Productivity Growth and Convergence in Crop, Ruminant and Non-Ruminant Production: Measurement and Forecasts

Carlos E. Ludena[1], Thomas W. Hertel[1], Paul V. Preckel[1], Kenneth Foster[1], and Alejandro Nin[2]

[1]Department of Agricultural Economics
Purdue University
403 West State St.
West Lafayette, IN 47907, USA
Email: ludenac@purdue.edu, hertel@purdue.edu
and [2]International Food Policy Research Institute (IFPRI)

Contributed paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia, August 12-18, 2006

Research support under the USDA National Research Initiative for Markets and Trade (2001-35400-10214) is gratefully acknowledged.

Productivity Growth and Convergence in Crop, Ruminant and Non-Ruminant Production: Measurement and Forecasts

Abstract

There is considerable interest in projections of future productivity growth in agriculture. Whether one is interested in the outlook for global commodity markets, future patterns of international trade, or the interactions between land use, deforestation and ecological diversity, the rate of productivity growth in agriculture is an essential input. Yet solid projections for this variable have proven elusive – particularly on a global basis. This is due, in no small part, to the difficulty in measuring historical productivity growth. The purpose of this paper is to report the latest time series evidence on total factor productivity growth for crops, ruminants and non-ruminant livestock, on a global basis. We then follow with tests for convergence amongst regions, providing forecasts for farm productivity growth to the year 2040. The results suggest that most regions in the sample are likely to experience larger productivity gains in livestock than in crops. Within livestock, the non-ruminant sector is expected to continue to be more dynamic than the ruminant sector. Given the rapid rates of productivity growth observed recently, non-ruminant and crop productivity in developing countries may be converging to the productivity levels of developed countries. For ruminants, the results show that productivity levels may be diverging between developed and developing countries.

JEL Classification: D24, O13, O47, Q10

Key words: Malmquist index, productivity, convergence, projections, crops, livestock

Introduction

There is considerable demand for projections of future productivity growth in agriculture. Whether one is interested in the outlook for global commodity markets (OECD-FAO, 2005), future patterns of international trade (Anderson et al., 1997), or the interactions between land use, deforestation and ecological diversity (Ianchovichina et al., 2001), the rate of productivity growth in agriculture is an essential input. Yet solid projections for this variable have proven elusive – particularly on a global basis. This is due, in no small part, to the difficulty in measuring historical productivity growth. The purpose of this paper is to present the latest time series evidence on total factor productivity growth for crops, ruminants and non-ruminant livestock, on a global basis. We then follow with tests for convergence amongst regions, and provide forecasts for farm productivity growth to the year 2040.

Productivity measurement in agriculture has captured the interest of economists for a long time. Coelli and Rao (2005) present a review of multi-country agriculture productivity studies, reporting a total of 17 studies in the decade between 1993 and 2003. The majority of these studies indicate technological regression for developing countries and technological progress for developed countries. Coelli and Rao however find that there has been technological progress for all regions in the sample.

Most of the studies on productivity growth in agriculture have focused on sector-wide productivity measurement, with less attention to the estimation of sub-sector productivity. This omission is not because of a lack of interest, but for reasons of data availability on input allocation to individual activities. Because of this lack of information, sub-sector productivity has usually been assessed using partial factor productivity (PFP) measures such as “output per head of livestock” and “output per hectare of land”. However, PFP is an imperfect measure of productivity. For example, if increased output per head of livestock is obtained by more intensive feeding of animals, then total factor productivity growth may be unchanged, despite the apparent rise in PFP. In general, the issue of factor substitution can lead PFP measures to provide a misleading picture of performance (Capalbo and Antle, 1988).

A more accurate measure of productivity growth must account for all relevant inputs, hence the name: *Total* Factor Productivity (TFP). However, TFP measurement requires a complete allocation of inputs to specific agricultural subsectors. For example, how much labor time was allocated to crop production and how much to livestock production on any given farm, or in a given country? Given the importance of this problem, the literature is extensive on this topic. To overcome this problem, Nin et al. (2003) propose a directional Malmquist index that finesses unobserved input allocations across agricultural sectors. They use this methodology to generate multi-factor productivity for crops and livestock. This technique will form the basis for the historical analysis presented in this paper.

However, we first update and extend the work of Nin et al. (2003), to account for the wide differences in productivity growth among different species of livestock (Delgado et al., 1999; Rae and Hertel, 2000; Nin et al., 2004). Delgado et al. show that between 1982 and 1994, output per head in beef 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 growth in this PFP measure for non-ruminants (pigs and poultry) was sharply higher than the rate of productivity growth in ruminants (cattle, sheep and goats). With these kinds of differences in partial factor productivity, it is likely that there are also large divergences in TFP. Therefore, in this paper, we extend the work of Nin et al. (2003), by disaggregating livestock productivity measures into ruminant and non-ruminant measures using FAO data between 1961 and 2001.

A key part of this historical analysis is the decomposition of productivity growth into two components: technical change, or movement in the technology frontier for a given sub-sector, and "catching up", which represents improved technology bringing the country in question closer to the global frontier (Färe et al., 1994). We believe that forecasts of future productivity growth must distinguish between these two elements of technical progress, and this is reflected in our approach to forecasting future technology. Having produced this historical time series for TFP by agricultural sub-sector, we then test for productivity convergence across regions, using time series techniques. These time series relationships also form the basis for our forecasts of productivity growth over the period 2001-2040.

The results suggest that most regions in the sample are likely to experience larger productivity gains in livestock than in crops. Within livestock, the non-ruminant sector TFP growth is expected to continue to be larger than the ruminant sector. Given the rapid rates of productivity growth observed recently, non-ruminant and crop TFP in developing countries may be converging to the productivity levels of developed countries. For ruminants, the results show that productivity levels may be diverging between developed and developing countries.

Productivity Measurement Methodology and Data

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. Nin et al. (2003) modify the directional distance function measure (Chung, Färe and Grosskopf, 1997) for use in the measurement of agricultural sub-sector productivity. There are two features that distinguish their work 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 across 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.

