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Measures of Fixed Capital in Agriculture

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Abstract

Capital is a fundamental component of agricultural production, and the accumulation of capital is key to growth in agriculture and the process of development. Unfortunately, cross-country data sets on agricultural fixed capital are rare. Using a common methodology that allows comparisons across countries, as well as over time, this paper introduces a data series on fixed capital in agriculture, based on national accounts data. The fixed capital measure differs remarkably from the Food and Agriculture Organization's data series on tractors, which has been widely utilized as a proxy for agricultural fixed capital. The authors construct comparable measures of capital in livestock and tree stock. They examine the evolution of the capital stocks from 1970 to 2000, paying particular attention to the changing composition of agricultural capital, as well as differences in the accumulation of capital for high-income and middle and lower-income countries. Using the capital measures in agricultural productivity analyses, the data yield estimated input elasticities substantially different from those found previously in the literature. The authors show explicitly that this is due to the improved data set on agricultural capital stocks, as well as the methodology used in the study.

This paper—a product of the Agriculture and Rural Development Team, Development Research Group—is part of a larger effort in the department to examine the determinants of agricultural growth. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at DLarson@worldbank.org. This study was supported by the Bank's Research Support Budget under the research project, "The Contributions of Governance to Growth in Agriculture".

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MEASURES OF FIXED CAPITAL IN AGRICULTURE

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Introduction

Data on sectoral investment and capital stocks are essential for empirical research in sectoral productivity, yet cross-country panels are rare for countries outside of the OECD. Crego et al. (1998) introduced a database on the capital stock in the agricultural and manufacturing sectors for 57 developed and developing countries for the years 1967-1992. We have updated the agricultural component of this database to the year 2000 for a subset of 30 countries. We construct three capital sub-components series: treestock, livestock, and fixed capital in agriculture. We modify a commonly used methodology for integrating investment to obtain the fixed capital stock. This methodology can also be used to compute comparable fixed capital stocks for other sectors and for the economy as a whole, in order to facilitate comparative analyses.[1]

After describing selective characteristics of the updated agricultural capital data set, including the evolution of aggregate capital stocks over time and the changing composition of agricultural capital, we revisit an earlier analysis of agricultural productivity that utilizes our data set on agricultural capital. We then show how the frequently used practice of employing farm machinery as a proxy for agricultural fixed capital leads to substantially different results.

Background

Measures of agricultural capital are fundamental to two important and related fields of empirical study. The first concerns the determinants of agricultural productivity and growth; the second concerns the structural transformation of developed and developing countries. Both areas of study are important for understanding economic development, since agriculture remains the largest source of employment in many poor countries today.[2] In general, as economies grow, labor flows from agriculture to other sectors. As a consequence, the shares of labor and GDP in the agricultural sector decline as part of this process; however in economies that perform well, the sector continues to grow through a build-up of physical and human capital and through the adoption of more productive technologies.[3]

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[1] This avenue of research is beyond the scope of this paper. Larson et al. (2000) provide an analysis of capital stocks in manufacturing and agriculture, as well as for the economy as a whole for 60 countries from 1967-1992.

[2] For example, the World Bank's World Development Report (2008) on agriculture estimates that 75 percent of the world's poor live in rural areas and that most poor rural households depend on agriculture as their primary source of income. The report classifies 21 developing countries as agricultural and an additional 19 as transitional.

[3] See Mundlak (2001), Mundlak, Larson, and Crego (1998), and Larson and Mundlak (1997).

Measured stocks of capital are required to characterize the transformation process and to distinguish growth that is due to the accumulation of input factors from that due to changes in factor productivity. Moreover, in order to compare this transformation process among countries, a compatible measure is needed across countries and through time. In general, this has been lacking, especially for panels that include developing countries.[4] By necessity, empirical studies have therefore looked to proxies for agricultural capital, most often measures related to on-farm machines, livestock, and orchards, or have omitted capital entirely.[5] As we argue below, the composition of capital varies as the prevalent technologies change as part of the structural transformation of economies. Consequently, the roles played by on-farm machines or other proxies for a general measure of capital change. In general, machinery capital becomes less relevant as the stock of capital in agriculture grows; this creates problems for studies of agricultural productivity and growth.

Mundlak, Larson, and Butzer (1999) and Coelli and Rao (2005) list a number of early cross-country studies of agricultural productivity, including important studies by Bhattacharjee (1955), Hayami and Ruttan (1970, 1971), Evenson and Kislev (1975), Nguyen (1979), Mundlak and Hellinghausen (1982), Kawagoe and Hayami (1983, 1985), Antle (1983), and Lau and Yotopoulos (1989). Varied capital measures, based on combinations of farm machinery, tractors, livestock, orchards, and, less frequently, data on irrigation and farm structures, were used. Recent econometric studies are less uniform in their methodology, but many still include capital proxies (most often in the form of livestock and machinery) in estimated production functions; examples include Fulginiti and Perrin (1993, 1998), Block (1994), Craig, Pardey, and Roseboom (1997), Wiebe et al. (2003), Cermeño, Maddala, and Trueblood (2003), Lio and Liu (2008), and Cermeño and Vázquez (2009).

Increasingly, agricultural productivity studies have also drawn on non-parametric or semi-parametric approaches. These are related to index number theory, and frequently employ data envelope analysis (DEA) programming methods to estimate either input or output distance

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[4] Ball et al. (2008, 2004) construct panel data sets of agricultural capital stocks for various OECD countries starting in the early 1970s. The Groningen Growth and Development Centre (GGDC) houses the EU KLEMS database on output and input growth at the industry level for 25 European Union member states, as well as the United States and Japan from 1970 to 2007 (www.euklems.net).

[5] Two-sector models of structural adjustment require comparable measures of capital in and out of agriculture. The lack of a consistent measure has prompted some researchers to exclude direct measures of agricultural capital from their analyses. See, for example, Restuccia, Yang, and Zhu (2008), Bah and Brada (2009), and references therein. In an examination of sectoral differences in TFP, Caselli (2005) used assumptions on factor shares to derive the sectoral (agricultural vs. nonagricultural) capital stocks necessary to compute TFP measures comparable across sectors.

functions from which productivity measures are defined. In the context of country panels, these studies most often entail decomposing changes in total factor productivity, via a Malmquist index fitted to measured inputs and outputs.[6] In some instances, a second-stage regression is used to explain variations in calculated productivity in terms of a set of determining state variables – for example, past research expenditures or the strength of political institutions.

Still, while the approaches applied to the problem of estimated agricultural productivity have become more varied, the underlying measures have not, and the alternative methods often build on the same data and the same proxies for capital as earlier studies. See, for example, Lusigi and Thirtle (1997), Arnade (1998), Coelli and Rao (2005), Fleming (2007), Fuglie (2008), Alene (2010), Headey, Alauddin, and Rao (2010), Nin-Pratt and Yu (2010), and Fulginiti (2010).[7]

Data set on agricultural capital stock

The series of agricultural capital stock presented here consists of three components: fixed capital, livestock, and treestock. In this sense, we distinguish between stores of capital that arise through investments and privately held productive natural endowments including land and water resources. National accounts report fixed capital investment, which does not wholly include livestock and treestock; therefore, we compute each component separately. Data sources along with the computer program used to calculate the capital series are documented in Crego et al. (1998).[8]

We construct the fixed-capital series based on national account investment data, using a modification of the perpetual inventory method. The method requires integration of the investment data to obtain capital stocks. For livestock the initial data are the number of animals. We need only calculate the values of the individual herds and then aggregate these values to obtain the total for the full stock of animals. For treestock we use the estimated present value of future income derived from the area planted in orchards.

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[6] See Färe et al. (1994) for an early application.

[7] Exceptions include the studies by Ball et al. (2008, 2004, 2001) in which the authors construct capital stocks from investment data for various OECD countries.

[8] The paper can be downloaded from the World Bank at http://go.worldbank.org/IJ0CWCLVR0. More recent agricultural investment series were obtained from updates of the original sources, as well as from United Nations National Accounts data.

Fixed capital

The data series on fixed capital is based upon national accounts data on fixed investment, which includes structures, equipment, machinery, and the like. The mapping from fixed investment to fixed capital follows the methodology of Ball et al. (1993). The capital stock is represented as a weighted sum of past investments where the sequence of relative efficiencies of capital of different ages serves as the weights. The following function of physical depreciation is chosen to describe the relationship between the efficiency of an asset and its age. Let L be the lifetime of the capital good, and β be a curvature parameter bounded from above by 1 in order to restrict productivity to be nonnegative. Then,

$$\begin{aligned} s_j &= (L - j)/(L - \beta j),\ 0 \le j < L \\ s_j &= 0,\ j \ge L \end{aligned} \tag{1}$$

The asset is discarded at age L, at which time its relative productivity becomes zero. To analyze this expression, we note that $ds_j/dj = L(\beta - 1)/(L - \beta j)^2 < 0$, for $0 \le j < L$, indicating that the productivity falls with age (use). The speed of the change in the depreciation with age depends on the sign of curvature parameter, β:

$$d^2 s_j / dj^2 = 2L\beta(\beta - 1)/(L - \beta j)^3. \tag{2}$$

When β is positive but less than unity $d^2 s_j/dj^2 < 0$, the physical depreciation accelerates with time (use), and the productivity curve is concave. Conversely, when β is negative, the productivity curve is convex. The lifetime of the asset is taken as a random variable with a normal distribution truncated at two standard deviations on both sides. Figure 1 illustrates the dependence of the productivity paths of buildings and agricultural machinery on the parameters in question.[9] The data sources that we use do not provide any information on the separate components of fixed capital, and so, we choose a single set of parameters.[10] Thus the capital stock in any given year is the sum of the relative efficiency for that year of all past investments.

