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Economic Development and the Role of Agricultural Technology

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Abstract: In earlier debates on economic development, the agricultural sector's role was somewhat controversial. While dualistic models highlighted the importance of agriculture, the mainstream literature placed a greater emphasis on the creation of a modern industrial sector. Soon agriculture disappeared from the mainstream development literature to re-emerge recently with a variety of multiple-sector growth models emphasizing the key role of agriculture and specifically technology in agriculture. This paper is an empirical cross-country analysis of agricultural technology's role in economic development. Specifically, the hypothesis being tested is whether improvements in agricultural technology have a significant impact on long-run economic growth. The results indicate that agricultural modernization has a positive effect on both measures of economic growth and human development.

Keywords: agriculture, technology, growth, well-being

Economic Development and the Role of Agricultural Technology

Introduction

Initially development economics concentrated on questions concerning the industrialization process. The main questions had to do with how to modernize through overcoming the constraints of traditional society. The latter was often linked with agriculture and rural people, commonly called peasant agriculture. This sector was generally thought to act as a drag on the development process. Thus traditional and peasant farming were obstacles, systems which had to be reduced and eventually eliminated if modernization was to succeed.

However, economic historians often saw agriculture as playing a critical role in the industrialization of England. Dualistic models also directly modeled traditional agriculture in the long-run growth process. In these models the conclusion often implied that the long-run growth process must be a balanced one with agricultural productivity a necessary condition for eventual industrial/manufacturing growth. In other words, if productivity in agriculture remained stagnant, the development of a modern manufacturing sector would be limited.

Throughout much of the 1980s and 1990s much of the analysis of the role/contribution of agriculture was carried out by agricultural economists. Much of this work concentrated on technological innovation in agriculture, the institutional structure necessary to foster technical innovation, etc. However, in terms of long-run growth models, agriculture disappeared. This sector and its role were, for the most part, ignored in models of long-run growth emphasizing industrialization and manufacturing.

Recently, however, one finds a re-emergence of interest in agriculture. Papers by Gollin, et. al. (2002) and Olsson and Hibbs (2005) argue that agriculture and the productivity of agriculture is the key to understanding the timing of the shift from an agrarian based to an industrially based society. The importance of agricultural technology in reducing poverty is found in Lipton (1977), Kerr and Kolavalli (1999), Datt and Ravallion (1998), Ravallion and Datt (1999), Mellor (2001), and Thirtle et al. (2003) to name a few. In addition, some non-traditional roles have also been attributed to agriculture in the development process.

Given the literature referred to above on the importance of agriculture and agricultural technology in the development process, the hypothesis in this paper concerning agriculture is that improvements in agricultural technology are a pre-condition to, and have a significant positive impact on, long-run growth. The implication of such a hypothesis would be that countries which did not have the necessary pre-condition, that is they did not improve agricultural technology, did not grow as fast as those that did. The paper is an empirical exercise in testing the above hypothesis.

The paper is organized as follows. The first section will review the literature, both traditional and non-traditional, on agriculture's role in the growth and development process. Section two will discuss the data utilized as well as the empirical methodology that is applied. Sections three and four will summarize the empirical results with respect to growth and various measures of agricultural technology. Section five will present the results related to human development. Finally, section six summarizes the paper and presents the important conclusions.

Review of the Literature

Much of the early thinking on economic development ignored agriculture altogether. For example, Rosenstein-Rodan's (1943) early work concentrated on manufacturing and industry. He argued that the piecemeal establishment of manufacturing in poor regions lacking infrastructure would not likely be successful. Instead, investment in industry and manufacturing had to be on a broad front such that various industries could create markets for each other's products.

There were a set of theories which, however, did see a role in the development process for agriculture. These were dualistic theories of development constructed by Lewis (1954), Fei and Ranis (1961), and Jorgenson (1961). These theories divided the less developed economy into the traditional and modern sector. The modern sector was driven by profit maximization and the accumulation of physical capital. The traditional sector was subsistence oriented and usually thought to be dominated by peasant agricultural production. This sector was characterized by output sharing mechanisms rather than profit maximization.

In many of these models it was presumed that the traditional sector was characterized by surplus labor. That is, there was so much labor in this sector that it could be withdrawn and put to productive work in the modern sector without any fall in output in the traditional sector (marginal product of labor in the traditional sector is zero). In effect, "free growth" was possible through mobilization of labor for modern production. However, once surplus labor was exhausted, the expansion of the modern sector might very well be strangled. Continued withdrawal of labor would lead to falling output in the traditional sector leading to a rise in the relative price of the traditional sector output relative to that in the modern sector. Johnston and Mellor (1961) built upon these ideas in their analysis of the role of agriculture in overall economic development. They argued that agriculture supplied the labor necessary to man the modern sector firms as well as the food necessary to feed that labor. In addition, the agricultural sector was seen as serving as a market for the produce of the modern sector, a stimulus from the demand side. Finally, perhaps most importantly, agriculture was likely to serve as the main source of savings necessary to finance the expansion of the modern sector.

After these developments, agriculture disappeared from general models aimed at analyzing economic growth and development. Instead, much of the literature concerned with agriculture concentrated on analyzing productivity growth in the traditional, agricultural sector. Perhaps the most interesting and innovative work in this area has been undertaken by Hayami and Ruttan (1985) in developing a theory of induced technical and institutional innovation.

Recently, multiple sector growth models have begun to be constructed with agricultural sectors. Matsuyama (1991) developed an endogenous, two sector growth model. In this model the engine of growth, the driving force, was learning by doing in the manufacturing sector. He compared and contrasted the implications of a closed and open economy model. In the closed economy case, an increase in agricultural productivity (as measured by total factor productivity) spurs overall economic growth since this eases the expansion of learning by doing via manufacturing. However, in the open economy case there is a negative link between agricultural productivity and overall growth. This occurs because the more productive the agricultural sector is, the more resources that will be devoted to agriculture based on comparative advantage. This, of course, implies less manufacturing, less learning by doing, and less growth.

The results from Matsuyama's model are, of course, based on assuming that all learning by doing occurs in manufacturing, none in agriculture. However, learning by doing in manufacturing could enhance productivity in agriculture and perhaps vice versa. More generally, the model's results stem from the assumption that agriculture is, by nature, incapable of sustaining rapid productivity growth. Thus it is inevitable that higher initial productivity in agriculture (exogenously determined) would lower long-run growth.

