierra Leone	0.08	-0.03	2.54	0.09	0.05	0.06	1.65	2.71	3.89*	-13.6*	-11.5*	8.22*
Spain	1.59	2.62	2.11	1.67	2.59	1.77	3.14	2.82	5.55*	-5.3*	-2.95*	-0.46*
Sudan	-0.07	-0.68	0.31	0.40	0.19	1.06	-0.07	n.a.	n.a.	n.a.	n.a.	n.a.
Tanzania	1.34	1.35	2.32	0.81	0.66	1.97	2.11	1.39	1.49*	5.06*	4.38*	4.65*
Zambia	0.38	-0.61	0.97	-0.02	-0.76	-0.71	0.99	0.84	-0.29	-0.40	0.28	3.02
Zimbabwe	0.63	0.92	0.42	0.34	0.48	-0.06	0.95	0.27	0.60	0.02	-0.40	2.42

World	0.76	0.93	0.78	0.75	1.11	-0.07	1.81	0.51	1.23	2.33	7.61	6.52
Developed Countries	1.45	2.64	1.51	1.04	2.57	0.93	2.11	1.06	4.12	5.03	3.14	10.4
Developing Countries	0.66	0.43	1.81	0.57	0.51	0.38	2.38	0.54	0.64	1.69	3.3	2.93
Least Developed Countries	0.19	-0.03	0.15	0.54	0.14	0.40	1.24	0.63	0.19	0.89	0.39	2.12
Africa	0.98	0.75	0.82	0.65	0.70	0.20	1.54	0.47	0.57	0.47	0	2.66
Sub-Saharan Africa	0.38	0.21	0.78	0.57	0.24	0.59	0.80	0.32	0.26	1.17	-0.6	1.73
Asia	0.44	0.03	1.90	0.44	-0.09	0.63	1.96	0.29	0.36	2.26	3.73	3.49
Asia Developing	0.71	0.19	2.55	0.96	0.25	0.50	2.71	0.65	0.47	2.46	3.67	3.23
East and South East Asia	0.37	0.17	1.49	0.44	0.03	-0.28	1.58	0.48	0.24	-0.6	1.58	1.78
North Africa and Middle East	-0.37	-0.52	-0.30	0.42	-0.06	-0.05	1.54	1.01	1.67	2.7	3.04*	3.55
Western Europe	1.56	3.50	2.16	0.93	3.33	0.96	2.47	1.06	3.66	2.84*	3.22*	6.0*
Eastern Europe	1.27	1.05	1.62	0.93	2.03	1.18	2.10	0.92	2.17	1.43	1.54	3.8
North & Central America	1.10	1.78	1.78	1.11	2.07	1.73	1.63	1.25	2.68	1.79*	2.38	1.92
Latin America & Caribbean	0.83	0.72	0.82	0.71	0.98	0.10	2.59	0.59	0.93	-0.2	0.48	3.45
Caribbean	0.39	-2.19	1.16	-0.30	-2.03	-0.96	1.02	-0.73	-1.45	-2.0	1.41	0.1
South America	0.85	0.85	0.45	0.73	1.23	0.29	3.05	0.68	1.20	0.08	1.11	4.0

*Countries for which the LP problem is not feasible for all years

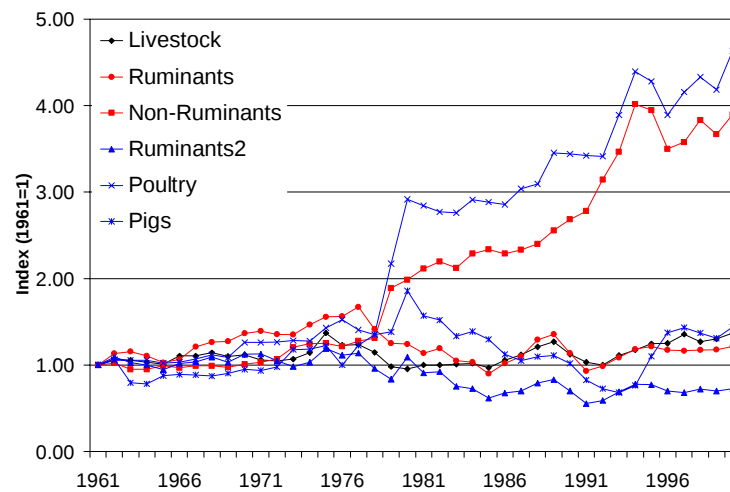
n.a. = not included in the analysis due to zero output value in pigs

