M Alauddin, TJ Coelli & DSP Rao (2005)

PROJECT TITLE

The Sustainability of Agricultural Productivity Growth in a Changing Environment: An International Perspective

PROJECT SUMMARY

Despite significant growth in world agriculture in recent decades, there are real concerns that the accompanying environmental consequences of agricultural intensification may threaten sustainability. This project aims to investigate agricultural productivity in 120 countries using cutting-edge econometric techniques and panel data over fifty years, with an emphasis on modelling the sustainability of productivity growth as a complex and multidimensional problem involving economic, environmental and institutional factors. It identifies major problems and potential solutions emphasizing sustainable livelihoods for the rural masses in developing countries, and examines Australia's role in maintaining global agricultural growth.

AIMS AND BACKGROUND

Over the last five decades to 2000 the world population has increased by 140 per cent from 2.5 billion to 6 billion. By the middle of this century the world is likely to witness a population growth of between 3 and 4 billion with most of this increase occurring in the poorest regions where the income elasticity of demand for food is at its highest. Though there has been a significant reduction in global poverty in the last decade, there are still an estimated 1.1 billion people living under $1/per day and 2.1 billion people under $2/day, two thirds to three fourths of whom live in rural areas in Asia and Sub-Saharan Africa (Thirtle et al. 2003). However, the incidence of poverty has increased in Sub-Saharan Africa and most of the transitional economies (World Bank 2003).

The striking feature of the process of development of world agriculture over the last hundred or so years is the transition from a land-based to a productivity-based agricultural system underpinned by scientific and technological advances. Although this transition commenced in the second half of the 19th century in most of the developed world, it only began a century later in much of the contemporary developing world (Ruttan, 2002), and some of the least developed countries are still yet to experience this technical revolution. Advances in science and technology following the Industrial Revolution have underpinned this change. On the other hand, as colonies the countries of the contemporary developing world benefited little from these advances except through the trickle down mechanism or where the direct interest of the colonial powers was paramount.

The sustainability of food production per capita preoccupied classical economists such as Malthus and Riacrdo. While the race between food production and population is critically important, the focus has shifted significantly to considering the sustainability of ecosystems and environmental factors on which continued agricultural development in particular, and economic development in general, depends. This issue is currently the concern of many (see, for example, Conway 1997). High population pressure and rapid pace of human activity including urbanization, industrialization and other economic activities have led to the dwindling supply of arable land per capita and the concomitant process of agricultural intensification in the developing world.

In the face of the rapid pace of industrialization and growth in GNP, environmental problems have worsened in many parts of the developing world (Tisdell and Dragun, 1999, p.1). While such developments often improve human welfare in terms of modernization and human-made environments, their impact on the natural environments has been far from benign. Alauddin (2004) finds a dichotomy between improvements in human-centred indicators of welfare such as human development and related indices and eco-centric indicators such bio-diversity indicators. A growing body of evidence recognizes the delicate nature of the growth-environment nexus as a consequence of the fragility of the physical environment (see, for example, WRI 2000).

The World Bank (1996, 4-5) sounds a cautionary note in that 'many environmental problems continue to intensify and in many countries there are few grounds for optimism ... costs of inappropriate economic policies on the environment are very high'. A similar concern is echoed by the World Resources Institute. WRI (2000, p.3), citing recent evidence argues that

> 'degraded agricultural lands threaten world's food production. The unprecedented scale of agricultural intensification raises two principal concerns. First there is a growing concern over the vulnerability of the productivity of the agro ecosystems to the stresses imposed on them by the intensification of agriculture. Can technological advances and increased inputs continue to offset the depletion of soil fertility and freshwater resources? As soil fertility reduces and water becomes scarcer, what will be the impact on food prices? Second are the broader concerns about negative external impacts of agricultural production are often accentuated by intensification?. These negative impacts include additional stresses that agro ecosystems can generate beyond their own boundaries but which are not reflected in agro ecosystem management and production costs, or in the prices consumed pay for food and fibre goods'.

It has long been realized that with a growing population and an accompanying decline in the supply of arable land per capita, there is very little prospect for expanding food production by bringing in more land under cultivation. The only way forward is to augment the productivity per hectare of cultivated land. In their influential work, Hayami and Ruttan (1985, 310-11) espouse internal land-augmentation (extending the intensive margin of cultivation) as opposed to external land-augmentation (extending the frontier of cultivation) as a way of overcoming severe constraints on the supply of arable land per capita.