This idea that productivity growth is slow in agriculture is actually contradicted by empirical analysis. Martin and Mitra (2001) utilize a panel data set for approximately 50 countries over the period 1967-1992 to analyze this issue. They found that at all levels of development technical progress appears to have been faster in agriculture than in manufacturing. In addition, "there is strong evidence of convergence in levels and growth rates of TFP in agriculture, suggesting relatively rapid international dissemination of innovation" (p.417). These results suggest that a large agricultural sector need not be a disadvantage in the overall growth process. It may likely be an advantage if productivity growth is rapid.

There is also a huge literature on the role of the agricultural sector and agricultural technology in reducing poverty. Thirtle, et al. (2003) shows that research-led technological change in the agricultural sector generates enough productivity growth to generate high rates of return in Africa and Asia and substantially reduces poverty in these regions. Additionally, Lipton (1977) showed that agricultural growth based on improved technology was effective in reducing poverty in developing countries. Kerr and Kolavalli (1999) argued that it was research-led technological change in agriculture that led Asian countries from famines to food sufficiency. Mellor (2001) argued that agricultural productivity reduces both rural as well as urban poverty, an idea echoed in Datt and Ravallion (1998) and Ravallion and Datt (1999). Sectoral studies conducted for individual countries or selected regions by Datt and Ravallion (1996), Warr (2001), and Woden (1999), conducting research on India, Southeast Asia, and Bangladesh respectively, show that growth in the primary or agricultural sector helps to reduce both rural as well as urban poverty more effectively than urban growth.

Theorists have now begun to explicitly model the agricultural sector in multiple sector growth models. A recent example of this is provided by the work of Gollin, Parente, and Rogerson (2002). They extend the neoclassical model to incorporate an agricultural sector. They attempt to model the structural transformation that comes with development (agriculture shrinking, manufacturing expanding). The intuition of the model can be summarized as follows. Agricultural output per person must reach a certain level before modern technology will be applied to agricultural production and labor can flow out of agriculture and into industry. The rate at which labor can then flow out is determined by the rate of technological change in agriculture. Low agricultural productivity (labor productivity) can thus substantially delay the onset of industrialization.

Other research has examined new links between agriculture and the growth of the rest of the economy. One can think of these new links as representing non-traditional roles for agriculture. Timmer (1995) argues that agriculture plays a significant role in reducing poverty by stimulating the development of agribusiness activities as well as stimulating the demand for manufactured inputs. Stringer (2001) argues that the agricultural sector performs important social welfare functions in developing nations. For example, during an economic downturn or an external income shock or financial crisis, agriculture can act "as a buffer, safety net, and as an economic stabilizer" (p.7). The flexibility of the production process allows for labor to be substituted for capital thus cushioning economic blows. Thus people frequently return to the farm during bad times.

One can summarize much of this discussion in the following way. Agriculture's role in the development process can be seen as a supplier of resources, most importantly labor, for the expansion of modern manufacturing. If disequilibrium exists such that the marginal product of labor in manufacturing exceeds that in agriculture (the marginal product of labor in agriculture need not be zero as Lewis originally argued), then transferring labor from the agricultural sector to the manufacturing sector will enhance overall growth. Empirically, there seems to be support for the proposition that factor market disequilibrium creates an opportunity to enhance growth by reallocating resources from agriculture to manufacturing (see Humphries and Knowles (1998), Dowrick and Gemmell (1991), and Feder (1986)). A second strand of thought argues that before the industrialization process can occur an increase in agricultural productivity must occur. Related to this, improvements in productivity in agriculture may indeed be easier for less developed nations to bring about, that is the potential for raising agricultural productivity may be very great, providing the foundation for rapid overall growth. Finally, enhanced agricultural productivity may be the most effective mechanism for improving well being in rural areas and this in turn may promote more rapid overall growth.

This paper focuses on the role of agricultural productivity (as measured by agricultural technology) in the process of overall growth and its impact on well being. Several questions suggest themselves. Is the modernization of agriculture an important determinant of overall growth? Is this effect robust to the inclusion of other variables? Given the non-traditional roles for agriculture, does agricultural modernization have a significant impact on human development? Is this impact robust to the inclusion of other variables? The key contribution of this paper is to utilize several measures of agricultural technology in an empirical estimation process which seeks to answer these questions. The methodology and data that will be utilized to address these questions is discussed in the following section.

Methodology and Data

In this paper, it is hypothesized that better agricultural technology which leads to improvements in agricultural productivity is a pre-condition for and has a significant impact on long-run growth, where growth is defined as the average rate of change of real per capita GDP from 1960 to 1995. This paper utilizes four different measures of agricultural productivity. The first two measures of agricultural productivity are a measure of fertilizer intensity and an interaction term of fertilizer and tractor intensity. Often agricultural technology is divided into two categories: biochemical and mechanical. Biochemical technologies generally require an intensification of fertilizer usage while mechanical innovations require increased usage of implements such as tractors, often combined with increased fertilizer use. The third measure is an interaction term incorporating fertilizer intensity, tractor intensity, and education of the labor force.

This incorporates a human capital element under the assumption that biochemical and mechanical technologies can only be effectively used if the individuals utilizing them have sufficient knowledge.

The first three measures of productivity discussed above are indirect in nature in that the assumption is that the more intensive the use of tractors, fertilizer, and education, the more productive the agricultural sector. The fourth measure of agricultural productivity is total factor productivity in agriculture as measured by the Malmquist index. The index uses a non-parametric approach for constructing production frontiers for a group of countries and measuring each country's output relative to that frontier. Productivity growth measures the extent to which a country moves towards this frontier even as this frontier itself moves out (via technological change) through time. It is a general measure of productivity (incorporating the effect of all inputs) rather than a partial measure (such as the average product of labor or capital).

The first three measures of agricultural technology are utilized in the analysis of this section of the paper. In order to get some intuition in terms of the relation between economic growth and the first three measures of agricultural technology, the analysis begins by checking the correlation between economic growth (growth in real GDP per capita) over the time period 1960 to 1995 and each of the three measures of agricultural productivity at the beginning of the period.