Following Färe et al. (1994), the product-specific directional Malmquist TFP index measures the TFP change between two data points by calculating the ratio of the distances to the frontier for a particular period of each data point. The index between period *s* (the base period) and period *t* is defined as the geometric mean of two Malmquist indexes, one evaluated with respect to period *s* technology and one with respect to period *t* technology:

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

where $\vec{D}_0^s\left(x^t, y^t\right)$ represents the distance from the period *t* observation to the period *s* frontier. The output specific Malmquist index in (1) indicates that we measure TFP growth for output $y^s{}_i$, while holding all other outputs $y^s{}_{-i}$ constant[1]. As with the Malmquist index, a value greater than one indicates an increase in productivity from period *s* to *t*. This measure is decomposed into an efficiency component (catching-up) and a technical change component (changes in the production frontier):

$$DEFF(s,t) = \frac{\left(1+\vec{D}_0^t\left(x^t, y_i^t, y_{-i}^t; y_i^t, \mathbf{0}\right)\right)}{\left(1+\vec{D}_0^s\left(x^s, y_i^s, y_{-i}^s; y_i^s, \mathbf{0}\right)\right)} \tag{2}$$

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

---

[1] We calculate the distance functions between period *s* and period *t* required to estimate the Malmquist index by solving four linear programming (LP) problems.

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”. Once a country catches-up to the frontier, further growth is limited by the rate of innovation, or movement of the frontier itself.

Data for inputs and outputs were collected principally from FAOSTAT 2004 and covered a period of 40 years from 1961 to 2001. The data included 116 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 characteristics of these data are well-suited to use in conjunction with the product-specific distance measure as noted by Nin et al. (2003). To estimate the disaggregate TFP measures for crops, ruminants and non-ruminants, we assume five allocatable inputs: land under crops is allocated to crops, ruminant stock and milking machines to ruminants, and non-ruminant stock to non-ruminants. In addition, feed is allocated to livestock but cannot be allocated between ruminants and non-ruminants. All other inputs remain unallocatable to outputs.

Total Factor Productivity Growth: Historical Results

The results of our TFP calculations are summarized in Table 1. Given the number of observations, the volume of output is very extensive. Hence, we will be selective in the results that we present. We focus on historical productivity measurement and forecasts for 8 regions of the world, as shown by the groupings of countries in at bottom of Table 1. The three agricultural sub-sectors for which we report directional TFP measures are: crops, ruminants and non-ruminants. For each agricultural sub-sector we report in Table 1 the average change in total factor productivity, as well as the change in efficiency (EFF) and technical change (TCH) derived from the directional Malmquist index, by decade, as well as for the full 40 year period.

The regional measures presented in Table 1 were obtained by combining individual country observations with regional observations, where the latter are treated as separate observations, obtained by aggregating inputs and outputs in individual countries within the regions (Table 1) using value share weights. The reason for including these regions directly in our productivity measurement exercise stems from a technical limitation of the directional Malmquist Index -- it is not well defined in all cases. In these cases, the linear program used to calculate the index is infeasible. As a consequence of these infeasibilities, we cannot build up weighted productivity measures for each region, as other authors have done (Coelli and Rao, 2005). However, at the regional level, these infeasibilities do not appear, and so we are able to obtain a full time series for every region by including the aggregated regions, along with the individual countries in the sample, directly in the efficiency measurement exercise. In this way, the individual country observations serve to identify the production possibilities frontier for agriculture, while the technical efficiency and technological change indexes are simultaneously computed for individual countries and for regions, and reported only for the latter.

Let us begin with our estimates of agricultural productivity growth, worldwide, over the entire, 40 year historical period. The global productivity estimates in Table 1, as well as those for aggregate agriculture, have been created as an adjusted share-weighted sum of the individual regions' crops, ruminants, and non-ruminants productivity measures also reported in Table 1.[2] The shares used in this process are based on the value of production in the year 2001, as reported

---

[2] An alternative would be to estimate TFP for aggregate agriculture directly using the non-directional distance function approach (since there is only one output involved, as in Nin et al.). While this would offer a preferred estimate of aggregate agriculture TFP, it has a significant drawback for present purposes, namely it is inconsistent with our subsector measures. Therefore, we report aggregate agricultural TFP using the weighted subsector measures to offer a more consistent analysis of TFP growth world wide, building up from the subsector level.

by the FAO. We adjust these directional measures by a region-specific adjustment factor so that they are consistent with the aggregate agriculture productivity estimate calculated from the traditional Malmquist index. Not only does this ensure comparability with other studies of agricultural TFP, it also renders these estimates usable in projections frameworks that do not embody the directional productivity concept.

The top right hand corner in Table 1 suggests that global agricultural TFP grew over the 1961-2001 period at an annual rate of 0.94%. TFP growth may be decomposed into technical change and efficiency change (catching-up). From the entries in the top right hand corner of Table 1, it is clear that, taking into account the production-weighted averages of different regions/sub-sectors, the frontier in agriculture advanced more rapidly (1.17%/yr.) than individual regions' TFP, thereby leading to negative technical efficiency growth (-0.22%/yr.). World average annual TFP growth also appears to have been increasing over the past three decades, rising from 0.11% in the 1970's to 1.52% in the 1990's. As we will see below, this is due to accelerating TFP growth in those developing regions where substantial economic reforms have taken place since 1980: China, Eastern Europe and the Former Soviet Union, Sub-Saharan Africa and Latin America.

When we break up aggregate agricultural TFP growth into sub-sectors, we find that, for the world as a whole, non-ruminant annual TFP growth (2.1%/year) far out-stripped that in the other sub-sectors. This high rate of TFP growth has been fueled by a rapidly advancing frontier, with annual technological change estimated to be more than 3.2% over 1961-2001. As a consequence, virtually all regions have fallen further away from the frontier (negative technical efficiency growth rates averaging -1.08%/year) over this period.

In the case of ruminants, the same general pattern as with non-ruminant TFP growth exists, although growth in the frontier has been much slower, and the industrialized countries have, as a group, been marginally increasing their technical efficiency, although all other regions have been falling back from the frontier. Overall annual TFP growth in ruminants has been about 0.62%. For crops, annual TFP growth has been about 0.72%, with a somewhat more rapid growth in the frontier than for ruminants. Once again, all of the developing country regions have been falling away from the frontier, with the rate of catch-up in Industrialized Countries offsetting this so that the world average efficiency growth is almost zero.