Unsurprisingly, then, explaining productivity growth in agriculture has been the subject matter of extensive research. Colin Clark (1940), in his pioneering study *Conditions of Economic Progress*, first examined productivities per unit of land area and per unit of labour over time and across countries. Almost three decades later Hayami (1969) and Hayami and Inagi (1969) revived interests in cross-country time series analysis of land and labour productivity in agriculture. Subsequent research in this area involved estimation of cross-country production functions and multifactor productivity estimates (see for example, Trueblood and Ruttan 1995). Hayami and Ruttan (1970), Kawagoe et al (1985) and Lau and Yotopoulos (1989) employed meta-production function analyses in growth accounting frameworks to account for differences in agricultural labour and land productivity among individual countries and between developed and developing countries. Findings resulting from these studies rather unsurprisingly identified internal resource endowments (land and livestock), modern technical inputs (machinery and fertilisers) and human capital (general and technical education) as sources of variation among countries (Ruttan 2002).

More recently, researchers have elaborated on the question of resource constraints and sources of technical change. Hayami (2002) and Ruttan (2002) identify sources and constraints to productivity growth, van Ark (2002) attempts to measure the influence of information and communication technologies on productivity growth, and Craig et al. (1997) and Thirtle et al. (2003) gauge the influence of research and development (R&D) expenditure on growth in productivity.

Since these studies, there have been significant changes in the policy direction in at least two ways: First, the world now pays much more attention than in the past to letting the market forces operate and to the private sector. It is therefore important to view how much of the developing world where the operation of the market forces may penalise the very poor and where the private sector is still small cope with the interplay of the forces of growth and environmental change. Second, the depletion and degradation land and water resources seem manifestly clear. Therefore, the focus of technological innovations must shift from land-augmentation to environment-augmentation (environment-saving) by considering environment as factor of production (Lopez 1994).

In light of the above the explanation of productivity change warrants a revisit incorporating new developments in econometric techniques and environmental factors. To-date research in this area has been piecemeal and has been constrained by significant data limitations. For example, land quality indexes that are commonly used were developed by Peterson (1987). These are based on internal land augmentation such as irrigation and development of land infrastructure and are determined significantly by market forces with little role for environmental factors such as soil quality. At the other end of the spectrum Prescott-Allen (2001) focuses more or less exclusively on the environmental factors and assign weights somewhat arbitrarily. While both the indexes are useful none is complete by itself. Furthermore, the Peterson study relates primarily to the early 1980s data and therefore predates much of the impact of the environmental consequences of the process of agricultural intensification in the developing world.

The preceding discussion identifies several gaps in the existing literature. First, when making international comparisons of productivity performances it uses partial productivity measures such as labour productivity or land productivity. Secondly, the Peterson land quality indexes are used as a proxy for environmental factors. There are not only inadequate but also outdated. Third, the need for incorporating environment as a factor of production is assumed away (cf. Lopez 1994).

The proposed study seeks to fill these gaps by the following means.

- Estimation of total factor productivity in agriculture for more than 120 countries covering a period of 40 years;
- Development of suitable indices of environmental quality by combining econo-centric (Peterson type) and environment-centric (Prescott-Allen type) factors. This will create a comprehensive data base for a range of environmental indicators.
- Development of performance measurement methods that explicitly account for the adverse effects on the environment. In this regard, the project will review the existing measures like the "green gross domestic product" and develop and further refine existing methods to measure productivity change after adjusting for environmental change leading to *green productivity measures*; and
- Econometric analysis and examination of the sustainability of agricultural productivity performance and identify economic, policy, environmental and geographical, and institutional factors that that play a major role in improving green productivity growth and, thereby, help improve sustainability of global agricultural output.

E3 SIGNIFICANCE AND INNOVATION

As a first study of its kind, this study provides a comprehensive and integrated view of the process of agricultural productivity growth in an international perspective. The issue is of global significance. The proposed research is significant in three important ways:

1. It considers an important issue of sustainability of agricultural productivity growth as complex and multidimensional problem involving economics, environmental and institutional factors.
2. It has a global focus and identifies Australia's role in tackling a global issue.
3. Anticipated outcomes will advance knowledge by (a) providing a better understanding of the of the issues that underlie the process of agricultural development for 120 countries, mostly from the developing world; (b) making use of the techniques at the forefront of the literature exposing the limitations of the existing techniques; (c) by identifying major issues and challenges with special emphasis on the prospects for sustainable livelihoods of the rural masses.