Table 1 goes here

The *lnFert61* variable is the natural log of fertilizer intensity for the year 1961. It is measured as kilograms (nitrogen, potash, phosphates) per hectare of land in 1961. The second measure of agricultural technology is *lnModern61*. It is an interaction term formed by multiplying fertilizer intensity (1961) by tractor intensity (tractors per hectare of land in 1961). The third measure is *lnAgModern61* which is an interaction term formed by multiplying fertilizer intensity in 1961 by tractor intensity in 1961 by average years of schooling (1965). This is a broader measure of agricultural technology since it incorporates the impact of tractors and human capital. Average years of schooling in 1965 represents the earliest availability of this data. The correlation table shows that all three measures of initial agricultural productivity are highly correlated to economic growth.

In order to test the hypothesis of the paper, we begin by constructing a simple model given by:

(1a) $GR6095 = a + b(lnGDP60) + c(lnFert61) + d(Asia) + e(LatA) + f(SSA) + \varepsilon$,

(1b) $GR6095 = a + b(lnGDP60) + c\,(lnModern61) + d(Asia) + e(LatA) + f(SSA) + \varepsilon$,

(1c) $GR6095 = a + b(lnGDP60) + c\,(lnAgModern61) + d(Asia) + e(LatA) + f(SSA) + \varepsilon$.

The dependent variable is given by *GR6095* which is the growth rate of real GDP per capita from 1960 to 1995. In addition to the measures of agricultural technology, the two equations also include the natural log of GDP per capita in 1960 (*lnGDP60*) in order to capture any sort of convergence effect which might occur. Additionally, regional dummy variables for Asia (*Asia*) Sub-Saharan Africa (*SSA*), and Latin America (*LatA*) are also included. Equations (1a), (1b) and (1c) try to capture the impact of agricultural technology on per capita GDP growth for the given period after we control for the influences of per capita GDP at the beginning of this time period, to account for any convergence or residual effect, as well as regional impact from the three regions mentioned above.

It should be pointed out that the type of analysis illustrated above is subject to an endogeneity issue or problem. There are two related issues that explain the endogeneity problem. First, endogenous variables are those variables which are determined by other variables in the system as opposed to exogenous variables which can be considered external shocks to the system. The other most important source of endogeneity is reverse causality that is when two variables (or more) may be causing each other simultaneously. Thus, to be able to make an authentic causal claim one needs a truly exogenous variable, that is, a variable which is not related to any of the other variables in the system, unobserved or observed. The implication of such endogeneity issues for the purpose of this paper is that our main independent variable (a measure of agricultural technology) and the dependent variable could be influenced by some other unobserved factor and/or the variables could be bi-directionally causal. Thus making arguments concerning causality from independent to dependent variables becomes problematic. Although we have chosen measures of technology at the start of the time period under analysis, this does not completely solve the problem. The ideal solution to the problem would be to use instrumental variables estimations. However, useful and appropriate instruments are not immediately obvious and using the wrong instruments would lead to unreliable results. With this in mind, we have decided not to pursue instrumental variables analysis. However, given the discussion above we would like to acknowledge the imitations in our present analysis given the possible endogeneity issues.

After estimating the above equation(s) the model is broadened to identify and control for other variables that may also have affected the growth of per capita GDP during that period. This will also serve as a test of robustness of the results to model specification. The more general model is given by the following equations:

(2a) $GR6095 = a + b(lnGDP60) + c(lnFert61) + d(lnSchool65) + e(lnInv6095)$
$+ f(LogFrankRom) + g(ICRGE80) + h(Asia) + i(LatA) + j(SSA) + \varepsilon$,

(2b) $GR6095 = a + b(lnGDP60) + c(lnFERT61) + d(lnSchool65) + e(Inv6095)$
$+ f(LogFrankRom) + g(Statehist) + h(Asia) + i(LatA) + j(SSA) + \varepsilon$,

(3a) $GR6095 = a + b(lnGDP60) + c(lnModern61) + d(lnSchool65) + e(lnInv6095)$
$+ f(LogFrankRom) + g(ICRGE80) + h(Asia) + i(LatA) + j(SSA) + \varepsilon$,

(3b) $GR6095 = a + b(lnGDP60) + c(lnModern61) + d(lnSchool65) + e(lnInv6095)$
$+ f(LogFrankRom) + g(Statehist) + h(Asia) + i(LatA) + j(SSA) + \varepsilon$,

(4a) $GR6095 = a + b(lnGDP60) + c(lnAgModern61) + d(lnInv6095) + e(LogFrankRom)$
$+ f(ICRGE80) + g(Asia) + h(LatA) + i(SSA) + \varepsilon$,

(4b) $GR6095 = a + b(lnGDP60) + c(lnAgModern61) + d(lnInv6095) + e(LogFrankRom)$
$+ f(Statehist) + g(Asia) + h(LatA) + i(SSA) + \varepsilon$.

One of the additional variables added is a measure for educational attainment given by *lnSchool65* which is the natural log of the years of total schooling of the population in 1965. Since *lnAgModern61* includes a measure of human capital, the *lnSchool65* variable was excluded from the estimation of equations (4a) and (4b) to avoid multicollinearity issues. Additional variables include a measure of investment given by *lnInv6095* which is the natural log of average investment from 1960 to 1995 (this is gross capital formation which consists of additions to the fixed assets of the economy plus the net change in inventories), a measure of institutional quality given by *ICRGE80* which is an average of five different measures of institutional quality, a variable for state antiquity given by *Statehist* , and a series of dummy variables for Asia (*Asia*), Latin America (*LatA*), and Sub-Saharan Africa (*SSA*). Finally, most previous empirical work generally include some measure of the degree of openness of a nation. To measure this, the instrumental variable constructed by Frankel and Roemer (1996) is utilized. It is the log of the predicted trade share of an economy, based on a gravity model of international trade that only uses a country's population and geographical features (*LogFrankRom*). Frankel and Roemer (1996) indicate that this variable is strongly related to actual trade shares.[1]

Several of these variables need further explanation. The *Statehist* variable is an index measuring the type of state that exists (tribal level or above, foreign or locally based, the territorial extent of the state) and how long it has existed for various regions of the world. The time period covered is from 1 to 1950 C.E. The higher the index number, the longer a state has been in existence. The hypothesis is that the longer the state has been in existence, the more likely it will have resolved issues of internal conflict and the more legitimate the state is likely to be viewed by its citizens. Thus growth is likely to be higher. The *ICRGE80* variable is an average of measures of corruption, repudiation of contracts, expropriation risk, rule of law, and bureaucratic quality for the year 1980. The higher this average, the better the quality of institutions and better quality institutions are thought to enhance growth. As it turns out, the *Statehist* and *ICRGE80* variables are strongly related to each other. As a result, in order to avoid multicollinearity issues these variables were not included together in any estimation. This accounts for two versions,

(a) and (b), for each of the equations given above. Version (a) includes the institutional quality variable *ICRGE80* and version (b) includes the state antiquity variable *Statehist*.