Data on the value of gross fixed capital formation in agriculture (in local prices) were obtained from national accounts data. If the data series on investment is not sufficiently long,

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[9] The s curvature parameters (β) and lifetime parameters (L) in Figure 1 are taken from Ball et al. (1993). For buildings, β=0.75 and L=38 years; for agricultural machinery, β=0.50 and L=9 years.

[10] Judging the available evidence, we used the following parameters: curvature of 0.70, mean service life of 20 years, and standard deviation of 8 years.

information on the initial capital stock is also needed to construct the capital series, which is rarely available. Researchers use several different techniques for fixing, or seeding, the initial value. They are often forced to choose among competing seeding techniques based on criteria such as whether the methods generate negative initial values (see for instance, Nehru and Dhareshwar, 1993). This choice would not be necessary if the investment series were sufficiently long (large *T*) because the productivity of old capital goods is low and their contribution to the current stock is small.

Therefore, our approach is to generate lengthier investment time series when they do not exist. We do this by regressing the logarithm of the investment-output ratio on time for the study period. We then use this regression to estimate past values of the investment-output ratio and apply them to the published output data to generate the needed missing investment values. If the output values are not available, we can estimate them from a regression of output on time.[11]

The data series on fixed capital stock are constructed in constant local prices. To facilitate cross-country comparisons, the series need to be valued in comparable units. We value the series in current prices in local currency using national GDP deflators. Using "market exchange rates" from the International Monetary Fund, we convert the values to current US dollars. The series is then deflated by the US agricultural GDP deflator to obtain the capital stock series in constant (1990) US dollars.[12]

Livestock capital

A considerable amount of agricultural capital is embodied in livestock, which are used to perform various roles – such as breeding and draft power. According to the United Nation's accounting practices, animals that are not used for slaughter are included as fixed capital investments.[13]

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[11] Researchers at the FAO are introducing a more sophisticated method of estimating missing investment data, where they account for the possibility of structural breaks in the GDP and investment series (Anriquez and Daidone, 2010).

[12] For more discussion, see Appendix A in Larson et al. (2000).

[13] Based on the System of National Accounts (SNA) used by the United Nations, "Gross fixed capital formation includes outlays on reclamation and improvement of land and development and extension of timber tracts, mines, plantations, orchards, vineyards etc., and on breeding and dairy cattle, draft animals, and animals raised for wool." (United Nations, 1991, p. xiv). In the 1993 version of the SNA, cultivated assets are noted to be part of gross fixed capital formation; "Cultivated assets consist of livestock or trees that are used repeatedly or continuously over periods of time of more than one year to produce other goods or services. Thus, livestock that continue to be used in production year after year are fixed assets. They include, for example, breeding stock, dairy cattle, sheep reared for wool and draught animals. On the other hand, animals raised for slaughter, including poultry, are not fixed assets. Similarly, trees (including shrubs) that are cultivated in plantations for the products they yield year after year – such as fruit trees, vines, rubber trees, palm trees, etc. – are fixed assets. On the other hand, trees grown for timber that yield a finished product once only when they are ultimately felled are not fixed assets, just as cereals and vegetables that produce only a single

However, after closely examining the data, we find that this is not the case for many countries. Furthermore, changes in livestock used for slaughter are included as "increases in stocks," not as fixed capital. Thus we construct a separate data series on livestock capital, recognizing that there may be some overlap, but also that livestock accounts for a considerable share of agricultural capital and should not be ignored. We return to this issue in Appendix A.1.

Conceptually, the calculation of the livestock is fairly straightforward. The Food and Agricultural Organization (FAO) reports the quantities of all farm animals -- cattle, sheep, pigs, poultry, and so on. We aggregate the value of these individual components to obtain the livestock. Ideally, we would use market prices of live animals to value local herds, but these data were not consistently available. In their place, we use regional export unit values, based on FAO trade data, to value domestic herds. We calculate separate prices for each region by dividing regional dollar export values by regional export quantities. These unit prices are then applied to national herd statistics for each category of livestock. We convert the aggregate values to constant (1990) dollars by using the U.S. gross domestic product (GDP) deflator for the agricultural sector.

Treestock

Standing orchards, plantations, and smallholder trees represent another important category of investment in agriculture. According to United Nations accounting practices, the value of investments in treestock should be included along with other land improvements in national accounting systems. However, a close examination of country data suggests that, in practice, such stocks may go unaccounted (see Appendix A.1). We therefore construct a direct estimate of the value of treestock.

The available information for constructing the treestock consists of FAO data on the area harvested by crops, production, and output prices. We begin by using the condition for long-run equilibrium, in which the cost of investment in the orchard equals the present value of the expected future income generated by the orchard. The income from the orchard is value of output less the costs of production. There are no published data on production costs; thus we construct our estimates under the assumption that production costs account for 80% of gross revenues.

We derive the yield (output per hectare) from the data on output and area. The yield depends on the age of the trees, but the necessary information for estimating the yield curve is not

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crop when they are harvested cannot be fixed assets." In the most recent (2008) version of the SNA, the terminology changes from "cultivated assets" to "cultivated biological resources," while the description remains similar.

available. We therefore calculate the present value of the orchard under the assumption that the orchards are halfway through their assumed lifetime.[14] For the expected price, we calculate a five-year moving average of actual domestic producer prices, converted to nominal dollars, centered on the current year (two periods forward and two periods lagged). The income per hectare is imputed forward in time (with discounting) for each crop and then aggregated. We use the U.S. interest and inflation rates to calculate a real interest rate, which serves as the discounting factor. Finally, we convert the result to constant (1990) dollars by applying the U.S. agricultural GDP deflator.

Data[15]

The economies included in the agricultural investment data set are Australia, Austria, Canada, Cyprus, Denmark, Egypt, Finland, France, Greece, India, Indonesia, Italy, Kenya, Republic of Korea, Malawi, Mauritius, Morocco, the Netherlands, Norway, Pakistan, Peru, the Philippines, Sri Lanka, Sweden, Republic of Tanzania, Tunisia, Turkey, United Kingdom, United States, and Uruguay.

For most countries included in the data set on agricultural capital stocks, the series on the sectoral breakdown of fixed investment begin in the 1960s, thus sufficiently complete to estimate capital stocks beginning in 1967. All series on livestock and treestock begin in 1961. Looking forward, there is potential for the expansion of the data set on agricultural fixed capital to include more countries, but with a later starting date for the series.[16]

Evolution of capital stocks

Having a data series on agricultural capital which is comparable across countries and over time allows us to examine the evolution of capital stocks and assists us in gaining insight on the process of agricultural growth. In Figures 2 and 3, we present the frequency distribution of growth rates of the capital components for the 30 countries in our sample.[17] Capital accumulation in agriculture since 1970 has been positive in all of the countries (Figure 2). The median growth rate of agricultural

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[14] Estimated lifetimes are assigned specifically for each tree crop, ranging from 20 years for coffee to 200 years for olives (see Appendix A.2). For a discussion of vintage in the evaluation of orchards, see Akiyama and Trivedi (1987).

[15] The data set on agricultural capital stocks is available online at: http://www.farmfoundation.org/news/articlefiles/1725-capital_update_2000.pdf.

[16] Since the dissolution of the Soviet Union, Czechoslovakia, and Yugoslavia in the early 1990s, many of the newly independent countries report data on agricultural gross fixed capital formation.

[17] Average annual growth rates reported in this paper were obtained from trend regressions (natural log of variable on time).

capital is 5.3%. We see a similar pattern for each of the components of agricultural capital. Fixed capital and treestock have median growth rates of 5.6 and 5.7%, respectively. While livestock grew in all countries, the growth was slower than for the other two components (median of 3.6, with the distribution lying almost completely to the left of the others). This changing composition of agricultural capital is even more apparent in Figure 3. In 90% of the countries in our sample, the share of livestock in total agricultural capital fell over the period, with treestock and fixed capital becoming increasingly important inputs to agricultural production, depending upon the geographical constraints faced by the country.