The project is innovative in terms of the methodology used and its embrace of a holistic rather than a piecemeal approach to a very complex problem.

E4 APPROACH AND METHODOLOGY

The approach and methodology in this study consist of four major components:

1. Estimation of Total Factor Productivity (TFP) levels and growth;
2. Compilation of a range of environmental indicators;
3. Estimation of environmentally adjusted “green productivity” measures; and
4. Econometric analysis of productivity growth and policy conclusions.

Estimation of TFP Levels and Growth

Closely related to the aims of the project are the methods and techniques to be used. In sharp contrast to much of the earlier work on productivity in agriculture, which had an emphasis on labour productivity, the present study focuses on total factor productivity growth, which takes into account all the important measurable inputs into agriculture. That is, in addition to labour, the current study also considers land, fertilizer, tractors and livestock inputs in modelling agricultural production. Furthermore, much of the past work on agricultural productivity was based on estimated production functions which in the recent literature have been termed “augmented neoclassical” production functions or index number calculations (see, for example, Ruttan 2002; Pingali and Heisey 2001). In contrast, the current study makes use of the most recent work done by two of the chief investigators Coelli and Rao (see Rao and Coelli, 2004; and Coelli and Rao, 2005)

This will be of particular value in our study because this will allow us to investigate the relationships that may exist between each of these components of TFP growth and the various factors (economic, environmental, political, institutional and social) that are included in the analysis. It is expected that the relationships will differ among these two components because of the different stages of development of the countries which are trying to catch up to the frontier, versus those that are shifting it out.

The methods that we use to estimate and decompose TFP growth are based upon the Malmquist TFP index methods proposed by Fare et al (1994). The Malmquist TFP index measures the TFP change between two data points (s and t) by calculating the ratio of the distances of each data point relative to a common technology. If the period t technology is used as the reference technology, the Malmquist (output-orientated) TFP change index between period s (the base period) and period t is can be written as

$$m_o^t(y_s, x_s, y_t, x_t) = \frac{d_o^t(y_t, x_t)}{d_o^t(y_s, x_s)}.$$

Alternatively, if the period s reference technology is used it is defined as

$$m_o^s(y_s, x_s, y_t, x_t) = \frac{d_o^s(y_t, x_t)}{d_o^s(y_s, x_s)}.$$

Note that in the above equations the notation $d_o^s(x_t, y_t)$ represents the distance from the period t observation to the period s technology. A value of m_o greater than one will indicate positive TFP growth from period s to period t while a value less than one indicates a TFP decline.

These two (period s and period t) indices are only equivalent if the technology is Hicks output neutral. That is, if the output distance functions may be represented as $d_o^t(x,y) = A(t)d_o(x,y)$, for all t. To avoid the necessity to either impose this restriction or to arbitrarily choose one of the two technologies, the Malmquist TFP index is often defined as the geometric mean of these two indices

$$m_o(y_s, x_s, y_t, x_t) = \left[\frac{d_o^s(y_t, x_t)}{d_o^s(y_s, x_s)} \times \frac{d_o^t(y_t, x_t)}{d_o^t(y_s, x_s)}\right]^{1/2}.$$

The distance functions in this productivity index can be rearranged to show that it equivalent to the product of a technical efficiency change index and an index of technical change

$$m_o\left(y_s, x_s, y_t, x_t\right) = \frac{d_o^t\left(y_t, x_t\right)}{d_o^s\left(y_s, x_s\right)}\left[\frac{d_o^s\left(y_t, x_t\right)}{d_o^t\left(y_t, x_t\right)} \times \frac{d_o^s\left(y_s, x_s\right)}{d_o^t\left(y_s, x_s\right)}\right]^{1/2}$$

The ratio outside the square brackets in the above equation measures the change in the output-oriented measure of Farrell technical efficiency between periods s and t. That is, the efficiency change index is equivalent to the ratio of the Farrell technical efficiency in period t to the Farrell technical efficiency in period s. The remaining part of the index in the above equation is a measure of technical change. It is the geometric mean of the shift in technology between the two periods, evaluated at x_t and also at x_s.