There have been a number of papers that have utilized *ICRGE* for various years as a measure of institutional quality (Knack and Keefer, 1995), in an attempt to explain growth. Easterly and Levine (2003) have used a similar set of variables to try to make a distinction between the effects of endowments and the effects of institutions on per capita GDP. Acemoglu, Johnson, and Robinson (2001) and Rodrik, Subramanian, and Trebbi (2004) use instruments for measures of institutional quality and attempt to distinguish between the effects of geography, institutions, and policy on GDP per capita.

Much of the data used to estimate this and the previous equation are taken from Bockstette, Chanda, and Putterman (2002). Specifically, *GR6095*, *lnGDP60*, *lnInv6095*, *ICRGE80*, *Statehist*, and the regional dummies all come from this paper. The *lnSchool65* variable comes from Barro and Lee (1993). The fertilizer intensity and tractor intensity variables are taken from the World Resources Institute (www.wri.org/) who in turn derived the data from the FAO.

The discussion of the previous section indicated that agriculture is likely to play an important role in terms of providing a safety net for a society lacking formal programs aimed at social welfare. Under such an assumption one would expect that the level of human development would also be influenced by agricultural modernization. In order to test this proposition, per capita GDP growth is replaced with the average level of the human development index (*HDI*) from 1975 to 1995 as the dependent variable. The HDI is a summary measure of human development which is calculated as

HDI = 1/3 (life expectancy index) + 1/3 (education index) + 1/3 (GDP index).

The life expectancy index measures life expectancy at birth (relative measure), the education index is a weighted index of the adult literacy rate and the gross enrollment index, and the GDP index is calculated using adjusted GDP per capita (PPP US$). The data used to calculate the average is taken from various issues of the *Human Development Report*. Thus the following equation is estimated to test the hypothesis.

(5a) $HDI7595 = \alpha + \beta(lnFert61) + \gamma(lnInv6095) + \delta(ICRGE80) + \zeta(LogFrankRom) + \theta(Asia) + \lambda(LatA) + \nu(SSA) + \varepsilon.$

(5b) $HDI7595 = \alpha + \beta(lnModern61) + \gamma(lnInv6095) + \delta(ICRGE80) + \zeta(LogFrankRom) + \theta(Asia) + \lambda(LatA) + \nu(SSA) + \varepsilon.$

Notice that *lnAgModern61* is not utilized as an independent variable. This is due to the fact that it incorporates a measure of educational levels and education, as discussed above, is also incorporated in *HDI7595*. Also, the *lnGDP60* is also excluded since convergence in GDP is not being tested. The above equations are also estimated utilizing the *Statehist* variable as a substitute for *ICRGE80*. These are both measures of the quality of institutions and the argument here is that improved institutional quality is likely to result in improved well being. The inclusion of *lnInv6095* in the estimating equation is linked to the hypothesis that the more investment that occurs in a country, the greater economic opportunities are likely to be and thus the more likely that individuals will be able to find jobs and thus experience improvements in well being. The greater the openness to trade is also included since it is hypothesized that the resulting increases in income will improve welfare. Finally, as outlined in Section One of the paper, agricultural productivity has been included in the estimated equation because it is thought by some scholars to have a direct impact on poverty and thus well being. That is, a highly productive and prosperous agricultural sector is likely to have farmers that are in good health and have greater access to education in addition to higher incomes.

The data set covers 89 countries (27 African, 22 Latin American, 14 Asian, 5 Middle Eastern, 16 European, 5 others). For various regressions some countries have missing values, thus the size of the sample accordingly shrinks. The next section of the paper will discuss and interpret the results.

Results: First Three Measures of Technology

The results of the estimations of equations (1a), (1b), and (1c) are presented in Table 2. All estimations are OLS estimations and all the results are based on White heteroscedasticity-consistent standard errors and covariances. As can be seen, all three measures of agricultural technology have positive, significant effects on long-term economic growth. In addition, it appears that when we control for initial agricultural technology, irrespective of how it is measured, conditional convergence is also occurring among the countries in the sample, given the negative, statistically significant coefficient for GDP per capita in 1960. Finally, the dummy variables for Latin America and Subsaharan Africa were negative and statistically significant.

Table 2 goes here

The results indicate that agricultural technology, measured three ways, had a significant impact on long-run growth. In order to test the robustness of the result, equations (2a), (2b), (3a), (3b), (4a), and (4b) are estimated and the results are presented in Table 3. All estimations show that there is evidence of conditional convergence. Moreover the results also testify to the robustness of the statistically significant and positive impact that agricultural technology has on per capita GDP growth from the mid-1960's to the mid 1990's.

Table 3 goes here

Examining the results for equations (2a) and (2b), one can see that the *Statehist* and *ICRGE80* variables are positive and statistically significant when included separately. The variables *lnSchool65* and *lnInv6095* are positive, but are only statistically significant for (2b) and (2a) respectively. The *LogFrankRom* variable has a positive sign in (2a) and a negative sign in (2b) and is statistically significant in neither. The dummy variables for Latin America, Asia, and Subsaharan Africa are negative but only statistically significant in (2b).

Examining the results for equations (3a) and (3b), one can see that both *lnSchool65* and *lnInv6095* are both positive in sign in both estimations, but only education is statistically significant. Both *Statehist* and *ICRGE80* are positive and statistically significant when entered separately. *LogFrankRom* is negative in sign, but is not statistically significant. The Latin American dummy variable is negative and statistically significant in both formulations. Sub-Saharan Africa and Asia are negative and statistically negative only in (3b).