Next, turn to the block of entries in Table 1 representing TFP growth rates in the Industrialized Countries. It is quite striking that in these countries, where the share of consumer expenditure on food is relatively low, and only a small portion of the labor force is employed in agriculture, TFP growth rates are 40% higher than world average for the historical period. This higher growth rate is fueled by high annual TFP growth in the crops (1.47%) and non-ruminants sub-sectors (1.23%). This is an extraordinarily high rate of TFP growth for a mature sector in mature economies, and testifies to the enormous productivity of the public and private investments in agricultural research over the past half century in these countries. The slowest rate of TFP growth is for ruminants (0.71%). Even so, the ruminants TFP growth rate over this 40 year period is higher than for all other regions, with the exception of China.

The next region displayed in Table 1 represents the so-called "Economies in Transition" (EIT) which include Eastern Europe and the Former Soviet Union. As the name indicates, they represent a group of economies that have undergone very substantial changes in the past decade and a half. And their TFP growth record reflects this. Indeed, the decade of the 70's shows negative TFP growth in this region. This is followed by some improvement in the 1980's and rapidly accelerating productivity growth in the 1990's, following the collapse of the Soviet Union and the opening up of the Eastern Bloc. This is acceleration is particularly striking in the case of crops and non-ruminant livestock production.

Productivity growth in China has been notoriously hard to measure due to the tendency for output statistics to be artificially inflated in order to meet pre-established planning targets. However, there is little doubt that the TFP performance of agriculture in China has been strengthening since the 1970's, when it declined at an average annual rate of nearly 2%. This improvement is particularly striking in the case of livestock production, where productivity growth in the 1980's and 1990's has been extraordinarily high. In the case of ruminant production, we attribute most of this TFP growth – between 6-7% per year over the past two decades – to "catching up". On the other hand, TFP growth in non-ruminants in China appears to have been driven by outward movement in the technological possibilities facing this sector.

For East and Southeast Asia we estimate a very modest weighted rate of TFP growth for this region, just 0.18%/year, with negligible growth in crops TFP. In fact, in contrast to other regions, crop TFP appears to have fallen since the 1970's. Non-ruminant TFP growth is the only bright spot for this region, with a 1.25% growth rate over the 40 year historical period. The next region in Table 1 is South Asia. Due to the fact that the efficiency series for this region were one for all years in the sample, it was not possible for us to model these series. To solve this problem, we estimated this block using a composite of all developing countries in Asia, including China, East and Southeast Asia, as well as South Asia and several countries in the Middle East. This is clearly a limitation of the present study, but it does permit us to obtain an exhaustive set of estimates for the world as a whole, which is our ultimate goal. For this region, we find slow, but positive TFP growth in crops and ruminant livestock, with faster growth in non-ruminants.

For the Middle East and North Africa (MENA) much like South and Southeast Asia, the lack of growth in crop and ruminant TFP leads to negligible aggregate productivity growth with non-ruminants being the only subsector with a reasonably strong performance over the historical period. Sub Saharan Africa shows modest TFP growth across all three subsectors, with a marked improvement in crops productivity since the structural adjustment reforms of the 1980's. In fact, the overall weighted average rate for this region over the 1990's is 0.79% per year. The Latin America & Caribbean region also shows accelerating growth in TFP – particularly in the 1990's when Brazil in particular undertook major rural sector reforms. This jump in TFP growth is most noticeable in crops and non-ruminants. The overall average rate of TFP growth across all subsectors is nearly 1.7%/year in this region over the 1991-2001 period.

Analysis of Historical Productivity Growth: Testing for Convergence

Productivity convergence occurs when the less developed economies experience faster TFP growth than their developed neighbors, therefore reducing the technological gap between them. Convergence in agricultural productivity across countries has been tested by various authors. Suhariyanto and Thirtle (2001) find no evidence of convergence among 18 Asian countries. Schimmelpfennig and Thirtle (1999) and Rezitis (2005) find evidence of productivity convergence in agriculture between the US and European countries. Coelli and Rao (2005) find that countries that were less efficient in 1980 have a higher TFP growth rate than those countries that were on the frontier in 1980. They conclude that these results indicate a degree of catch-up due to improved technical efficiency along with growth in technical change. However, based on our historical results, it makes little sense to test for convergence in aggregate agricultural TFP, given the wide differences in subsector performance.

To test for convergence we use the approach outlined by Cornwell and Watcher, (1999), which looks for convergence in efficiency levels. These authors argue that these efficiency levels can be interpreted as the county's ability to absorb technological innovations, and therefore represent productivity catch-up to the frontier by technology diffusion. This would allow us to test for convergence in the efficiency levels across regions. We use these convergence tests to formally examine the hypothesis that there exists a common trend for subsector efficiency levels across regions. We first conduct augmented Dickey Fuller tests on each of the calculated efficiency series to determine their long-run properties. For those regions whose measured efficiency is non-stationary we test for cointegration using Johansen (1991) and Johansen and Juselius (1990) approach. If a linear combination of two or more non-stationary series is stationary, then these series are said to be cointegrated. If the regionwise efficiency levels are cointegrated, that would indicate a long term relationship in the diffusion of technology between those regions. This is precisely the kind of link in TFP across regions that we are looking for.

Convergence Results

The augmented Dickey-Fuller tests indicated that, except for North America, Australia and New Zealand, and South Asia, the hypothesis of unit root non-stationarity at zero frequency cannot be rejected. Consequently, these series with suspected unit roots will be treated as non-stationary and potentially subject to cointegration. With the non-stationary series we apply cointegration tests. Table 2 contains the cointegration tests results for each pair of countries/regions for crops, ruminants and non-ruminants, in that order.

Each cell in this table has three entries referring to the results of convergence tests for crops, ruminants, and non-ruminants, respectively. Consider, for example, the entries in the

China row, under the second column of Table 2. Here, the 5 in the first entry denotes convergence with developed countries in crop productivity levels at 5% significance, but shows no cointegration (no entry) for ruminants and non-ruminants. In the case of Latin America, there is 1 in the first entry of the developed countries row, denoting convergence at the 1% significance level. This suggests a regular, long term pattern of technology diffusion of crop production technology from the developed countries to these two developing regions. There is also convergence of Sub-Saharan Africa's crop TFP to the EIT, MENA, Asia and Latin America.