The above Malmquist TFP indices (and its components) can be calculated for each country between each pair of adjacent years, since we have access to panel data on agricultural inputs and outputs for each of these 120 countries over a period of 40 years. The calculation of the required distances requires the estimation of a multi-input, multi-output production frontier in each year. This can be done using either non-parametric methods (e.g. data envelopment analysis) or using parametric methods (e.g. by estimating a distance function using stochastic frontier techniques). The latter method has the advantage that it is a statistical technique that can accommodate data noise, while the former method has the advantage that it does not require the imposition of a particular functional form for the technology. Given that both techniques have their relative merits, we intend to apply both methods and assess the sensitivity of our results to the choice of methodology. For more information on these methods see Coelli et al (1998).

The Malmquist TFP indices used for comparing levels of agricultural productivity across countries will not satisfy the property of transitivity (see Forsund, 2004). The project team will make use of the weighted and unweighted EKS methods proposed in Rao and Odonnell, 2002 to compare TFP levels. For purposes of comparisons TFP growth, the team will make use of chain-linked indices.

Compilation of a range of environmental indicators

This aspect of the project is quite challenging. Lack of readily available and useable information on various aspects of the physical environment in agriculture renders this task quite difficult. The project team will make an assessment of the existing data on environmental indicators and will then explore the possibility of constructing a comprehensive set of indicators that measure changes in the environment that is more directly related to agriculture. In particular, the team will focus on degradation of soil and water quality. This will require information on soil quality including loss of organic matter and, land utilization including incidence of multiple cropping, amount of land area protected, land modification urbanization.

It will also assess the incidence of groundwater irrigation. Employing long run data on precipitation and evapotranspiration (Publications in Climatology 1963; Mitchell et al. 2001), it is possible to obtain a clear picture of the incidence of recharging of aquifers. To the extent that they are not fully charged for a significant part of the year excessive use of groundwater can lead to significant lower of groundwater tables and dry land salinity. This might already be happening in parts of parts of South Asia (Shah et al. 2003; Alauddin and Hossain, 2001). Groundwater economy in South Asia is a burgeoning industry with significant ramifications of the environment. Useful information can be gathered from IWMI in Colombo.

One important way to measure environment quality, amongst others, is to construct a bio-diversity index. Alauddin (2004, 261-62; see also Alauddin and Tisdell, 1998) estimated the index for 24 countries by using the highest percentage of protected land as a ceiling and by setting it equal to unity (e.g. 43.1 per cent for Ecuador). The indices for other countries can be derived using Ecuador as the base. The procedure is somewhat analogous to the derivation of HDI or related measures. The proposed project will modify the index by adjusting it where possible, for quality of protected areas and extend it to as many countries as possible.

Estimation of Green TFP indexes

Once a comprehensive set of measures of environmental quality are compiled, then the research team will employ two different strategies to analyse the influence and role of environmental factors in agricultural production.

1. First the team will use a more standard approach and employ the latest panel data econometric techniques to analyse the relationship between productivity growth performance and various environmental indicators and examine if productivity growth is at the expense of environmental degradation. The team will also employ the Battese and Coelli (1995) model to see if these factors can be directly incorporated into a stochastic frontier model

2. The chief investigators will make use of more recently developed efficiency measurement techniques to derive productivity measures that directly account for any environmental consequences resulting from growth in traditional measures of agricultural productivity. The project team will use the following methodology in developing “green productivity” indicators:

- Treat environmental consequences as “undesirable outputs” or alternatively as “environmental inputs” into agricultural production;
- Modify the production technology to accommodate environmental consequences leading to what may be considered an “environmental” or “polluting” technology;
- Describe and characterise the environmental technology using directional distance functions (see Färe and Grosskopf, 2004 for definitions and properties);
- Estimate the directional distance functions using agricultural data collected for the project;
- Use estimated distance functions in compiling “green” productivity indexes, and provide a standard decomposition of these indexes into technical change and efficiency change measures; and
- Examine sustainability of agricultural productivity growth at the country, regional and global level through an analysis of the “standard: and “green” agricultural productivity growth estimates.