We can gain insight on the dynamics of growth in agriculture by examining the changing composition of agricultural capital over time. The patterns of capital accumulation for each component vary over time. In Table 1, we present the average annual growth rates for the sample for each decade. Fixed capital grew at a rapid pace of 7.3% in the 1970s. The slowdown in fixed investment began in the 1980s and continued into the 1990s, though fixed capital was still growing by 3.6%. Livestock grew at a similar pace in the 1970s and 1980s (3.9 and 4.0% respectively), but then experienced slower growth in the 1990s. Treestock achieved a growth rate for the entire period comparable to that of fixed capital, but with a very different pattern over the decades. Treestock grew slower than fixed capital and livestock in the 1970s (3.2%) but achieved nearly double-digit growth rates in the 1980s. While the growth slowed in the 1990s, treestock continued to grow faster than fixed capital and livestock. Thus the decreasing share of livestock in total agricultural capital was due in part to the rapid growth in treestock in the 1980s and 1990s, as well as the slowdown in the accumulation of animal stocks in the 1990s.

In addition to the time dimension, there is much cross-country variability in agricultural capital stocks. For purposes of comparison, we divide the sample into high-income countries versus middle- and lower-income countries (Table 2).[18] High-income countries achieved higher growth rates of fixed capital (6.2% versus 5.5%), while the growth of treestock was considerably faster in middle- and lower-income countries (6.6% versus 4.0%). The growth rate of livestock was only slightly higher in middle- and lower-income countries (3.8% versus 3.3%).

These growth patterns led to interesting changes in the composition of capital for each income group as shown in Table 3 and Figure 4. The shares of each component in total agricultural

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[18] The income classifications are based upon the World Development Indicators of the World Bank in 2000.

capital were similar across income groups in 1970. Nearly half of total agricultural capital was composed of fixed capital. Treestock accounted for one-third, and the livestock share was around 20%. By 2000, the differences in the composition of capital were pronounced. In high-income countries, the share of fixed capital did not change, but livestock only accounted for 9% of total agricultural capital and treestock increased to 45%. In middle- and low-income countries, the share of treestock increased to 47% as well. Livestock still accounted for 17% of total agricultural capital, while the share of fixed capital fell to 37%.

Comparison of data on agricultural fixed capital with FAO data on tractors

The new database on agricultural fixed capital has several advantages, in particular the sound theoretical basis for the construction of the series, as well as the broad coverage of fixed capital to include structures and all types of equipment and machinery. From the United Nations' System of National Accounts (2008), fixed assets are defined as "produced assets that are used repeatedly or continuously in production processes for more than one year." Tractors represent one component of fixed capital.

The obvious drawback to the new database is the limited availability of national accounts data on gross fixed capital formation needed to construct the stock of fixed capital.[19] In the absence of cross-country data sets on agricultural fixed capital, the most commonly used proxy is FAO data on the numbers of tractors in use. This is a partial measure, in that it does not include buildings, irrigation systems, local infrastructure, as well as other types of machinery, nor does it take account of the varying quality and horsepower of tractors.[20] We compute the correlation between the FAO data series on the numbers of tractors in use and our data on agricultural fixed capital (of which tractors are one component) for each country; the average of the country correlations is 0.43. The median correlation is 0.8, so for half of the countries in our sample, the data series are somewhat correlated. Only 30% of the sample have correlations greater than 0.9, while the correlation was actually negative for seven countries. In Figure 5, we plot the data on fixed capital in agriculture

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[19] As discussed, raw data needed to construct the livestock and treestock measures are available from the FAO for a larger number of countries.

[20] In some studies, the data on tractors is converted into horsepower equivalents in an attempt to control for the quality differences in tractors (e.g. Craig, Pardey, and Roseboom (1997)).

against the FAO data on tractors.[21] The prevalence of vertical clusters suggests that the data on tractors were more stagnant than the data on the value of agricultural fixed capital.

Looking at Table 1, we see from the decade growth rates that the data series for tractors display the same pattern of slowing growth as fixed capital. However there are remarkable differences between the growth rates of tractors and fixed capital by income groups. In higher-income countries, there was very little growth in tractors, while fixed capital stocks grew at over 6%. It is clear from these comparisons that tractors are not a convincing proxy for agricultural fixed capital, and, by inference, of total agricultural capital.

We compare the data on agricultural capital to other economic variables to obtain a sense of its relevancy for economic growth. Figure 6 shows the relationship between average labor productivity (output-labor ratio) and the fixed capital-labor ratio for agriculture.[22] This scatter diagram traces the production function in terms of capital intensity, without allowing for the effects of other pertinent variables. In Figure 7, we plot capital intensity in the 1980s (the ratio of fixed capital stock to GDP in agriculture) against structural transformation in the 1990s (as measured by the percentage decline in the ratio of agricultural labor to total labor). Both figures suggest positive relationships between our data set on agricultural fixed capital stocks and measures of economic growth. However, plotting tractors per worker against agricultural GDP per worker (Figure 8) shows a weaker and much more volatile relationship.

Agricultural production function

Mundlak, Larson, and Butzer (1999) first utilize the panel data set on agricultural capital in an analysis of agricultural productivity for 37 countries for the time period 1970-1990. They present a model of production under heterogeneous technology, where the implemented technology is chosen jointly with the level of inputs. The empirical formulation allows for the dependence of parameters of the function, as well as the inputs, on a set of state variables, where state variables are defined to be a set of variables which characterize the environment in which the production decisions are

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[21] For ease in displaying the figure, data from the United States were excluded in Figure 5. Including the US would not alter the finding of the lack of a strong relationship between the two series.

[22] Since livestock and treestock are included in agricultural GDP, it would be more appropriate to examine the relationship between agricultural GDP and *total* agricultural capital, which includes these components. We compromise here for the purpose of a more direct comparison with Figure 8. Both fixed capital and capital of agricultural origin (livestock and treestock) are included in the productivity analysis which is reviewed in the next sections.

made. Examples of state variables may include such variables as culture, geography, institutions, and market integration.

Mundlak, Butzer, and Larson (2010) provide an in-depth discussion of panel data analysis, and in particular the dominance of the within estimator, utilizing an updated version of the data set on agricultural capital stock to extend the analysis to 2000.[23] The authors draw comparisons with the between estimators as well, noting that although the between estimators are biased, they still relay information valuable to understanding the underlying processes of growth. The authors explore the role of the country and time effects in accounting for the variability in productivity, and the ability of the state variables to capture some of these effects.

Using this prior work as a staging ground, we show the consequences of using an incomplete measure of capital on the estimates of production elasticities by replacing our measure of agricultural fixed capital with the FAO data on tractors. Before doing so, though, some background information on the underlying approach is required.

Theory

We estimate agricultural production, y, as a function of the inputs, x, and state variables, s, for a panel of countries, i, over time, t. Output and inputs are expressed in logs.

$$y_{it} = x_{it}\beta(s) + s_{it}\gamma + m_{0it} + u_{0it} \tag{3}$$

where $u_{0it} \sim$ IID $(0, \sigma_{00})$, $u_{jit} \sim$ IID $(0, \sigma_{jj})$, $E(u_{0it}u_{jit}) = 0$. Output and input prices are included in the set of state variables. With panel data the term m_{0it} is decomposed to a country effect and a time effect $m_{0it} = m_{0i} + m_{0t}$.[24]

The effect of the state variables is assumed to be linear; they serve as shifters in the production function. We impose the simplifying assumption of constant elasticities, so that $\beta(s)=\beta$. This elasticity is conditional upon the set of state variables, so that a different set of state variables will yield different estimates of β. Equation (3) is estimated under the within and between transformations of the data.

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[23] This is a revised version of Mundlak, Butzer, and Larson (2008).

[24] The full empirical framework is presented in Mundlak, Butzer, and Larson (2008).

Data

Output and inputs

Output is measured as agricultural GDP in 1990 US dollars.[25] Inputs to agricultural production include land, capital, labor, and fertilizers. Hectares of agricultural area are used for the measure of land. This includes arable land, land under permanent crops, and permanent pastures. Agricultural labor is defined as the economically active population in agriculture. Fertilizer consumption is measured in metric tons. It is often viewed as a proxy for the whole range of chemical inputs.[26] The construction of the agricultural capital data has already been described.

State variables[27]

State variables are meant to represent the economic environment related to the choice of the implemented techniques. Since the motivation for including these variables have already been discussed in full in the previous papers, we review them briefly here.

Technology

Three variables are included to account for differences in technology. The most commonly used variable to represent the level of technology in a country is a measure of human capital, which can be proxied by schooling years of the labor force (aged 15+).[28] The peak yield variable represents a measure of the frontier of implemented technologies. It is measured by country-specific Paasche indices, constructed from peak commodity yields weighted by land areas. The development indicator variable measures the overall level of development in a country, which would incorporate the effects of various public goods such as infrastructure, public health, research, and institutions. The hypothesis is that higher levels of technology would have a positive effect on agricultural productivity.

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[25] Various sources of National Accounts data were used to compile longer time series, including the United Nations, World Bank, OECD, IMF, and if necessary, country-specific sources.

[26] Data on agricultural area, agricultural labor, and fertilizers were downloaded from the FAOSTAT database.

[27] As previously mentioned, the list of possible state variables is vast. The variables presented in this analysis were chosen based upon our priors of what are important determinants of agricultural productivity, as well as for the availability of the data. This list is not meant to be exclusive, but rather suggestive. Indeed, there must be other determinants as the state variables in our model account for about half of the country effect (Mundlak, Larson, and Butzer, 2010).