Examining the results for equations (4a) and (4b), one finds that *lnInv6095* is positive, but it is statistically significant only in (4a). *LogFrankRom* is negative, but is not statistically significant in either estimation. The *Statehist* and *ICRGE80* variables are both positive and statistically significant when entered separately. The Latin America dummy variable is negative and statistically significant in both formulations, while Sub-Saharan Africa is negative and statistically significant in (4b).

At this point one might wonder if the results discussed above are influenced by the poor data quality for the measures of technology in agriculture for the 1960s. In order to explore this possibility, equations (1a), (1b), (2a), (2b), (3a), and (3b) were all re-estimated using values for fertilizer intensity and fertilizer intensity times tractor intensity for 1975. The results with respect to these variables remain unchanged. Agricultural technology has a positive, statistically significant effect on growth from 1960 to 1995.

In summary, two sets of variables seem to have had significantly positive effects on long-term growth: all three versions of the agricultural technology variable and *Statehist*/*ICRGE80* variables. This implies that improvements in agricultural technology along with good quality institutions within stable states leads to more rapid economic growth. In all but one of the formulations *LogFrankRom* had a negative sign, but it was never statistically significant. This result is somewhat surprising since there is a large literature that seems to imply that trade openness not only allows for gains from comparative advantage (level effects on GDP), but also facilitates the spillover of technical knowledge (Keller, 2004) from developed to developing countries (raising the growth rate of GDP). The lack of significance of the trade or openness variable may very well be due to the fact that trade may allow for the spillover of agricultural knowledge from country to country (Alston, 2002). Thus trade may lead to increases in GDP growth via improvements in technology utilized. This effect would not be captured by the above estimations.

Results: Malmquist Productivity

In the previous section three proxy measures for agricultural productivity were used. The implicit inference was that higher values for these variables represented better technologies and thus more productive agricultural sectors. A more direct measure is provided by Trueblood and Coggins (2003). Their paper examines productivity growth in agriculture for a large sample of nations for the time period 1961 to 1991. Malmquist productivity indexes, discussed earlier in the paper, are constructed utilizing the non-parametric approach for constructing frontiers. Utilizing these measures equation (1a), (2a), and (2b) are re-estimated by substituting the Malmquist productivity growth measures, *AgTFP*, for the variable *lnFert61*. The results are presented in Table 4.

Table 4 goes here

As can be seen, in all three estimations the *AgTFP* is positive, although it is statistically significant for just two. Economic convergence is supported in all three formulations. The *lnSchool65* variable is positive and statistically significant, whereas the *lnInv6095* while positive is only significant for one estimation. Both *Statehist* and *ICRGE80* are positive and statistically significant. The trade variable is not significant in any formulation.

An alternative set of data on agricultural productivity is provided in Ludena, et al. (2005).[2] Their paper examines productivity growth in agriculture for a large sample of nations for the time period 1961 to 2000. It too constructs Malmquist productivity indexes which are multifactor measures of productivity change. Utilizing these measures, equations (1a), (2a), and (2b) are re-estimated by substituting the Malmquist productivity measures from Ludena, et al. (2005) for the variable *lnFert61*. The growth rate of GDP per capita now represents the average growth rate from 1960 to 2000 (*GR6000*) while the investment variable now represents average investment also for the period 1960 to 2000 (*lnInv6000*). The results of these estimations are presented in Table 5.

Table 5 goes here

As can be seen, in all three estimations the *AgTFP* variable is both positive and statistically significant. Again agricultural productivity is important for growth. It appears that economic convergence is supported in all three formulations. Both the *lnSchool65* and the *lnInv6000* are also positive and statistically significant. Thus improved education and increased investment enhance growth in the long-run. In addition, both *Statehist* and *ICGRE80* have positive signs and are statistically significant, which implies that good institutions and states enhance growth. However, the *LogFrankRom* remains insignificant, which indicates that perhaps trade's effect on growth may not be direct, but may operate through its impact on productivity.

Results: Human Development Index

The next step in the analysis is to shift focus to a broader definition of development and to see how agricultural modernization has affected the general well-being of a country. So far the focus had been on factors that have an impact on economic growth. Now the analysis moves on to test how much impact agricultural technology and productivity might have had on human development itself. As mentioned in the previous section, the recent literature has found significant connections between the agricultural sector and poverty reduction, increases in social welfare or reduction in morbidity, etc. These measures of well-being are perhaps best captured by human development as measured by the Human Development Index (HDI) constructed by the UNDP. In order to analyze this relationship between human welfare or development and agricultural modernization, the dependent variable used in Tables 2, 3, and 4 is replaced with the average of the HDI index from 1975 to 1995. Accordingly, the next set of results is based on estimates of Equations (5a) and (5b) and are presented in Table 6.[3] In addition, *AgTFP,* as developed by Trueblood and Coggins (2003), is utilized as a measure of agricultural productivity (the last column in Table 6). Finally, the *lnGDP60* is no longer included since the HDI index also includes a measure of per capita GDP.

Table 6 goes here

In a number of ways the above results echo the results for economic growth presented in Tables 3, 4, and 5, especially with respect to agricultural technology and productivity. These show that agricultural technology/productivity is a causal factor for improved well-being as well as for economic growth. The investment variable is also positive and statistically significant across all estimations. Institutional quality also seems to have a robust, positive, and statistically significant effect on well being. Openness (*LogFrankRom*) does not seem to have an influence on the Human Development index. The regional dummy variables for Asia and Subsaharan Africa are negative and, for the most part, statistically significant. The Latin American dummy is positive and statistically significant. The above equations were also estimated using *Statehist* as a substitute for *ICRGE80*. The results for the agricultural technology/productivity variables remain unchanged.