The analytical framework for the study of directional distance functions and the construction additive and multiplicative index numbers for measuring productivity change is reasonably well-developed. The project team believes that there is considerable scope for developing the econometric methodology necessary for the estimation of the directional distance functions – an area that is still in its infancy. The chief investigators are confident of making significant contributions in this direction.

Estimation of green gross domestic product for agriculture

Two methods are currently available for deriving the green national accounts estimates. These are as follows:

(a) User cost method

Elserafy (1989) proposes this method where net receipt derived from an asset is split into two components: those that accrue at the expense of capital/assets degradation and those earned independently of asset degradation. This method is based on the idea that say a natural resource field theoretically be sold and the revenue can be invested in financial assists and thereby earning interest (X) each year to infinity or that receipt (R) could be earned from exploitation of the assets for a finite of ' n ' years until reserve are fully exhausted. The discounted sum of those two potential sources of income can then be equated:

$$\sum_{j=0}^{n} \frac{R_{t+j}}{(1+r)^{j}} = \sum_{j=0}^{\alpha} \frac{X}{(1+r)^{j}}$$

This is simplified by assuming that future expected revenue remains constant at the revenue in time period and rearranged as

$$R - X = \frac{R}{(1+r)^{n+1}}$$

The difference between total annual receipt (R) and true income is capital depreciation cost, regarded in Keynesian sense user cost.

(b) Net Price Method

An alternative approach to estimate depreciation of natural assets is based on net receipt price minus marginal cost, attributable to extractable of the natural resource in a given year. Thus net receipt multiplied by the quantity extracted which can be regarded as the user cost or economic depreciation of the asset. It is then deducted from GDP. It is called Hotelling - rent approach. This method has been used in the World Resource Institute Studies of National Accounts and resource depletion in Indonesia, Costa Rica, Philippines (Crowards TM, 1996, p 216). Crowards (1996) has derived modified net national product for natural depletion and represented as follows:

NNP = C+ K- (PN - MCN)(LN - D) + (PR - MCR) (G - LR)

Where, C is aggregate consumption. K is investment. PN is price of the non-renewable resources. PN is marginal cost of extraction of non renewable resources. LN is quantity of extracted of non-renewable resources. D is discoveries of non-renewable resources. PR is price of non renewable resources. MCR is marginal of non renewable resources. G is the growth of renewable resources. LR is the quantity harvested or loss of renewable resources. Growth of 'G' in excess of harvests 'LR ' could increase net product and similarly, discoveries ' D ' will reduce the deduction made loss of these resources and could even result in a net addition.

Given that the focus of this project is on agriculture and that the above two methods are relevant to estimation of aggregate national accounts, their adaptation for the purpose is warranted. Land and water are the two fundamental resources in agriculture.

Depreciation (degradation) in land and water quality especially groundwater is widely reported by researchers (Prescott-Allen 2001; Shah et al 2003). Furthermore, to a significant extent groundwater is a non-renewable resource because of significant divergence between precipitation and evapotranspiration, in many countries leaving the aquifers less than fully recharged for a significant part of the year. A significant body of literature clearly indicates growing dependence on this vital but fragile resource especially in the vast region of South Asia and China (see for example, Shah et al 2003; Shah and Wang 2004). The extent to which land is a renewable resource is debatable given its declining quality in many countries. A strong case, therefore, exists, for treating land and water as partially non-renewable resources and this must be reflected in the revised estimates of the agricultural sector GDP. In view of the data problems inherent in such an exercise appropriate sensitivity analysis will be carried out to derive a range of estimates agricultural GDP.

Table 1: Work Plan for the Project

Time Frame	Task
First Year: 2006	
January -March	Review of material and FAO Data for agricultural sector comparisons
April June	Estimation and revision of national, regional and global agricultural productivity estimates using the latest data from FAO
July September	Begin collection of data on environmental indicators
October-December	Review of literature on directional distance functions and begin work on the econometric estimation of distance function
Second Year: 2007	
January -March	Data collection to continue (through the year)
April - September	Estimation of directional distance functions using production and environmental data; preparation of papers on the econometric methodology for presentation at national and international conferences
October-December	Preliminary estimates of “green” productivity measures
Third Year: 2008	
January-June	Further refinement of the methodology and compilation of final results
July September	Analysis of green and standard productivity measures; policy implications; preparation of papers
October-December	Prepare data on agricultural output and productivity for dissemination

E5 NATIONAL BENEFIT

The proposed project is consistent with two of Australia’s national research priority areas (Research Priority 1: Environmentally Sustainable Australia & Research Priority 4: Safeguarding Australia).