[28] Total education data from Barro and Lee (2001) are reported for every five years up to 2000 through the World Bank website (http://go.worldbank.org/8BQASOPK40). Data for other years are obtained through linear interpolations.

Institutions

We use two variables obtained from Freedom House to measure the influence of institutions on agricultural productivity. The measure of political rights reflects the electoral process, political pluralism and participation, and functioning of the government. The civil liberties measure includes aspects of freedom of expression and belief, associational and organizational rights, rule of law, and personal autonomy and individual rights. The hypothesis is that the physical, legal, and regulatory infrastructure and institutions support overall, including agricultural, development; however, it is possible that these effects may already be captured by the development indicator variable.

Incentives

Three measures of incentives are included in the estimation. The effects of these variables would be over and above their indirect effect through resource allocation. The mechanism for the direct effect is through the choice of technique. Relative prices reflect the terms of trade between the agricultural sector and the overall economy. Price variability is a measure of the market risk faced by agricultural producers. In addition to the sector-specific risk, there is an economy-wide market risk, that of price volatility for the economy as a whole, measured by the rate of inflation. Inflation may also serve as an indicator of overall macroeconomic instability, which is thought to inhibit growth.

Physical environment

Two country-specific variables are included in the analysis to represent the physical environment: potential dry matter and factor of water availability. These are expected to have a positive impact on agricultural productivity.[29]

Sample description

The sample was determined by data availability. It consists of annual data from 30 countries for a 29-year period (1972-2000). The information conveyed by the sample is summarized in Table 4. In the first column, we report the average annual growth rates of the variables for the whole sample period. Agricultural output grew at a rate of 5.4%. All three components of agricultural capital grew faster than the other inputs. Agricultural fixed capital and treestock grew at rates of 5.8%. Livestock also grew during this period, but at a slower rate of 3.6%. Led by increasing rates of off-farm migration, agricultural labor declined at the average rate of 0.6%. Fertilizer grew on average at the rate of 1.9%. There was little change in the agricultural area. The terms of trade of agriculture

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[29] The measures are based on Buringh, van Heemst, and Staring (1975) and were used in Mundlak and Hellinghausen (1982) and Binswanger et al. (1987).

declined at the average rate of 1.3%. The technology measures show a growth rate of schooling of 1.7% and 1.4% for peak yield.

The data are subject to a great deal of variability over time and across countries. To describe the variability further, we decompose the total sum of squares to the three orthogonal components (within-country-time, between-country, and between-time). The last three columns of Table 4 show the percentage of each component in the total sum of squares. The between-country differences account for most of the variability in output (89%), with the between-time variability accounting for another 9%. Thus, a regression which allows for country and time effects, without any quantitative variables, would yield an R^2 of 0.98, so that the unexplained residual accounts for only 2% of the total sum of squares of output. The between-country variability accounts for an even higher percentage of the total variability in inputs.

Looking at the state variables, we see that schooling, development, and the institution measures are dominated by between-country variability. The peak yield measure varies primarily over time, reflecting the changes in the implemented technology. Price variability and inflation have a considerable amount of within variability, reflecting more transitory effects.

Empirical results

The importance of capital, in particular fixed capital, was shown in Mundlak, Larson, and Butzer (1999) and Mundlak, Butzer, and Larson (2010), the results of which are summarized in Table 5. We organize the empirical results of the model into three blocks. The first block presents the within-country-time estimates. The second block presents the between-time estimates, representing the time-series component, common to all countries, and as such captures the impact of changes over time in the available technology. The last block presents the between-country estimates, summarizing the between-country variability. The estimates are based on the locus of points that go across the different techniques implemented by the countries which, in principle, operate under the same available technology. Due to the orthogonal structure of the regressors, it is possible to estimate the three blocks separately.

As expected the different transformations yield different coefficients. The spread in productivity across countries is a different economic process than the spread in productivity for a country through time, thus the factors explaining the variability *should* differ. The within estimates represent a stable production function, while the between estimates will be biased.

Inputs

The sum of the within elasticities of both types of capital is 0.37, with fixed capital accounting for most of the impact on productivity. Turning to the between regressions, the elasticity on fixed capital is particularly high (0.59) in the between-time regression. This suggests that the pace of the implementation of changes in the available technology was strongly constrained by the level of the fixed capital stock in agriculture. The between-time estimate of capital of agricultural origin is significantly positive, though more modest in value (0.24). While the between-time coefficient on fixed capital is robust to different specifications of the model, the other between-time coefficients are difficult to interpret in light of the limited time series (31 years) and the concern over multicollinearity.

The between-country estimate of fixed capital is smaller than the within estimate, while the between-country coefficient on livestock and treestock is larger (0.14). These estimates are more similar to those obtained from cross-country studies, in which the impact of capital on the changes in technology over time is not considered.[30]

State variables

State variables are included in the analysis to eliminate the bias of the estimated input coefficients that is caused by the jointness property of choosing inputs and implemented technology simultaneously. Looking first at the within estimation, the technology variables give mixed results. The development indicator is quite robust, indicating that the more productive is the economy as a whole, the higher is the productivity of agriculture. Schooling and peak yield have unexpected negative coefficients, though the coefficient on peak yield is not significant. As expected, the price coefficient is positive, and that of the price variability is negative. Macroeconomic instability (in particular, inflation) does not have a significant effect. The institutional measures do not seem to be able to capture any effect beyond what was already reflected by the development indicator.

The between-country results reflect the determinants of cross-country variability at a given point in time, where countries implement different technologies, but presumably operate under the same set of available technology. Schooling is positively significant, suggesting that education was conducive to the techniques used by the more productive countries. Again, peak yield and the institutional measures are not significant. Development has changed to being significantly negative.

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[30] The early literature on cross-country studies on agricultural production was reviewed in Mundlak, Larson, and Butzer (1999).

The price variables continue to have the expected signs. Inflation has a significantly negative effect. Looking at the country-specific environmental variables, water availability increases agricultural productivity. Potential dry matter is significantly negative.[31]

Estimates utilizing FAO data on tractors

As discussed, in the absence of cross-country data sets on agricultural fixed capital, researchers often used FAO data on number of tractors as a proxy. We showed earlier that the data series on tractors are not a convincing proxy for agricultural fixed capital data. To demonstrate the implications for econometric analysis, we estimate agricultural productivity once again, with the FAO data on number of tractors in use replacing the data on agricultural fixed capital stocks. The results are presented in Table 6. The coefficient on tractors is not significant in the within estimations. Due to the omission of the fixed capital input, the other input elasticities change as well; the elasticities of capital of agricultural origin and land increase, while the elasticitiy of fertilizer falls slightly, and the labor elasticity becomes negative. Omitting this critical input for agricultural production from the econometric analysis leads to unrealistic results.

Interestingly, the input elasticities from the between-country estimations using the tractor data are similar to those using the agricultural fixed capital data (compare the last two columns of Tables 5 and 6). The coefficient on tractors is 0.11, while the coefficient on fixed capital is 0.13. The choice of capital series (tractors vs. fixed capital) has little effect on the between-country elasticities of capital of agricultural origin and labor. The reason for the similar results from the two regressions lies in the correlations of the transformed capital data. Examining the transformations of the capital data series, the correlations of the between-country transformations are much higher than those of the within transformations (0.79 vs. 0.19). This is because the differences in the composition of capital and the declining importance of tractors are lost as the time-dimension of the data is collapsed into country averages. Thus if the capital data series were compared on a cross-country basis, one may erroneously conclude that tractors are a valid proxy for agricultural fixed capital. It is critical to view both the between and within transformations of the data series to fully capture its evolution.

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[31] In a previous study where agricultural capital entered the estimation as a composite variable, potential dry matter had a significantly positive effect. Once agricultural capital was disaggregated into its various components, the coefficient on potential dry matter lost significance and even turned negative (Mundlak, Larson, and Butzer,1999).

Conclusion

This paper reports a time series of capital stock data for agriculture for 30 countries for the period 1970-2000. The capital stocks for agriculture consist of three components: fixed capital, livestock, and treestock. The data suggest that as economies grow, agricultural capital stocks accumulate, and the composition of agricultural capital changes. In particular, livestock declines as a share of total agricultural capital and capital from treestock and fixed investments in machinery, irrigation, and buildings becomes increasingly important. Moreover, the degree of the change differs between high-income and middle and low-income countries.

We review a study on agricultural productivity which highlights the important role of agricultural capital, particularly fixed capital. This finding differs from earlier studies which used incomplete measures of agricultural capital and different methodologies of estimation. We show explicitly that our findings are the result of both the improved data set on agricultural capital stocks and estimations which focus on the within transformation of the data. The results clearly show that data on tractors are poor proxies for agricultural fixed capital.