For ruminants, the second entry in each cell, most of the developing regions (China included) show convergence with the world average, although none show convergence with developed countries as a group. So, given the productivity growth rates that we have presented in this paper, there may well be divergence between developed and developing countries in ruminant production. This is consistent with the earlier findings of Rae and Hertel, based on convergence tests using PFP measures. For non-ruminants, the last entry in each cell, we observe that there is convergence of EIT and Latin America to developed countries, and, in the case of Latin America, convergence 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 productivity is prompting them to catch up with developed countries.

Productivity Projections 2001-2040

Before considering our own projections of agricultural productivity growth, it is useful to consider the approaches currently in use. One of the most widely cited models for forecasting future supply and demand of food products is the IMPACT model (Rosegrant et. al, 2001), which covers 18 commodities and 37 countries/regions. Future supply in this model is based on changes in area, yield and production in crops, and for, in the case of livestock, changes in output per head and production. Productivity growth in this model is an exogenous trend factor in the PFP response function. The USDA (2005) and OECD-FAO Agricultural Outlook (2005) also make projections of future supply and demand for agricultural products. They assume that historical growth trends in productivity hold for the period 2005-2014.

In constructing our forecasts of future productivity levels in agriculture, we depart in two significant ways from this current "state of the art". First of all, rather than forecasting PFP, we forecast TFP, building on our historical measures of TFP by the 8 major regions of the world previously identified. Secondly, rather than simply extrapolating based on past trends, we recognize that there are two important contributors to historical productivity growth: technical change and efficiency change, and these may behave quite differently over our forecast period. We feel strongly that the process of "catching up" to the frontier, in which some developing countries are currently engaged, is unlikely to continue unabated. The simple reason for this is that in cases such as China's "catching up" to the frontier in livestock production, they will eventually reach the frontier. At that point, China's productivity growth may be expected to slow down, with future growth constrained by outward movement in the technological frontier.

To project changes in the technical efficiency component of TFP growth, we assume that technological catch-up can be modeled as a diffusion process of new technologies, where the cumulative adoption path follows an S-shaped curve (Griliches, 1957; Jarvis, 1981). This curve denotes that efficiency change at the beginning changes slowly because new technologies take some time to be adopted. As technology becomes more widely accepted, a period of rapid growth follows until it slows down again and reaches a stable ceiling. In this case, we assume that efficiency levels for all regions will eventually reach the production possibility frontier.

We follow Nin et al. (2004) in modeling this adoption path using a logistic functional form to capture the catching up process for each of the countries/regions in the sample. Specifically, we use the following logistic function to represent the catching up process of each of the regions in the sample:

$$Z_{it} = \frac{K_t}{1 + e^{-\alpha - \beta t}} \tag{4}$$

where Z_{it} is the efficiency level of region i in year t, K_t is the maximum efficiency level, which in our case is equal to 1 and constant, and the parameters α and β determine the shape of the logistic function. The speed of change of the function is given by the value of β, where a higher value of β denotes a faster rate of catching up to the frontier. The parameters of the logistic function are estimated by transforming the observed efficiency values as follows:

$$Y_{it} = \log\left(\frac{Z_{it}}{K_t - Z_{it}}\right) = \alpha + \beta t \tag{5}$$

Positive and significant estimates of β for a particular region will denote that this region is catching up to the frontier. As in Nin et al. (2004), before estimating the logistic function, we perform Chow tests of structural breaks of the efficiency time series. With this, we account for historical changes in the efficiency series that may cause possible differences in the intercept or the slope or both. The estimates of the logistic function are then used to estimate the long run path of efficiency levels out to the year 2040.

We must also project the rate of technical change in future TFP growth. Here, we simply assume that countries grow at their historical trends. However, in the case of those regions with average growth rates higher than industrialized countries, the rate of future technical change is assumed to erode (linearly) over time so that it eventually falls to the rich country growth rate. In particular, we assume that, after 20 years, the regions with initial rates of technical change above the industrialized countries will be growing at the same rate as industrialized countries (otherwise, they would eventually exceed the productivity levels in the developed countries). Given the projected growth path of each of these two components of TFP, we calculate the TFP growth rates by multiplying the two components together, as was done with the calculation of the Malmquist index in equation 1.

The lower portion of each regional panel in Table 1 contains the TFP, efficiency and technical change projections for each subsector in each region over the period: 2001- 2041, as well as for each decade. The first thing to note is that the weighted annual average for the World is higher in the projections period than in the historical period for TFP (1.38% vs. 0.94%) and for all three agricultural subsectors. When we compare the component parts of TFP, we see that this difference is entirely due to the projected increase in technical efficiency over the next 40 years – and particularly over the next decade. This reflects a continuation of the improvements in efficiency observed between the 1980's and the 1990's. On the other hand, technical change is actually projected to be lower in the projections period – despite the fact that we are projecting this based on historical trends. This difference between the historical period and the projections period is due to the anticipated slowing down of the very high rate of technological change in a few key developing countries in the future as discussed in the preceding paragraph.

As we move to the left in the top panel of Table 1, we see which subsectors contribute the most to this higher rate of average TFP growth for agriculture. The overall average TFP growth rate for crops and ruminants is lower in the historical and projections period, with non-ruminants showing much higher TFP growth rates over the projections period. And, as anticipated above, this is fueled by high rates of "catching up" as predicted by our logistic model of technical efficiency. This catching up is particularly prominent in the first decade of the forecast period.

Next, consider the TFP forecasts for Industrialized Countries. Here, the growth rate is actually quite a bit lower than in the historical period (0.77% vs. 1.19% in the historical period) – as a consequence of a slower rate of technical efficiency growth. All three agricultural sectors show somewhat lower TFP growth in the industrialized countries over the forecast period. Overall, average agricultural TFP growth in these high income economies is lower in the forecast than in the historical period.

In the case of the Economies in Transition region, much of the historical TFP growth was attributed to technological progress. As a consequence, if we project these historical growth rates forward without modification, TFP in the EIT region would eventually overtake that in Western Europe and the United States. Therefore, we impose the condition that, by 2020, the rate of technological change in the EIT will have fallen to the rate observed for industrialized countries. Thus, for crops, the EIT rate of technological progress from 2021-2040 is just 0.74%/year. However, when combined with a higher rate of growth in technical efficiency, the resulting TFP growth rate for EIT exceeds that in Industrialized Countries.