The proposed project is at the cutting edge of research in the field and offers a solution to a longstanding problem encountered in constructing consistent panel data sets for productivity and a range of environmental indicators. The project aims to provide a theoretically superior panel data set designed to satisfy the crucial internal consistency of data and at the same time make use of all the existing data.

Given that the study aims to establish linkage between sustainable livelihoods and resource management, Australia can orientate its foreign aid toward direct attack on poverty through sustainable resource management. Australia has considerable expertise in tackling environmental issues involving for example, dry land salinity, forestry and fisheries. Given Australia’s comparative advantage, this could pay significant trade dividends if proper areas can be identified.

More importantly, given the present world security climate following September 2001, poverty alleviation in appropriately focussed geographical locations in the region could significantly reduce the chance of terrorism and crime in our region. The project through its findings can enhance Australia’s understanding of the economic and social issues that confront many countries (especially in Asia) in the developing world. Even through causes of terrorism and crime are complex, one could hardly deny economic disenfranchisement as an important cause. Australia’s role if appropriately played could make a positive contribution in safeguarding Australia.

E6 COMMUNICATION OF RESULTS

It is the considered view of the research team that the manner and mode of the communication of the principal results is crucial. The results consist of two principal components. The first is the set of cross-country and inter-temporal measures of agricultural productivity both in terms of levels and trends, and various environmental indicators. The second component is of a more analytical nature outlining the procedures and advances made in the analytical sections of the project.

The empirical results, produced in the form of a large tableau of productivity, derived environmental indicators for nearly 120 countries over a period a period of five decades will be made available in a user-friendly medium and format.

The team members anticipate authoring a number of quality research papers which will be presented at various international conferences and submitted to international journals for publication. Given their tract record it is highly probable that the outcomes of this research will find their way into reputable international outlets.

E7 DESCRIPTION OF PERSONNEL

The team for the project consists of very experienced researchers with highly complementary skills.

Dr Alauddin is well known for his research in the field of economic development, environment and sustainability. He has considerable experience in analysing development issues employing quantitative techniques as well as concepts from environmental and ecological economics. His first book (with Clem Tisdell) *The Green Revolution and Economic Development* provided an integrated view of the process in terms of growth, distribution, stability and sustainability. The book received a highly favourable review from Professor John W Mellor in *Economic Development and Cultural Change*. His subsequent research (epitomised by Alauddin and Tisdell 1998; Alauddin and Hossain 2001; Alauddin 2004) has and continues to investigate the intricate nature of the relation between growth, environment and sustainable livelihoods and has found its way into journals of international repute (further details are provided in Part B10). Alauddin’s long experience and expertise are eminently suited to this project. It is a natural extension his continuing research in the field.

Professor Rao has worked extensively on the construction of internationally comparable agricultural output aggregates for the Food and Agriculture of the United Nations which are commonly used in global agricultural productivity studies. He has jointly worked with Prof. Coelli on the issues of catch-up and convergence in global agriculture. So the proposed work is a natural extension of the work undertaken by Prof. Rao. His research expertise on index number methods for international comparisons is crucial for this project. In recognition of his contributions in the area of international comparisons, Rao has been appointed to the Technical Advisory Group for the 2004-06 ICP Round at the World Bank.

Professor Coelli is an econometrician whose methodological contributions in stochastic frontier and data envelopment analysis (DEA) methods are widely cited. Furthermore, much of his applied work has involved analyses of a range of agricultural industries in various developing countries. His skills and experiences are directly relevant to this project and highly complementary to Rao’s experience and familiarity with international comparisons and index numbers and Alauddin’s expertise in economic development. Professor Coelli is currently an Associate Editor for the *Journal of Productivity Analysis* and a Member of the Editorial Advisory Board for *Agricultural Economics*.

It is rare that such a team of eminent researchers with established research records is able to come together to tackle a very important problem, the solutions to which are likely to result in significant contribution to the field and are used as inputs into advanced research encompassing productivity growth and sustainable development.

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