One might argue that including the *AgTFP* measure of productivity might introduce multicollinearity between the dependent variable, the average value of HDI for 1975 to 1995, and the independent variable (*AgTFP*). That is, human capital is a component of the HDI measure and improved human capital is also likely to increase *AgTFP*. However, the important thing to note is that the results do not change dramatically when *AgTFP* is introduced as a substitute for *lnFert61* and *lnModern61*. One would have expected that if multicollinearity existed, there would be a dramatic change in the results. Additionally, several tests of multicollinearity revealed no evidence of multicollinearuty between the two variables.[4]

The results presented in the tables point to the importance of agricultural technology or agricultural modernization as a causal factor for economic growth and the well-being of the population. The paper began by asking the following questions. Is the modernization of agriculture an important determinant of overall growth? Is this effect robust to the inclusion of other variables? Given the non-traditional roles for agriculture, does agricultural modernization have a significant impact on human development? Is this impact robust to the inclusion of other variables? Now these can be answered. Modernization of agriculture is an important determinant of overall growth and it is robust to the inclusion of other variables. In addition, agricultural modernization does have a significant impact on the level of human development and this relationship, like the previous one, is robust to the inclusion of other variables.

Summary and Conclusions

In theorizing about long-run growth and development, agriculture seemed to disappear from the literature and ceased to play an important role after the development of dualistic models in the 1950s and 1960s. However, recently there has been a re-emergence of interest and a reconsideration of the importance of agriculture in the development process with a number of models being constructed which incorporate agriculture. These models and the theories they propose find agriculture in general and agricultural technology in particular to play a critical role in long-run growth and development.

An empirical analysis of agriculture's role in economic growth and development was undertaken in this paper. In particular, this paper analyzes the importance of a modernized agricultural sector for economic growth and development. Agricultural technology, as applied in this paper, is defined four different ways. Three of these represent proxy measures for agricultural productivity with the first measuring fertilizer intensity, the second fertilizer and tractor intensity, and the third including human capital as well as measures of fertilizer and tractor intensity. Using these proxy measures of agricultural productivity in the early 1960s the empirical results indicate that improved agricultural technology in the 1960s had a significant, positive influence on growth from 1960 to 1995. The fourth is a more direct measure of productivity. It is a Malmquist index measure of total factor productivity measured for two time periods, 1961 to 1991 and 1961 to 2000. It too is found to have a statistically significant positive influence on long-term growth.

The results reaffirmed the conclusions drawn from previous analysis concerning investment spending, education, and measures of institutional quality. That is, the work of Knack and Keefer (1995) and Bockstette, et al. (2002) indicated that institutional quality and state antiquity were both important factors in long-run growth. The results of this paper reaffirm these results. In addition, investment and human capital also seem to be important factors in long-run growth, thus reaffirming previous empirical work on growth theory (Jones, 2002). In addition to these variables, it seems that agricultural technology, also played an important role in economic growth.

The above analysis was repeated utilizing the human development index as the dependent variable. The hypothesis was that improved technology or modernization of the agricultural sector improves well being. Indeed, the measures of agricultural modernization seem to have statistically significant positive effects on human development.

The results of this paper complement the recent theoretical work incorporating the agricultural sector into multi-sector growth models. These theories indicate that historical, long-run growth was dependent on the growth of agricultural productivity via agricultural modernization. These theoretical conclusions are supported by the empirical work presented here.

References

Acemoglu, D., S. Johnson and J.A. Robinson, 2001. The Colonial Origins of Comparataive Development. *American Economic Review* 91 (5), 1369-1401.

Alston, J., 2002. Spillovers. *Australian Journal of Agricultural and Resource Economics* 46 (3), 315-346.

Barro, R.J. and J. Lee, 1993. International Comparisons of Educational Attainment. NBER Working Paper No. 4349.

Bockstette, V., A. Chanda, and L. Putterman, 2002. States and Markets: The Advantage of an Early Start. *Journal of Economic Growth* 7 (4), 347-369.

Datt, G., and M. Ravallion, 1998. Farm Productivity and Rural Poverty in India. *Journal of Development Studies* 34(4), 62-85.

Datt, G., and M. Ravallion, 1996. How Important to India's Poor is the Sectoral Composition of Economic Growth? *The World Bank Economic Review* 10(1), 1-25.

Dowrick, S. and N. Gemmell, 1991. Industrial Catching Up and Economic Growth: A Comparative Study Across the World's Capitalist Economics. *Economic Journal* 101 (405), 263-276.

Easterly, W. and R. Levine, 2003. Tropics, Germs, and Crops: How Endowments Influence Economic Development. *Journal of Monetary Economics* 50 (1), 3-39.

Feder, G., 1986. Growth in Semi-Industrialized Countries: A Statistical Analysis. In Chenery, H., S. Robinson, and M. Syrquin (eds.), *Industrialization and Growth: A Comparative Study*. Oxford University Press.

Fei, J. and G. Ranis, 1961. A Theory of Economic Development. *American Economic Review* 51 (4), 533-565.

Frankel, J. and D. Romer, 1999. Does Trade Cause Growth? *American Economic Review* 89 (3), 379-399.

Gollin, D., S. Parente, and R. Rogerson, 2002. The Role of Agriculture in Development. *American Economic Review* 92 (1), 160-164.

Hayami, Y. and V. Ruttan, 1985. *Agricultural Development: An International Perspective*. Johns Hopkins University Press, Baltimore, U.S.A., 506.

Humphries, H. and S. Knowles, 1998. Does Agriculture Contribute to Economic Growth? Some Empirical Evidence. *Applied Economics* 30 (6), 775-781.

Johnston, B. and J. Mellor, 1961. The Role of Agriculture in Economic Development. *American Economic Review* 51 (4), 566-593.

Jones, C., 2002. *Introduction to Economic Growth*. W.W. Norton, London, England, 237.

Jorgenson, D., 1961. The Development of a Dual Economy. *Economic Journal* (282), 209-334.

Keller, W., 2004. International Technology Diffusion. *Journal of Economic Literature* 42 (3), 752-782.

Kerr, J., and S. Kolavalli, 1999. Impact of Agricultural Research on Poverty Alleviation: Conceptual Framework with Illustrations from the Literature. EPTD Discussion Paper #56, Impact Assessment and Evaluation Group, IFPRI, Washington, D. C.

Knack, S. and P. Keefer, 1995. Institutions and Economic Performance: Cross-Country Tests Using Alternative Institutional Measures. *Economics and Politics* 7 (3), 207-228.