China's TFP growth rate in the projections period is higher for all subsectors than for the historical period. Although, with the exception of non-ruminants, the TFP growth for the next 40 years is lower than that for the decade of the 1990's. Again, the main difference is the projected rate of growth in technical efficiency which is extremely high for ruminants (a very small sector in China, accounting for just 7% of total output). It is also high for non-ruminants where TFP growth over the past two decades has been in excess of 4%, as China makes the transition from back-yard pig and poultry production systems to modern, industrial production.

In East and Southeast Asia, projected weighted average productivity growth for all three subsectors is -0.08% with higher productivity growth rates (3.67%) for non-ruminants. The projections for South Asia, based on the entire Developing Asia region, are higher than the historical estimates, with the highest growth rates for non-ruminant livestock. For Middle East and North Africa, TFP for all three subsectors is projected to be 0.22%, with higher growth in crops (0.45%). In Sub-Saharan Africa average agricultural TFP growth over the next 40 years is projected to be just over three quarters of one percent, fueled by both outward shifts in the frontier and improved efficiency. Subsector TFP growth in non-ruminants is negative over the projections period, whereas TFP growth in crops is close to one percent per year.

Finally, for Latin America, average agricultural TFP growth is projected to be higher than historically, with the difference largely driven by livestock productivity growth. The weighted annual average of sub-sector productivities for this region is projected to grow at 1.61% over the 2001-2010 period, falling to 1.3% in the final 20 years, for an overall average of 1.41%. As with the other regions, this difference is largely due to a slowing down of efficiency growth as producers move closer to the frontier. The ordering of subsector growth rates also follows the other developing country regions, outside of Africa, with non-ruminant TFP growing fastest, followed by ruminants and then crops TFP growth.

Summary and Implications for Forecasting Agricultural Growth and Input Use

Estimation of future food supply relies heavily of projections of future productivity growth in agriculture. The rate of productivity growth in agriculture is fundamental to forecasting global commodity markets, future patterns of international trade, and changes in land use. However, most of the current work relies on projections of yields and output per head of livestock, which, as PFP measures, are highly imperfect.

The contribution of this paper to the productivity measurement literature is that it provides TFP growth measures for crops, ruminants and non-ruminants, on a global basis, for the period 1961-2001. Additionally, it tests for convergence in technical efficiency and forecasts productivity growth of these three agricultural sub-sectors to the year 2040. These TFP forecasts are based on our analysis of historical productivity estimates, and account for technological diffusion across regions based on the convergence results.

The results indicate that developed countries have had greater historical productivity growth in crops and ruminant production than developing countries. However, developing regions show a much larger productivity growth rate in non-ruminant (pigs and poultry) production. The results indicate some degree of convergence between developing and developed countries in crops and non-ruminant production, but not so for ruminant production where there is evidence of technological divergence between developed and developing countries.

Our forecasts point to higher TFP growth in livestock in the developing world, while TFP growth in crops in the industrialized countries is forecast to exceed that for ruminants. The faster livestock TFP growth in developing countries is a positive development for consumers, given the relatively high income elasticities of demand for livestock products in the developing world. These future TFP growth rates also have important implications for land use, where more intensive use without additional inputs could further degrade its productivity. However, to evaluate these impacts, one needs an explicit simulation model, since an expanding livestock sector could also increase the demand for feedstuffs. The next stage of this research will incorporate these TFP estimates into a dynamic, global general equilibrium model in order to evaluate the impacts of such growth on international trade, land use, employment, and poverty.

References

Anderson, K., B. Dimaranan, T. Hertel, and W. Martin, 1997. Asia-Pacific Food Markets in 2005: A Global, Economywide Perspective. *Australian Journal of Agricultural and Resource Economics*, 41(1): 19-44.

Capalbo, S.M., and J.M. Antle. 1988. *Agricultural Productivity: Measurement and Explanation*. Resources for the Future, Washington DC.

Chung, Y.H., R. Färe, and S. Grosskopf. 1997. Productivity and Undesirable Outputs: A Directional Distance Function Approach. *Journal of Environmental Management*. 51:229-40.

Coelli, T., and D. S. P. Rao. 2005. Total Factor Productivity Growth in Agriculture: A Malmquist Index Analysis of 93 countries, 1980-2000. *Agricultural Economics*. 32: 115-134.

Cornwell, C.M., and J-U. Wachter. 1998. Productivity Convergence and Economic Growth: A Frontier Production Function Approach. Center for European Integration Studies. Working Paper B6.

Delgado, C., M. Rosegrant, H. Steinfeld, S. Ehui, and C. Courbois. 1999. Livestock to 2020: The Next Food Revolution. *2020 Vision for Food, Agriculture and the Environment* Discussion Paper 28, International Food Policy Research Institute, Washington, DC.

Färe, R., S. Grosskopf, M. Norris, and Z. Zhang. 1994. Productivity Growth, Technical Progress and Efficiency Change in Industrialized Countries. *American Economic Review* 84: 66-83.

Griliches, Z. 1957. Hybrid Corn: An Exploration in the Economics of Technological Change. *Econometrica*, 25: 501–522.

Ianchovichina, E., R. Darwin, and R. Shoemaker. Resource Use and Technological Progress in Agriculture: A Dynamic General Equilibrium Analysis. *Ecological Economics*, 38(2): 275-291.

Jarvis, L.S. 1981. Predicting the Diffusion of Improved Pastures in Uruguay. *American Journal of Agricultural Economics*, 63: 495–502.

Johansen, S. 1991. Estimation and Hypothesis testing of Cointegrating Vectors in Gaussian Vector Autoregressive Models. *Econometrica*, 59(6): 1551-1580.

Johansen, S., and K. Juselius. 1990. Maximum Likelihood Estimation and Inference on Cointegration - With Applications to the Demand for Money. *Oxford Bulletin of Economics and Statistics*, 52: 169-210.

Nin, A., C. Arndt, T.W. Hertel, and P.V. Preckel. 2003. Bridging the Gap between Partial and Total Factor Productivity Measures using Directional Distance Functions. *American Journal of Agricultural Economics* 85: 928-942.

Nin, A., T.W. Hertel, K. Foster, and A.N. Rae. 2004. Productivity Growth, Catching-up and Uncertainty in China's Meat Trade. *Agricultural Economics* 31: 1-16.

OECD. 2005. OECD-FAO Agricultural Outlook 2005-2014. OECD Press, 188 pp.