Acknowledgments

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Appendices

A.1 Livestock and Treestock as Components of Fixed Capital

To understand the extent to which fixed capital includes treestock and livestock, we calculate the ratio of these two components to fixed capital. In many countries the capital in livestock and treestock is considerably larger than that in fixed capital (Table A1). The magnitude of the difference raises doubts as to whether fixed capital includes these components. We cannot, however, conclude that this is the case for all countries, and we cannot answer the question of coverage of fixed costs with our data. Within the agricultural sector, the growth of fixed capital generally exceeds that of total capital, indicating a smaller growth rate of livestock and treestock.

A.2 Lifetimes of Tree Crops

To compute the value of treestock, we assign the following lifetimes for the trees: coffee, 20 years; bananas/plantains, cocoa, oranges and other citrus, apples, peaches/nectarines, papayas, lemons/limes, mangos, pears, currants, dates, figs, and grapes, 25 years; oil palm, rubber, and cherries, 30 years; cashews, 40 years; almonds, 50 years; coconuts, 75 years; tea, 100 years; and olives, 200 years.

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Figure 1: Examples of relative productivity paths

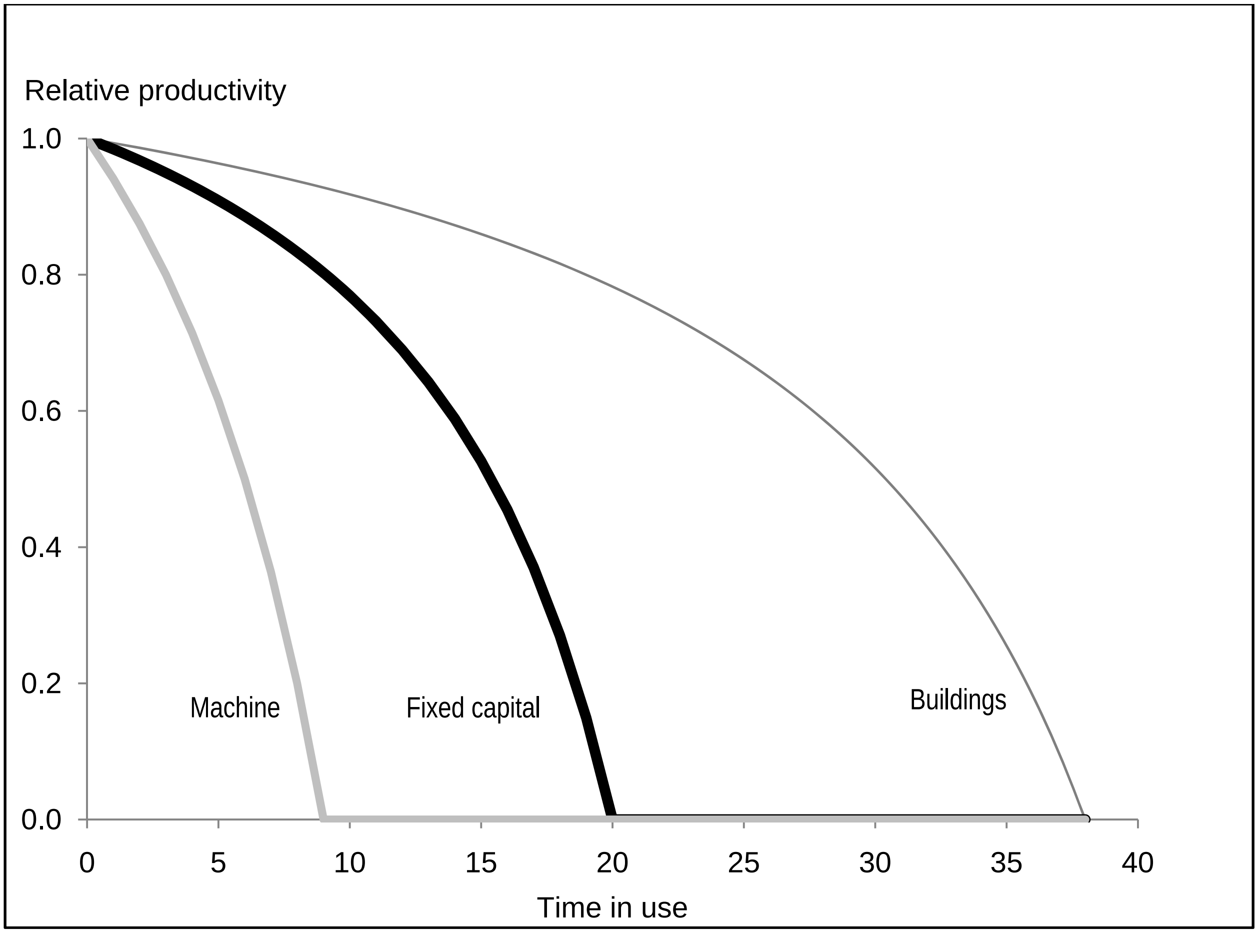


Figure 2: Growth of capital stocks, 1970-2000

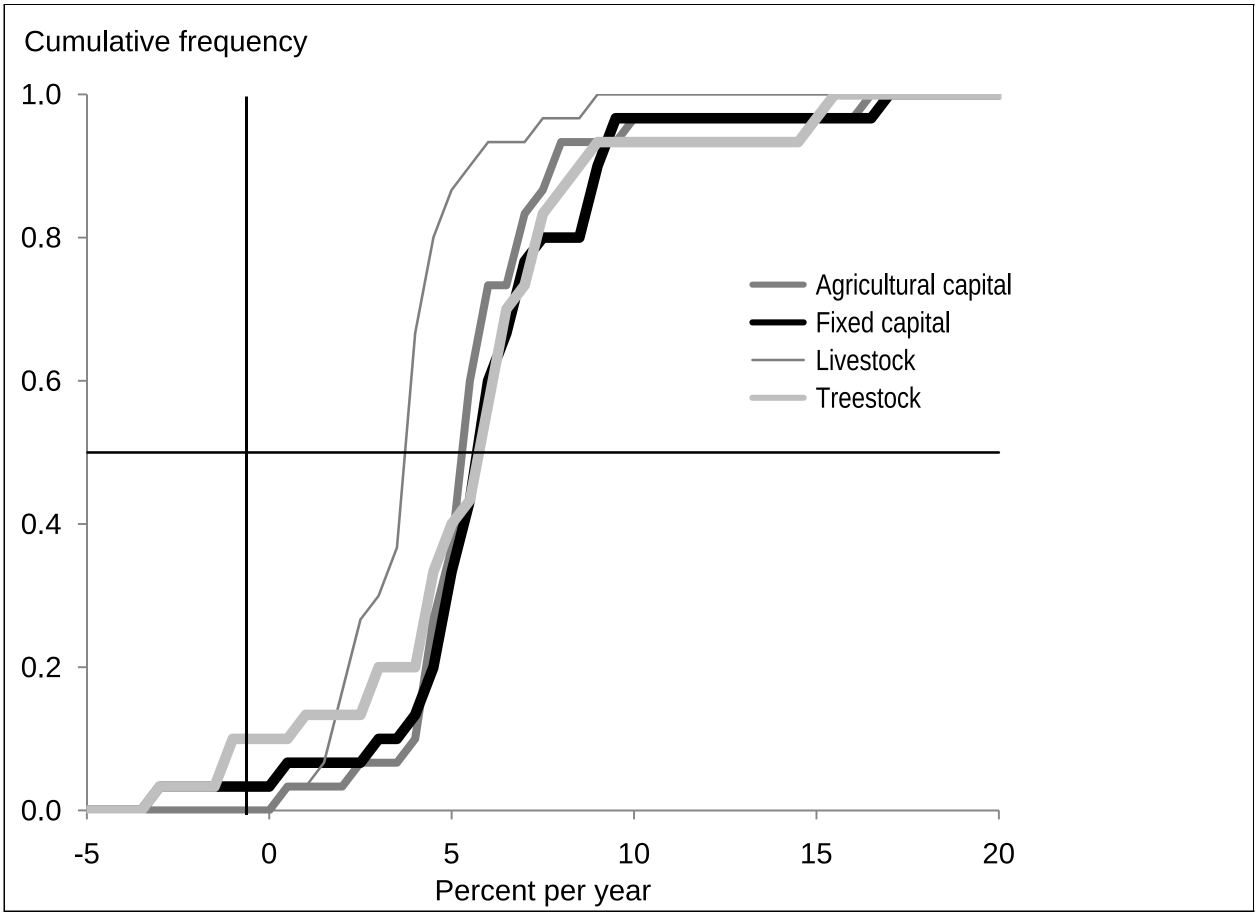


Figure 3: Changes in component shares of agricultural capital, 1970-2000

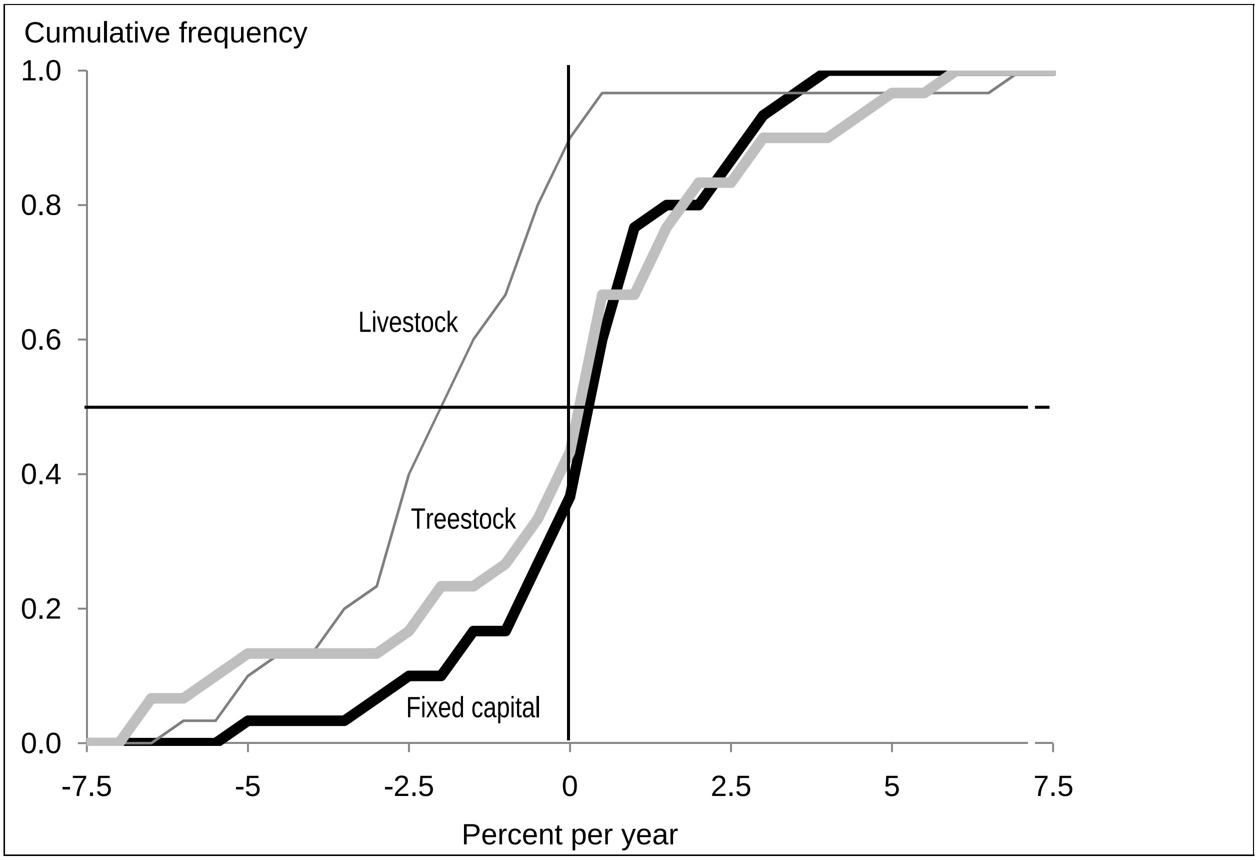
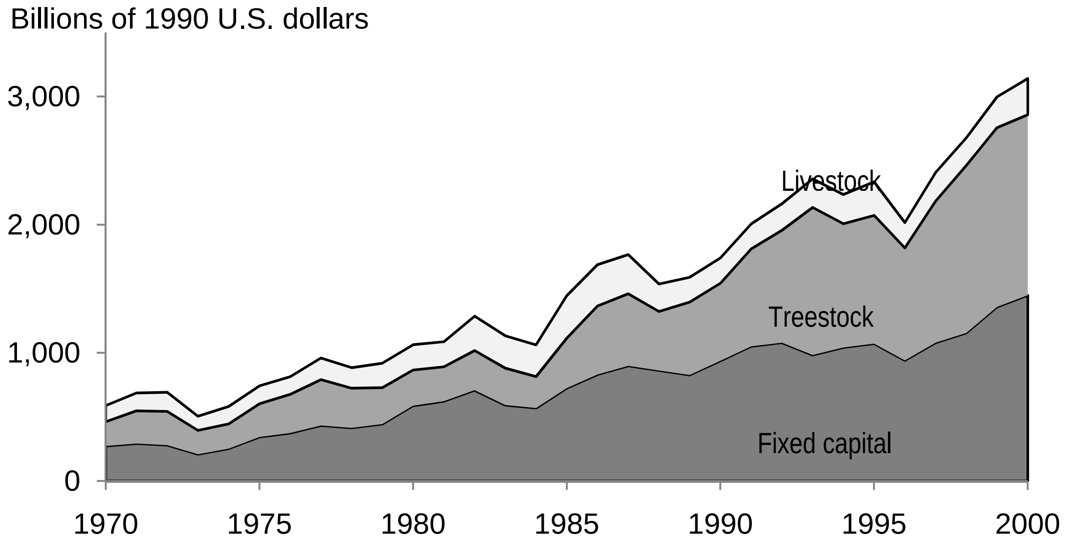