Lewis, W. A., 1954. Economic Development with Unlimited Supplies of Labour. *The Manchester School* 22 (1), 139-191.

Lipton, M., 1977. *Why Do Poor People Stay Poor? Urban Bias in World Development*. Temple Smith, London, 467..

Ludena, C.E., T.W. Hertel, P.V. Preckel, K. Foster, and A. Nin, 2005. Productivity Growth and Convergence in Crop, Ruminant and Non-Ruminant Production: Measurement and Forecasts. Prepared for Experts' Meeting on Long Term Scenarios of Asia's Growth and Trade, ADB, Manila, November 10-11.

Martin, W. and D. Mitra, 2001. Productivity Growth and Convergence in Agriculture And Manufacturing. *Economic Development and Cultural Change* 49 (2), 403-422.

Matsuyama, K., 1991. Increasing Returns, Industrialization, and Indeterminancy of Equilibrium. *Quarterly Journal of Economics* 106 (2), 617-650.

Mellor, J., 2001. Faster More Equitable Growth – Agriculture, Employment Multipliers, and Poverty Reduction. Paper prepared for USADD/G/EGAD.

Olsson, O. and D.A. Hibbs, 2005. Biogeography and Long-Run Economic Development. *European Economic Review,* 49 (4), 909-938.

Ravallion, M. and G. Datt, 1999. When is Growth Pro-Poor? Evidence from the Diverse Experience of India's States. World Bank policy research working paper series, 2263, World Bank, Washington, D.C.

Rodrik, D., A. Subramanian and F. Trebbi, 2004. Institutions Rule: The Primacy of Institutions Over Geography and Integration in Economic Development. *Journal of Economic Growth* 9 (2), 131-165.

Rosenstein-Rodan, P., 1943. Problems of Industrialization of Eastern and Southeastern Europe. *Economic Journal* 53 (2), 202-211.

Stringer, R., 2001. How Important are the ‘Nontraditional’ Economic Roles of Agriculture in Development? Discussion Paper No. 0118, Adelaide University, May.

Thirtle, C., L. Lin, and J. Piesse, 2003. The Impact of Research-led Agricultural Productivity Growth on Poverty Reduction in Africa, Asia and Latin America. *World Development* 31 (12), 1959-1975.

Timmer, C.P., 1995. Getting Agriculture Moving: Do Markets provide the Right Signals? *Food Policy* 20 (5), 455-472.

Trueblood, M.A. and J. Coggins, 2003. Intercountry Agricultural Efficiency and Productivity: A Malmquist Index Approach. World Bank, Washington, D.C.

Warr, P. G., 2001. Poverty Reduction and Sectoral Growth: Evidence from Southeast Asia. Paper presented at the WIDER Development Conference on Growth and Poverty, Helsinki.

Woden, Q., 1999. Growth, Poverty, and Inequality: A Regional Panel for Bangladesh. Policy Research Working Paper, 2072, The World Bank, Washington, D.C.

Footnotes

1. Originally these equations were estimated using as a measure of openness the variable exports plus imports divided by GDP. The results, for the other variables of the model, were very similar to those reported here using the measure developed by Frankel and Romer (1999). The latter is thought to be a more appropriate measure given the endogeneity issues connected with the trade share measure. Ideally, as noted previously in the paper, an instrumental variables analysis would be carried out. However, finding good instruments for the other variables in the analysis would be very difficult.
2. The authors would like to thank Ludena, et al. (2005) for making their data available.
3. The reader will note that *lnAgModern61* is not utilized as a measure of agricultural technology. This is due to the fact that this variable includes a measure of schooling. See the earlier discussion of equation (5b).
4. There was no evidence of pair-wise correlation. The R squared value of regression of HDI and *AgTFP* was only 0.29. Additionally, residual tests for autocorrelation and partial correlation of the equation with HDI and *AgTFP* showed no evidence of correlation. Tests of tolerance level and variance inflation factor based on the value of the R squared obtained from the above regression did not indicate presence of multicollineaarity. Additionally, centering was done by transforming the *AgTFP* values and the HDI values by subtracting the mean value from each case and then running the regression

with the centered values. This did not change the results in any significant manner.

Tables

Table 1: Correlations

	GR6095	*LnAgModern61*	*lnModern61*	*lnFert61*
GR6095	1			
lnAgModern61	0.543	1		
lnModern61	0.583	0.821	1	
lnFert61	0.443	0.771	0.792	1

Table 2
Long-Run Growth: Simple Model
(Equations (1a), (1b), and (1c))

	Ag.Var = *lnFert61*	Ag.var = *lnModern61*	Ag.Var = *lnAgModern61*
lnGDP60	**-0.008*****	**-0.005*****	**-0.008*****
t-Stat	3.89	3.61	4.49
AG. VARIABLE	**0.004*****	**0.001*****	**0.0004*****
t-Stat	4.41	5.15	6.99
Asia	0.003	-0.002	-0.006
t-Stat	0.89	0.54	1.43
SSA	**-0.02*****	**-0.02*****	**-0.02*****
t-Stat	4.75	5.24	5.11
LatA	**-0.01*****	**-0.01*****	**-0.02*****
t-Stat	4.52	6.03	6.35
Obervations	75	74	64
R-Squared	0.59	0.61	0.56

Note: Dependent variable: real per capita GDP growth from 1960 to 1995; a constant term is included in each equation but not reported here; * represents statistical significance at 90%, ** represents statistical significance at 95%, and *** represents statistical significance at 99%.