Rae, A.N. and T. W. Hertel. 2000. Future Developments in Global Livestock and Grains Markets: The Impacts of Livestock Productivity Convergence in Asia-Pacific. *Australian Journal of Agricultural and Resource Economics* 44: 393-422.

Rezitis, A.N. 2005. Agricultural Productivity across Europe and the United States of America. *Applied Economics Letters* 12: 443-446.

Rosegrant, M.W., M.S. Paisner, S. Meijer and J. Witcover. 2001. *Global Food Projections to 2020: Emerging Trends and Alternative Futures*. 2020 Vision Food Policy Report. Washington D.C., International Food Policy Research Institute.

Schimmelpfennig, D.S. and C. Thirtle. 1999. Research Spillovers Between the European Community and the United States, *Contemporary Economic Policy*, 19 (4): 457-68.

Suhariyanto, K., and C. Thirtle. 2001. Productivity Growth and Convergence in Asian Agriculture, *Journal of Agricultural Economics*, 52 (3): 96-110.

U.S. Department of Agriculture. 2005. USDA Agricultural Baseline Projections to 2014. Economic Research Service, Baseline Report OCE-2005-1, 116 pp.

Table 1. Historical and Projected Average Total Factor Productivity Growth Rates by Region and Sector, 1961-2040 (%)

Regions / Sectors	Period	Crops			Ruminants			Non-Ruminants			Weighted Average		
		TFP	EFF	TCH	TFP	EFF	TCH	TFP	EFF	TCH	TFP	EFF	TCH
World	**1961-00**	***0.72***	***-0.03***	***0.75***	***0.62***	***-0.03***	***0.65***	***2.10***	***-1.08***	***3.23***	***0.94***	***-0.22***	***1.17***
	1961-70	1.14	-0.12	1.26	0.00	-0.88	0.89	2.31	-0.04	2.35	1.11	-0.26	1.38
	1971-80	-0.14	-0.82	0.68	0.31	-0.39	0.70	0.72	-1.39	2.16	0.11	-0.83	0.95
	1981-90	0.57	0.16	0.41	1.13	0.70	0.43	2.71	-3.09	6.08	1.06	-0.31	1.42
	1991-00	1.33	0.68	0.65	1.06	0.50	0.57	2.72	0.27	2.43	1.52	0.57	0.95
	2001-40	***0.94***	***0.22***	***0.71***	***0.82***	***0.17***	***0.65***	***3.60***	***0.92***	***2.64***	***1.38***	***0.34***	***1.04***
	2001-10	1.30	0.56	0.74	1.13	0.48	0.65	4.64	1.52	3.05	1.86	0.71	1.13
	2011-20	0.97	0.25	0.71	0.87	0.22	0.65	3.81	1.11	2.66	1.45	0.40	1.04
	2021-30	0.79	0.09	0.70	0.70	0.05	0.65	3.16	0.70	2.43	1.19	0.19	1.00
	2031-40	0.70	0.00	0.70	0.60	-0.05	0.65	2.79	0.34	2.43	1.05	0.05	1.00
Industrialized Countries	**1961-00**	***1.47***	***0.53***	***0.93***	***0.71***	***0.05***	***0.66***	***1.23***	***-0.36***	***1.61***	***1.19***	***0.20***	***0.99***
	1961-70	2.19	1.36	0.80	0.52	0.01	0.51	1.10	0.15	0.95	1.46	0.70	0.75
	1971-80	1.75	0.59	1.15	1.15	0.54	0.61	1.48	0.35	1.12	1.51	0.52	0.98
	1981-90	0.69	-0.15	0.84	0.67	-0.08	0.76	0.95	-1.78	2.84	0.74	-0.47	1.23
	1991-00	1.25	0.33	0.91	0.50	-0.27	0.78	1.39	-0.14	1.54	1.05	0.05	1.00
	2001-40	***1.14***	***0.21***	***0.93***	***0.27***	***-0.39***	***0.66***	***0.63***	***-0.94***	***1.61***	***0.77***	***-0.21***	***0.99***
	2001-10	1.50	0.56	0.93	0.36	-0.30	0.66	0.79	-0.79	1.61	1.01	0.02	0.99
	2011-20	1.13	0.20	0.93	0.30	-0.36	0.66	0.68	-0.89	1.61	0.79	-0.20	0.99
	2021-30	1.00	0.07	0.93	0.25	-0.41	0.66	0.58	-0.99	1.61	0.68	-0.30	0.99
	2031-40	0.95	0.02	0.93	0.19	-0.47	0.66	0.48	-1.08	1.61	0.62	-0.36	0.99
Economies in Transition	**1961-00**	***1.13***	***-0.24***	***1.38***	***0.28***	***-0.19***	***0.47***	***1.20***	***-0.68***	***1.91***	***0.89***	***-0.29***	***1.19***
	1961-70	1.40	-0.04	1.44	0.30	-0.20	0.51	1.07	-0.63	1.73	1.04	-0.17	1.21
	1971-80	-0.38	-1.12	0.77	-0.18	-0.43	0.25	0.43	-0.82	1.28	-0.21	-0.88	0.69
	1981-90	0.85	-0.19	1.05	0.54	0.27	0.27	0.45	-1.82	2.38	0.70	-0.29	1.01
	1991-00	2.72	0.42	2.28	0.47	-0.38	0.85	2.90	0.58	2.28	2.09	0.21	1.86
	2001-40	***1.39***	***0.49***	***0.89***	***0.53***	***0.06***	***0.47***	***2.09***	***0.61***	***1.45***	***1.24***	***0.38***	***0.85***
	2001-10	2.14	0.90	1.20	0.55	0.08	0.47	2.57	0.76	1.77	1.74	0.64	1.07
	2011-20	1.46	0.56	0.89	0.54	0.07	0.47	2.15	0.66	1.46	1.29	0.43	0.85