Table 2. Annual Productivity Growth Rate of Technical Efficiency and Technological Change (%), 1961-2001

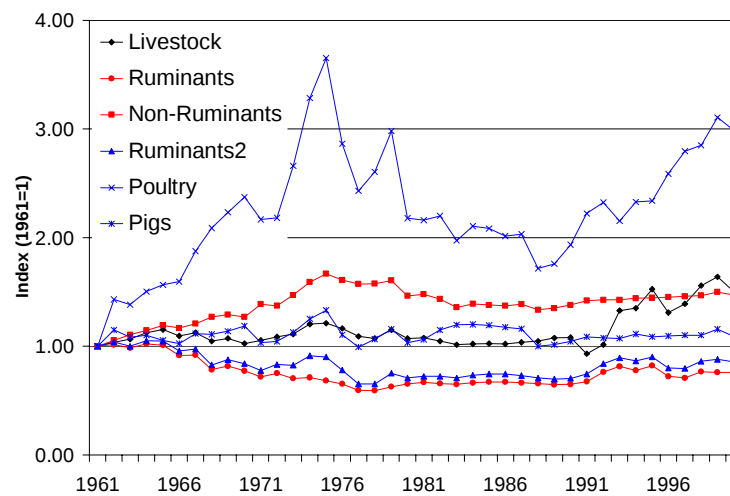
Country	Technological Change				Technical Efficiency			
	Agriculture	Crops	Ruminants	Non-Ruminants	Agriculture	Crops	Ruminants	Non-Ruminants
Angola	0.38	0.36	0.65	1.37	-1.71	-1.9	-0.8	-1.29
Austria	0.98	1.41	0.72	3.75	-0.14	0.86	-0.17	-2.2
Brazil	0.88	0.86	1.51	3.76	-0.07	-0.06	-0.31	0.55
Burkina	0.57	1.14	0.43	2.97	-1.13	-0.02	-1.15	-4.34
China	1.07	0.81	0.97	5.39	-0.07	-0.06	1.88	-1.9
Cuba	1.55	3.56	0.88	3.93	-2.26	-7.94	-3.02	-3.48
Guatemala	0.53	0.44	1.19	4.11	0.56	0.87	-0.62	-0.65
Guinea Bissau	0.35	0.37	0.68	1.43	-0.89	-1.19	-1.54	-3.02
Iran	0.76	1.34	0.88	2.36	-0.12	-0.17	-0.28	-0.34
Madagascar	0.82	0.96	1.9	3.38	-1.06	-1.38	-1.86	-2.67
Morocco	0.83	0.62	0.97	1.65	-0.05	0.04	-0.18	0.11
Mozambique	0.66	1.06	0.49	0.81	-0.88	-1.24	-1.21	-0.34
Sierra Leone	0.73	0.83	2.37	1.88	-0.64	-0.77	-2.26	-0.23
Spain	1.59	2.04	2.56	3.82	0.08	0.54	-0.77	-0.66
Sudan	0.44	0.5	0.92	0.6	-0.04	-0.31	0.14	-0.67
Tanzania	1.24	1.12	1.7	2.15	-0.42	-0.46	0.26	-0.04
Zambia	0.71	0.84	0.81	0.69	-0.72	-1.58	-1.51	0.3
Zimbabwe	0.94	0.75	1.38	1.33	-0.6	-0.27	-1.42	-0.37

Only countries for which the LP problem is feasible for all years are shown

a. Guatemala



b. Zambia



c. Zimbabwe

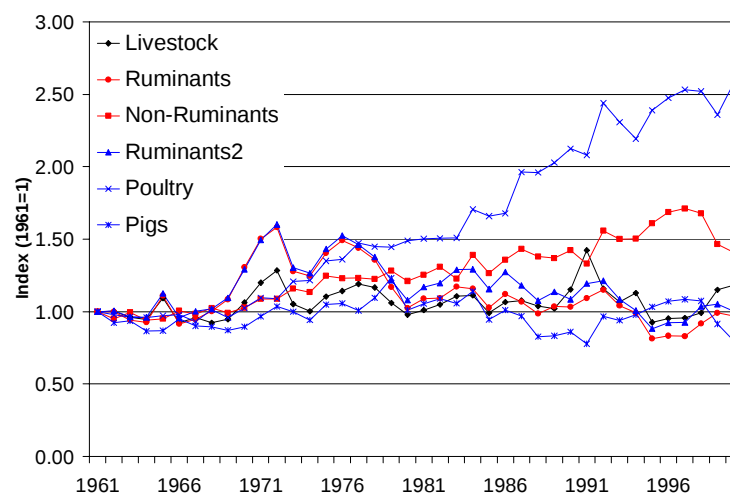


Figure 1. Cumulative Directional Malmquist indexes for Livestock and its sub-sectors in Guatemala, Zambia and Zimbabwe