Table 3
Long-Run Growth: Control Variables Included
(Equations (2a), (2b), (3a), (3b), (4a), and (4b))

	Ag Var = *lnFert61*		Ag Var = *lnModern61*		Ag Var = *lnAgModern61*	
lnGDP60	**-0.010*** **	**-0.018*** **	**-0.010*** **	**-0.018*** **	**-0.010*** **	**-0.018*** **
t-Stat	*-3.48*	*-4.70*	*-4.07*	*-4.70*	*-4.27*	*-4.63*
Ag. Var	**0.002** **	**0.001*** **	**0.0004*** **	**0.001*** **	**0.0002** **	**0.0003** **
t-Stat	*1.95*	*3.75*	*2.77*	*3.75*	*2.10*	*2.50*
lnSchool65	0.004	**0.005** **	**0.006** **	**0.005** **	0.004	0.003
t-Stat	*1.33*	*1.77*	*2.03*	*1.77*	*1.39*	*0.95*
lnInv6095	**0.009** **	0.001	0.006	0.001	**0.008** **	0.004
t-Stat	*1.85*	*0.26*	*1.28*	*0.26*	*1.72*	*0.98*
LogFrankRom	0.001	-0.001	-0.001	-0.001	-0.001	-0.001
t-Stat	*0.21*	*-0.31*	*-0.50*	*-0.31*	*-0.49*	*-0.28*
Statehist	**0.016** **		**0.017** **		**0.018** **	
t-Stat	*2.17*		*2.51*		*2.61*	
ICRGE80		**0.004*** **		**0.004*** **		**0.004** **
t-Stat		*3.23*		*3.23*		*2.51*
Asia	0.005	**-0.008** **	-0.002	**-0.008** **	-0.0021	-0.007
t-Stat	*0.91*	*-1.87*	*-0.45*	*-1.87*	*-0.39*	*-1.49*
SSA	-0.010	**-0.026*** **	-0.013	**-0.026*** **	-0.012	**-0.025*** **
t-Stat	*-1.16*	*-4.29*	*-1.54*	*-4.29*	*-1.42*	*-3.81*
LatA	-0.007	**-0.010** **	**-0.010** **	**-0.010** **	**-0.009** **	**-0.011*** **
t-Stat	*-1.60*	*-2.91*	*-2.43*	*-2.91*	*-2.17*	*-2.72*
Observations	65	63	64	63	64	63
R-Squared	0.67	0.74	0.69	0.74	0.68	0.70

Note: Dependent variable: real per capita GDP growth from 1960 to 1995; a constant term is included in each equation but not reported here; * represents statistical significance at 90%, ** represents statistical significance at 95%, and *** represents statistical significance at 99%.

Table 4
Long-Run Growth Equations Utilizing TFP (1961-1991)
(Trueblood and Coggins, 2003)

	Ag Var = *AgTFP*		
LnGDP	**-0.004****	**-0.009*****	**-0.015*****
t-Stat	*2.31*	*-3.60*	*-4.22*
Ag. Var.	**0.002*****	**0.002****	0.001
t-Stat	*2.54*	*2.26*	*1.53*
lnSchool65		**0.006****	**0.005****
t-Stat		*2.10*	*2.00*
lnInv6095		**0.009****	0.006
t-Stat		*2.07*	*1.37*
lnFrankRom		-0.0004	0.0002
t-Stat		*-0.25*	*0.15*
Statehist5		**0.019*****	
t-Stat		*2.90*	
ICRGE80			**0.003***
t-Stat			*1.94*
ASIA	0.0020	0.003	-0.002
t-Stat	*0.52*	*0.79*	*-0.44*
SSA	**-0.02*****	-0.009	**-0.023*****
t-Stat	*5.4*	*-1.34*	*-3.36*
LatA	**-0.012*****	-0.005	**-0.008****
t-Stat	(-4.39)	*-1.22*	*-2.17*
Observations	74	62	61
R-Squared	0.49	0.67	0.66

Note: Dependent variable: real per capita GDP growth from 1960 to 1995; a constant term is included in each equation but not reported here; * represents statistical significance at 90%, ** represents statistical significance at 95%, and *** represents statistical significance at 99%.

Table 5
Long-Run Growth Equations Utilizing TFP (1961-2000)
(Ludena, et al., 2005)

	Ag Var = *AgTFP*		
LnGDP	**-0.406***	**-0.983****	**-1.639*****
t-Stat	*-1.91*	*-2.91*	*-3.84*
Ag. Var.	**0.298*****	**0.252*****	**0.161****
t-Stat	*4.02*	*3.18*	*2.21*
lnSchool65		**0.725****	**0.501***
t-Stat		*2.18*	*1.67*
lnInv6000		**2.136****	**1.630***
t-Stat		*2.19*	*1.77*
lnFrankRom		-0.014	0.077
t-Stat		*-0.07*	*0.46*
Statehist5		**1.733*****	
t-Stat		*2.67*	
ICRGE80			**0.390*****
t-Stat			*2.68*
ASIA	0.434	0.145	-0.254
t-Stat	*0.96*	*0.35*	*-0.58*
SSA	**-1.851*****	-0.269	**-1.658*****
t-Stat	*-3.88*	*-0.33*	*-2.53*
LatA	**-1.198*****	-0.461	-0.529
t-Stat	*-3.67*	*-0.97*	*-1.17*
Observations	84	71	70
R-Squared	0.41	0.55	0.60

Note: Dependent variable: per capita GDP growth from 1960 to 2000; a constant term is included in each equation but not reported here; * represents statistical significance at 90%, ** represents statistical significance at 95%, and *** represents statistical significance at 99%.

Table 6
Estimates Utilizing HDI (75-95) as Dependent Variable

	Ag.Var = *lnFert61*	Ag.var = *lnModern61*	Ag.Var =*AgTFP*
Ag. Var.	**0.023*** **	**0.002***	**0.013***
t-Stat	*2.68*	*1.90*	*1.83*
lnInv6095	**0.076*** **	**0.076*** **	**0.088*** **
t-Stat	*2.83*	*2.78*	*3.82*
LogFrankRom	-0.009	0.004	0.008
t-Stat	*-0.74*	*0.34*	*0.51*
ICRGE80	**0.030*** **	**0.038*** **	**0.034*** **
t-Stat	*4.29*	*5.84*	*5.30*
Asia	**-0.062** **	**-0.074** **	-0.050
t-Stat	*-2.48*	*-2.16*	*-1.48*
SSA	**-0.117*** **	**-0.139*** **	**-0.158*** **
t-Stat	*-3.89*	*-4.40*	*-4.74*
LatA	**0.052** **	**0.049***	**0.059***
t-Stat	*2.00*	*1.79*	*1.88*
Observations	66	65	67
R-Squared	0.84	0.82	0.83

Note: Dependent variable: real per capita GDP growth from 1960 to 1995; a constant term is included in each equation but not reported here; * represents statistical significance at 90%, ** represents statistical significance at 95%, and *** represents statistical significance at 99%.