Regions / Sectors	Period	Crops			Ruminants			Non-Ruminants			Weighted Average		
		TFP	EFF	TCH	TFP	EFF	TCH	TFP	EFF	TCH	TFP	EFF	TCH
Economies in Transition (*contd.*)	2021-30	1.07	0.32	0.74	0.53	0.06	0.47	1.87	0.56	1.29	1.02	0.28	0.74
	2031-40	0.92	0.17	0.74	0.52	0.05	0.47	1.77	0.47	1.29	0.92	0.18	0.74
China	**1961-00**	***0.74***	***-0.06***	***0.80***	***2.82***	***1.85***	***0.95***	***3.33***	***-1.88***	***5.31***	***1.67***	***-0.47***	***2.17***
	1961-70	2.22	-0.25	2.48	0.27	-2.59	2.93	4.32	0.46	3.84	2.71	-0.20	2.92
	1971-80	-2.24	-2.81	0.59	-2.01	-2.75	0.76	-0.50	-3.64	3.27	-1.70	-3.06	1.41
	1981-90	0.93	0.84	0.09	7.12	6.99	0.12	5.36	-5.09	11.01	2.71	-0.51	3.39
	1991-00	2.11	2.06	0.05	6.22	6.19	0.03	4.26	0.91	3.33	3.05	2.01	1.04
	2001-40	***1.45***	***0.64***	***0.80***	***3.01***	***2.04***	***0.95***	***6.60***	***2.58***	***3.91***	***3.11***	***1.33***	***1.75***
	2001-10	2.23	1.42	0.80	5.84	4.84	0.95	8.83	3.76	4.88	4.47	2.37	2.04
	2011-20	1.50	0.69	0.80	3.22	2.24	0.95	7.02	2.96	3.94	3.29	1.49	1.76
	2021-30	1.12	0.32	0.80	1.81	0.85	0.95	5.65	2.16	3.42	2.54	0.91	1.60
	2031-40	0.95	0.15	0.80	1.25	0.29	0.95	4.93	1.46	3.42	2.17	0.55	1.60
East & South East Asia	**1961-00**	***0.02***	***-0.38***	***0.40***	***-0.22***	***-0.90***	***0.69***	***1.25***	***-1.51***	***2.82***	***0.18***	***-0.56***	***0.75***
	1961-70	0.27	-0.56	0.84	-0.15	-1.58	1.46	1.96	0.10	1.86	0.48	-0.52	1.01
	1971-80	0.99	0.40	0.59	1.16	0.63	0.52	1.52	0.00	1.52	1.07	0.36	0.71
	1981-90	-0.67	-0.85	0.18	-1.91	-2.20	0.30	1.02	-4.22	5.54	-0.49	-1.38	0.93
	1991-00	-0.48	-0.50	0.02	0.05	-0.41	0.46	0.53	-1.84	2.42	-0.32	-0.68	0.37
	2001-40	***-0.66***	***-1.06***	***0.40***	***-1.24***	***-1.91***	***0.69***	***3.67***	***0.84***	***2.80***	***-0.08***	***-0.83***	***0.75***
	2001-10	-0.51	-0.91	0.40	-1.15	-1.82	0.69	3.77	0.90	2.84	0.06	-0.70	0.76
	2011-20	-0.61	-1.01	0.40	-1.22	-1.88	0.69	3.76	0.86	2.87	-0.03	-0.79	0.76
	2021-30	-0.71	-1.11	0.40	-1.27	-1.94	0.69	3.59	0.82	2.75	-0.14	-0.88	0.74
	2031-40	-0.80	-1.20	0.40	-1.31	-1.98	0.69	3.55	0.77	2.75	-0.22	-0.96	0.74
South Asia	**1961-00**	***0.17***	***-0.22***	***0.39***	***0.35***	***-0.12***	***0.47***	***1.89***	***-0.77***	***2.69***	***0.27***	***-0.21***	***0.48***
	1961-70	-0.13	-1.08	0.97	-0.97	-1.73	0.78	2.23	0.70	1.51	-0.24	-1.17	0.95
	1971-80	-0.62	-0.96	0.34	-0.40	-0.73	0.34	0.02	-1.74	1.81	-0.55	-0.93	0.39
	1981-90	0.38	0.23	0.15	1.36	1.34	0.02	3.01	-2.06	5.23	0.69	0.41	0.29
	1991-00	1.07	0.96	0.10	1.43	0.68	0.74	2.32	0.05	2.27	1.19	0.87	0.32
	2001-40	***0.96***	***0.57***	***0.39***	***1.48***	***1.00***	***0.47***	***3.48***	***0.96***	***2.49***	***1.16***	***0.68***	***0.48***
	2001-10	1.07	0.68	0.39	1.65	1.18	0.47	3.75	1.08	2.63	1.29	0.80	0.48