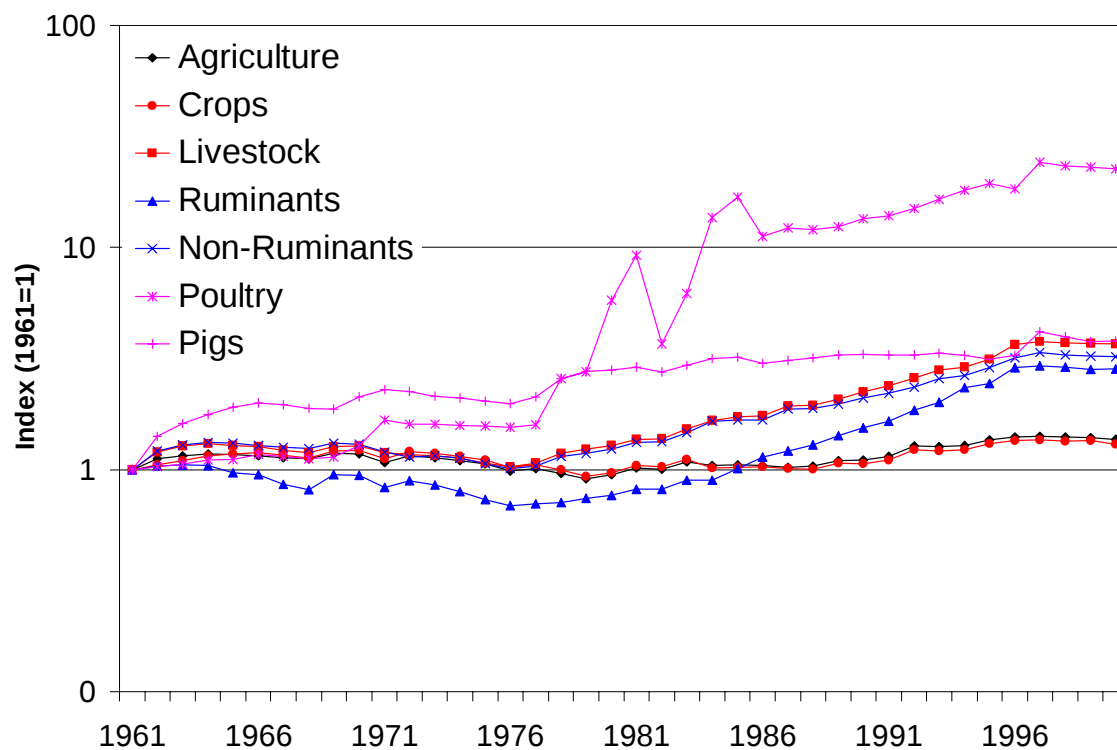


Figure 2. Cumulative Malmquist and Directional Malmquist indexes (in log form) for China

Table 3. Cointegration Test Significance (1% and 5%) for (Crops, Ruminants, Non-ruminants)

Country/Region	China	World	Developed Countries	Developing Countries	Western Europe	Eastern Europe	Former USSR	North Africa and Middle East	East & South East Asia	Latin America	Sub-Saharan Africa
Brazil			5,-,-			-1,-	5,-,-	5,5,-	5,5,-		5,-,-
China		-5,-	5,-,-				-,-5				
World				-5,-	-5,5	5,1,-	-1,-			-5,5	-5,-
Developed Countries					-,-5		-,-5			1,-5	
Developing Countries						-5,-		5,-,-		5,-,1	
Western Europe								5,-,-		5,-5	-,-1
Eastern Europe									-,-5-1	-5,-	5,5,5
Former USSR										-5,-	5,-,-
North Africa & Middle East										5,-,-	5,-,-
East & Southeast Asia										-,-5	5,-,5
Latin America											5,-,1