Figure 4: Components of agricultural capital

High-income countries



Middle and low-income countries

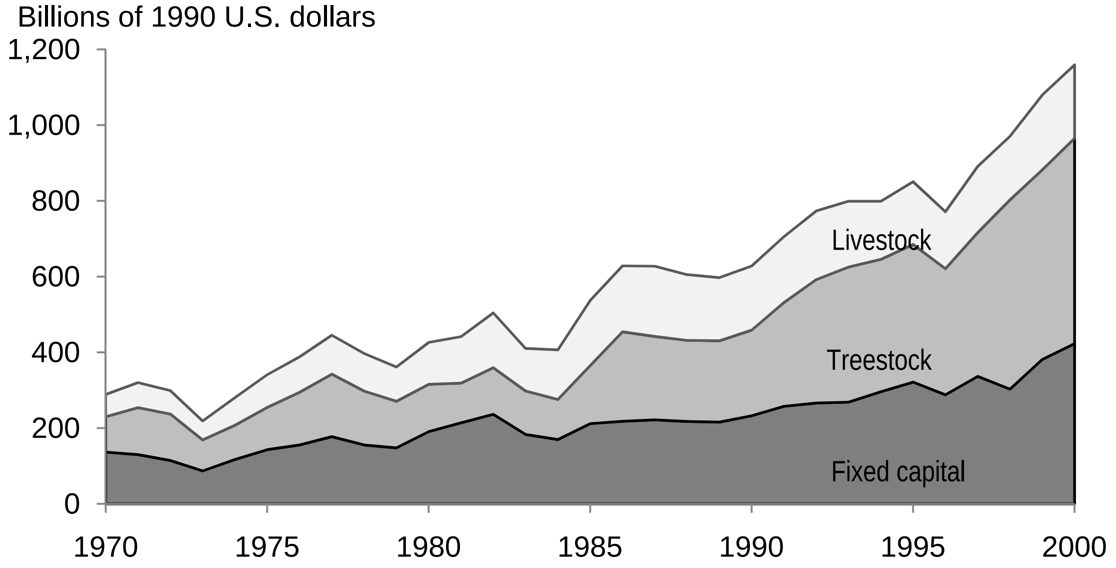


Figure 5: Tractors in use versus agricultural fixed capital stock, 1967-2003

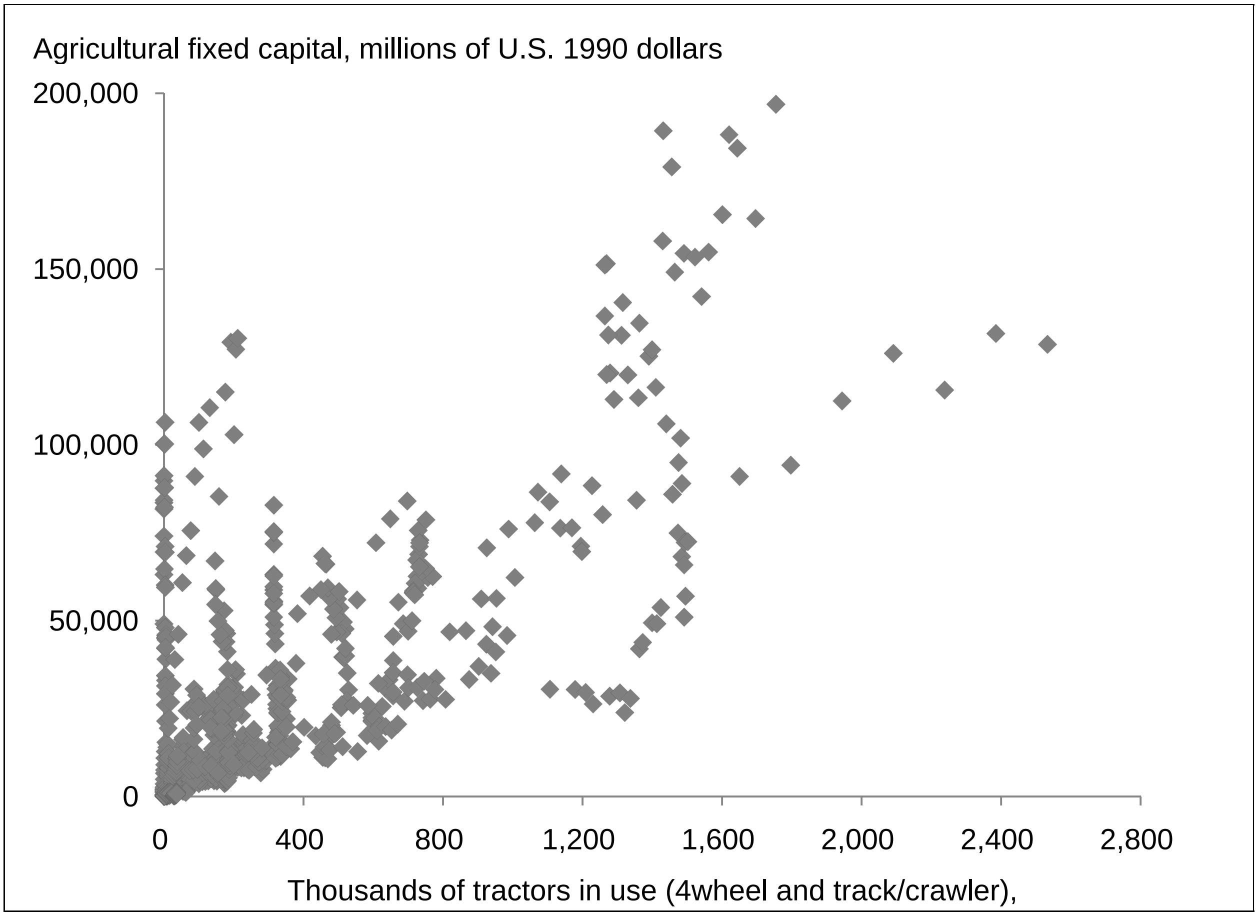


Figure 6: GDP per worker versus fixed capital per worker in agriculture, 1967-2003