Regions / Sectors	Period	Crops			Ruminants			Non-Ruminants			Weighted Average		
		TFP	EFF	TCH	TFP	EFF	TCH	TFP	EFF	TCH	TFP	EFF	TCH
South Asia (*contd.*)	2011-20	1.00	0.60	0.39	1.54	1.06	0.47	3.53	1.00	2.49	1.20	0.72	0.48
	2021-30	0.93	0.53	0.39	1.42	0.94	0.47	3.37	0.92	2.41	1.12	0.64	0.47
	2031-40	0.86	0.47	0.39	1.30	0.82	0.47	3.28	0.84	2.41	1.04	0.56	0.47
Middle East & North Africa	**1961-00**	***-0.03***	***-0.24***	***0.21***	***-0.02***	***-0.54***	***0.52***	***0.64***	***-0.22***	***0.87***	***0.03***	***-0.30***	***0.34***
	1961-70	-0.22	-0.57	0.35	-0.20	-0.80	0.61	0.74	0.03	0.72	-0.13	-0.57	0.44
	1971-80	-0.07	-0.32	0.25	0.56	-0.07	0.63	1.55	0.61	0.92	0.21	-0.18	0.39
	1981-90	0.33	0.16	0.17	-0.03	-0.42	0.39	0.37	-0.51	0.90	0.26	-0.02	0.28
	1991-00	-0.15	-0.23	0.08	-0.40	-0.84	0.45	-0.08	-0.99	0.94	-0.19	-0.43	0.24
	2001-40	***0.45***	***0.23***	***0.21***	***-0.31***	***-0.83***	***0.52***	***-0.28***	***-1.12***	***0.87***	***0.22***	***-0.12***	***0.34***
	2001-10	0.47	0.25	0.21	-0.21	-0.72	0.52	-0.16	-1.01	0.87	0.26	-0.07	0.34
	2011-20	0.45	0.24	0.21	-0.28	-0.80	0.52	-0.25	-1.10	0.87	0.23	-0.10	0.34
	2021-30	0.44	0.22	0.21	-0.35	-0.86	0.52	-0.32	-1.17	0.87	0.20	-0.13	0.34
	2031-40	0.42	0.21	0.21	-0.41	-0.92	0.52	-0.38	-1.22	0.87	0.17	-0.16	0.34
Sub Saharan Africa	**1961-00**	***0.15***	***-0.08***	***0.22***	***0.36***	***-0.03***	***0.40***	***0.50***	***-0.25***	***0.76***	***0.21***	***-0.08***	***0.29***
	1961-70	-0.34	-0.78	0.45	-0.10	-0.69	0.60	0.61	0.19	0.42	-0.24	-0.71	0.47
	1971-80	-0.80	-0.96	0.16	0.58	0.04	0.54	0.62	0.49	0.13	-0.44	-0.67	0.23
	1981-90	0.89	0.76	0.13	0.26	-0.15	0.42	0.67	-0.64	1.32	0.75	0.49	0.26
	1991-00	0.86	0.70	0.16	0.72	0.69	0.03	0.10	-1.04	1.15	0.79	0.59	0.20
	2001-40	***0.91***	***0.68***	***0.22***	***0.57***	***0.17***	***0.40***	***-0.05***	***-0.80***	***0.76***	***0.78***	***0.49***	***0.29***
	2001-10	1.09	0.86	0.22	0.57	0.18	0.40	-0.01	-0.75	0.76	0.92	0.63	0.29
	2011-20	0.96	0.74	0.22	0.57	0.17	0.40	-0.04	-0.79	0.76	0.82	0.53	0.29
	2021-30	0.84	0.62	0.22	0.57	0.17	0.40	-0.07	-0.81	0.76	0.73	0.44	0.29
	2031-40	0.73	0.51	0.22	0.56	0.17	0.40	-0.10	-0.84	0.76	0.65	0.36	0.29
Latin America & Caribbean	**1961-00**	***0.76***	***-0.33***	***1.10***	***0.08***	***-0.78***	***0.87***	***2.01***	***-0.87***	***2.91***	***0.77***	***-0.53***	***1.30***
	1961-70	0.38	-0.73	1.12	-0.88	-2.28	1.44	0.29	-2.51	2.89	0.05	-1.38	1.46
	1971-80	0.53	-0.34	0.87	-0.02	-1.74	1.75	2.68	-0.36	3.06	0.70	-0.70	1.41
	1981-90	0.51	0.02	0.49	0.49	0.27	0.22	1.64	-1.27	2.96	0.67	-0.11	0.78
	1991-00	1.61	-0.29	1.91	0.74	0.65	0.09	3.45	0.69	2.73	1.66	0.09	1.57
	2001-40	***0.62***	***-0.47***	***1.10***	***1.50***	***0.62***	***0.87***	***4.55***	***1.75***	***2.74***	***1.41***	***0.13***	***1.28***

Regions / Sectors	Period	Crops			Ruminants			Non-Ruminants			Weighted Average		
		TFP	EFF	TCH	TFP	EFF	TCH	TFP	EFF	TCH	TFP	EFF	TCH
Latin America & Caribbean (*contd.*)	2001-10	0.66	-0.43	1.10	1.65	0.76	0.87	5.48	2.57	2.82	1.61	0.30	1.29
	2011-20	0.63	-0.46	1.10	1.54	0.66	0.87	4.82	2.00	2.75	1.47	0.18	1.28
	2021-30	0.61	-0.48	1.10	1.45	0.57	0.87	4.19	1.46	2.69	1.34	0.06	1.27
	2031-40	0.59	-0.50	1.10	1.36	0.48	0.87	3.72	0.99	2.69	1.24	-0.04	1.27

Productivity growth rates for Agriculture estimated weighted shares of each sub-sector in agriculture in each period.

Countries in FAO data

1. Industrialized Countries: Australia, Austria, Belux, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, UK, USA

2. Economies in Transition: Albania, Bulgaria, Czech Rep., Slovakia, Hungary, Poland, Romania, former USSR, former Yugoslav SFR

3. China

4. East & South East Asia: Cambodia, Indonesia, Korea D P Rep., Korea Rep, Laos, Malaysia, Mongolia, Myanmar, Philippines, Singapore, Thailand, Viet Nam

5. Asia Developing: Bangladesh, Bhutan, China, Cambodia, India, Indonesia, Iran, Iraq, Jordan, Korea D P Rp, Korea Rep, Laos, Lebanon, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Saudi Arabia, Singapore, Sri Lanka, Syria, Thailand, Turkey, Vietnam, Yemen
6. Middle East and North Africa: Algeria, Egypt, Iran, Iraq, Jordan, Lebanon, Libya, Morocco, Saudi Arabia, Sudan, Syria, Tunisia, Turkey, Yemen

7. Sub-Saharan Africa: Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Rep, Chad, Congo, Dem R, Congo, Rep, Cote d'Ivoire, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia Madagascar, Malawi, Mali, Mauritania, Mozambique, Namibia Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe

8. Latin America & Caribbean: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Rp, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Suriname, Trinidad & Tobago, Uruguay, Venezuela

Table 2. Cointegration Results for Each pair of regions and countries for Crops, Ruminants and Non-Ruminants Efficiency Levels

Country/Region	World	Developed Countries	Developing Countries	Western Europe	Economies in Transition	North Africa and Middle East	East & South East Asia	Latin America	Sub-Saharan Africa
China	-,5,-	5,-,-	—	—	-,-,5	—	—	—	—
World		—	-,5,-	-,5,5	-,1,-	—	—	-,5,5	-,5,-
Developed Countries			—	-,-,5	-,-,5	—	—	1,-,5	—
Developing Countries				—	—	5,-,-	—	5,-,1	—
Western Europe					—	5,-,-	—	5,-,5	-,-,1
Economies in Transition						—	—	-,5,-	5,-,-
North Africa & Middle East							—	5,-,-	5,-,-
East & Southeast Asia								-,-,5	5,-,5
Latin America									5,-,1

*Each cell denotes the significance level of the cointegration test for crops, ruminants and non-ruminants, in that order. A dash denotes no cointegration. For example, in the pair Developed Countries/Latin America, 1,-,5 denotes cointegration at the 1% level for crops, no cointegration for ruminants and at the 1% level for non-ruminants.