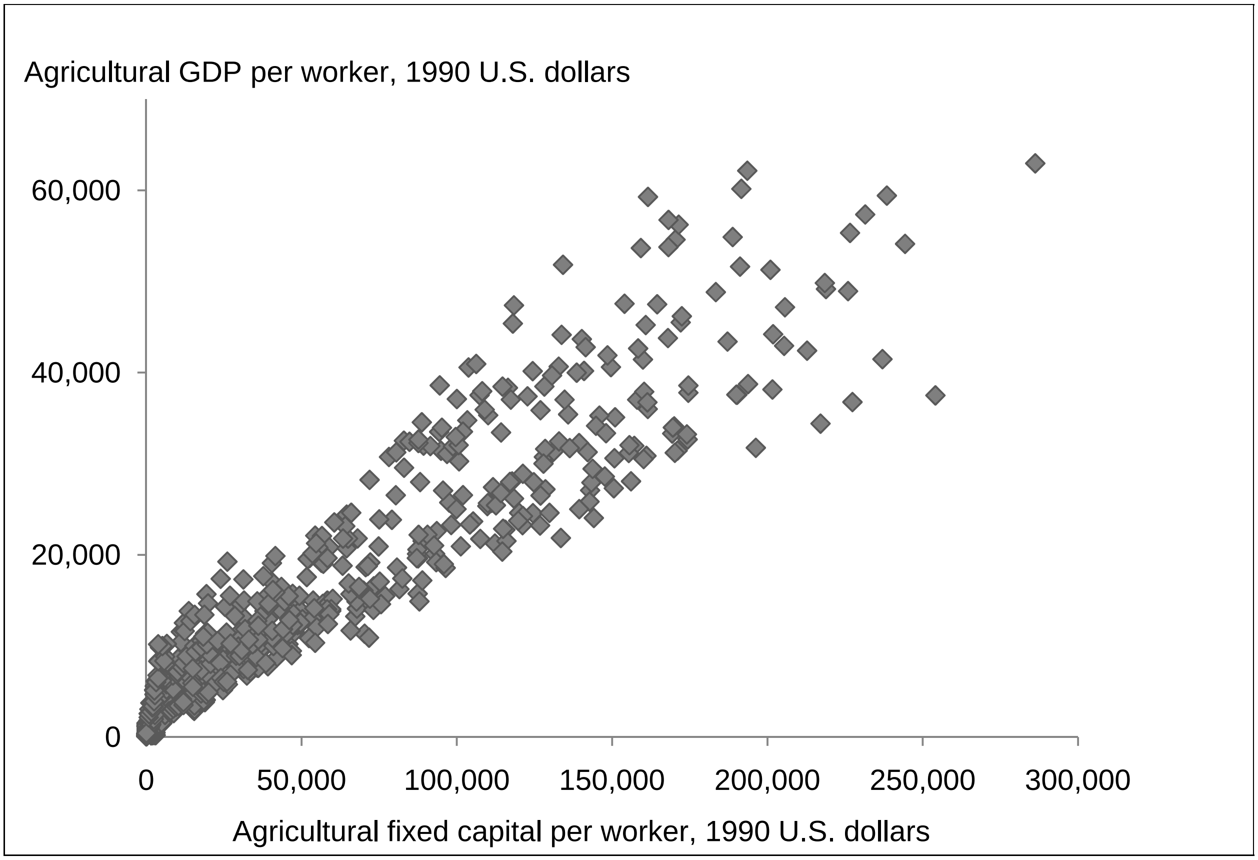


Figure 7: Capital intensity in agriculture and structural transformation

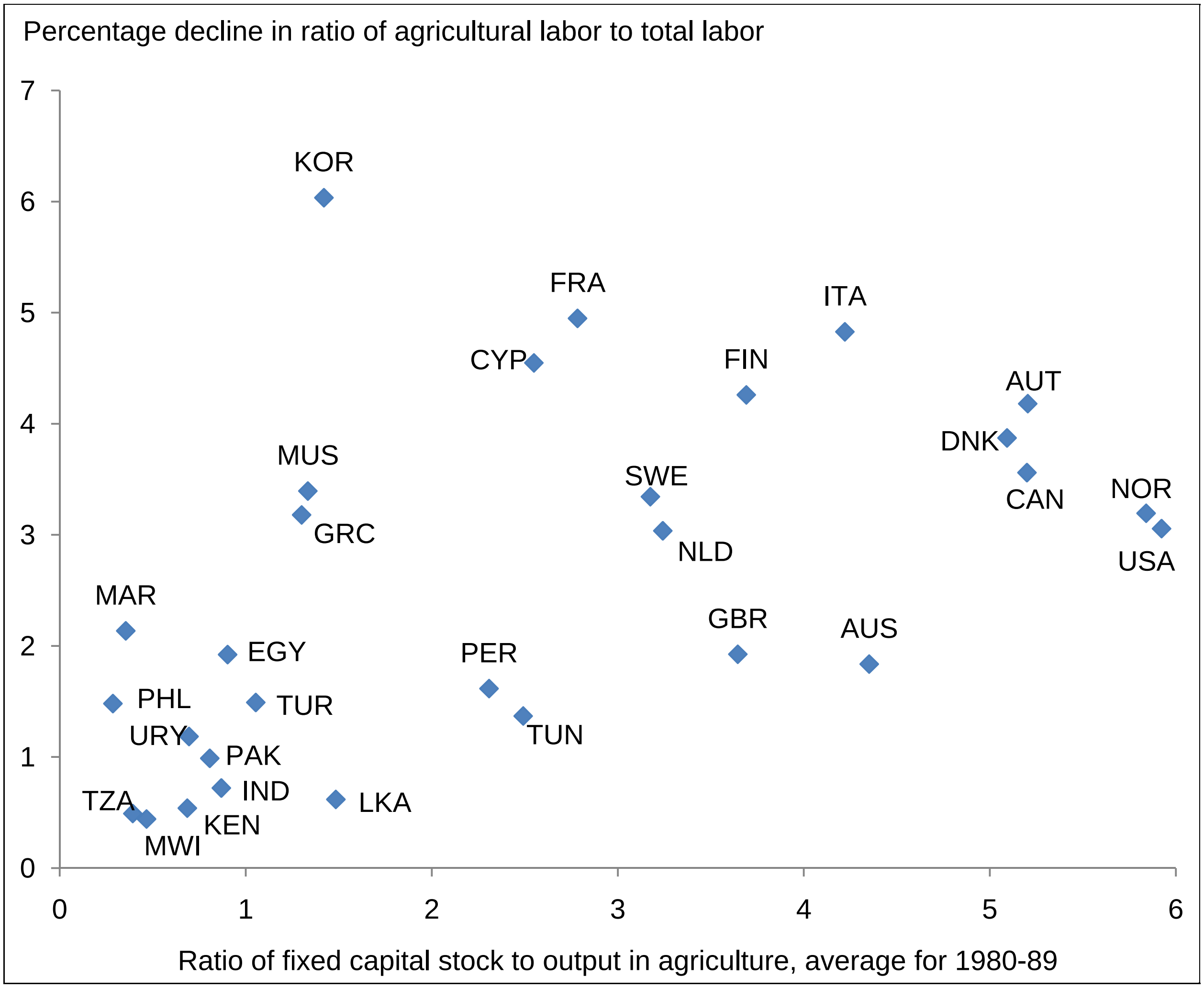


Figure 8: Agricultural GDP per worker versus tractors per worker, 1967-2003

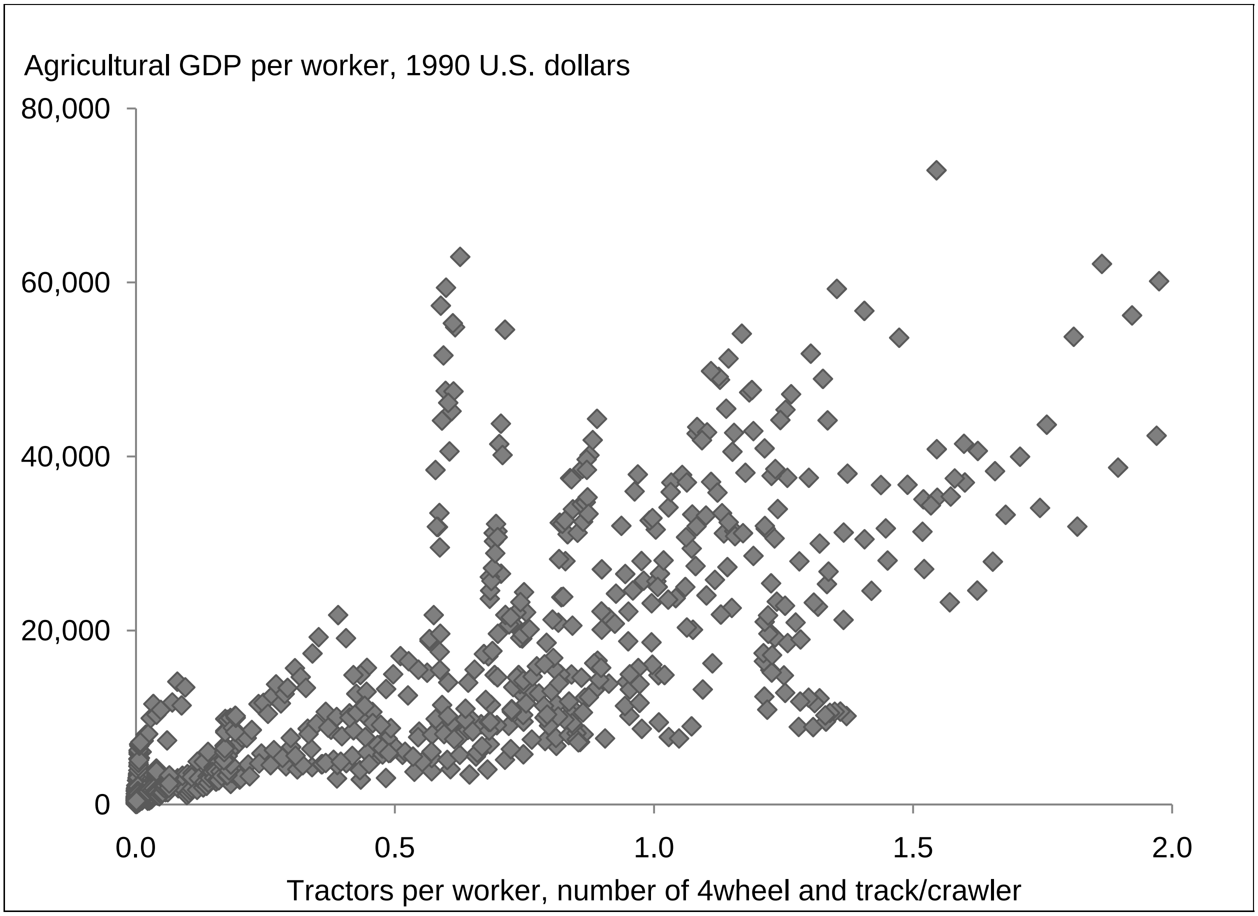


Table 1: Average Annual Growth Rates (percentage)

	Full Sample	**Decades**			**Country Classification**	
	1970-2000	1970s	1980s	1990s	High-Income	Middle- & Low-Income
Capital Component:						
Fixed Capital (Structures & Equipment)	5.86	7.31	4.24	3.58	6.26	5.51
Livestock	3.60	3.93	4.02	2.21	3.34	3.83
Treestock	5.37	3.18	9.93	5.89	4.01	6.57
Tractors	3.45	5.84	3.25	1.59	0.84	5.79

Table 2: Income Classification of Sample Countries

Income Category	Number of countries
Low Income	6
Lower Middle Income	6
Upper Middle Income	4
High Income	14
Total	**30**

Table 3: Component Shares in Total Agricultural Capital

	1970	2000
High-Income Countries		
Fixed Capital	.46	.46
Livestock	.21	.09
Treestock	.32	.45
Middle- & Low-Income Countries		
Fixed Capital	.47	.37
Livestock	.20	.17
Treestock	.32	.47

Table 4: Growth Rates and the Decomposition of the Sum of Squares, 1972-2000

	Average Annual Growth Rate	Decomposition of the Sum of Squares (percentage of total)		
	(%)	SSB(t)	SSB(i)	SSW(it)
Output:				
GDP	5.43	9.00	89.47	1.54
Inputs:				
Structures & equipment	5.80	6.60	91.03	2.37
Capital of Agricultural Origin	4.94	5.50	91.94	2.55
Livestock	3.59	3.09	95.72	1.18
Treestock	5.77	4.13	93.35	2.53
Tractors	3.26	1.51	94.12	4.36
Agricultural Area	0.01	0.00	99.93	0.07
Labor	-0.60	0.07	99.03	0.90
Fertilizer	1.87	1.01	96.47	2.53
Technology:				
Schooling	1.67	7.32	88.05	4.63
Peak yield	1.41	79.37	6.30	14.33
Development Indicator		1.10	95.46	3.44
Institutions:				
Civil Liberties		1.57	79.28	19.16
Political Rights		1.17	82.67	16.16
Prices:				
Relative prices	-1.26	25.01	23.14	51.85
Price variability		11.06	27.34	61.60
Inflation		3.12	8.50	88.37

Source: Mundlak, Butzer and Larson (2010)

Table 5: Agricultural Production Function, 1972-2000

	Independent block regressions					
Variable	Within time-country		Between time		Between country	
	Estimate	t-score	Estimate	t-score	Estimate	t-score
Inputs:						
Structures & Equipment	0.31	17.47	0.59	49.46	0.13	7.29
Capital of Agricultural Origin	0.06	2.89	0.24	22.18	0.14	12.08
Agricultural Area	0.45		0.34	1.01	0.03	3.16
Fertilizer	0.10	4.39	-0.24	-9.79	0.44	21.78
Labor	0.09	2.34	-0.78	-9.01	0.19	11.88
Sum of estimates	*1.00*				*0.93*	
Technology:						
Schooling	-0.13	-2.51	0.14	2.56	0.14	3.31
Peak yield	-0.02	-0.19			0.23	0.62
Development Indicator	0.63	9.04	0.58	19.32	-0.19	-2.38
Institutions:						
Civil Liberties	-0.02	-1.75	-0.00002	-0.002	0.03	0.81
Political Rights	0.01	0.70	-0.16	-15.37	0.03	1.19
Prices:						
Relative prices	0.29	9.13	-0.07	-2.42	0.97	5.97
Price variability	-0.31	-3.13	0.24	4.11	-1.84	-3.35
Inflation	0.002	0.76	0.004	1.62	-0.07	-3.99
Environmental:						
Potential Dry Matter					-0.66	-12.31
Factor of Water Availability					0.22	4.96
Summary statistics						
Panel R-squares		0.490		0.999		0.975
Durbin-Watson statistic			1.895			
N=870						

Source: Mundlak, Butzer and Larson (2010)

Table 6: Agricultural Production Function with Tractors as a Proxy, 1972-2000

Variable	Independent block regressions					
	Within time-country		Between time		Between country	
	Estimate	t-score	Estimate	t-score	Estimate	t-score
Inputs:						
Tractors	0.01	0.53	-1.55	-15.15	0.11	8.14
Capital of Agricultural Origin	0.13	5.30	0.72	59.18	0.13	11.32
Agricultural Area	0.87		-7.42	-15.28	-0.01	-0.55
Fertilizer	0.06	2.25	-0.76	-19.61	0.52	36.65
Labor	-0.07	-1.69	5.04	23.19	0.18	11.53
Sum of estimates	*1.00*				*0.93*	
Technology:						
Schooling	-0.01	-0.22	5.55	21.20	0.25	5.99
Peak yield	0.12	0.94			0.98	2.55
Development Indicator	0.96	12.28	1.19	25.94	-0.25	-3.12
Institutions:						
Civil Liberties	-0.02	-2.26	0.09	4.67	-0.01	-0.19
Political Rights	0.01	1.22	-0.47	-24.40	0.14	5.67
Prices:						
Relative prices	0.28	7.48	-0.69	-14.42	1.47	8.50
Price variability	-0.42	-3.73	0.50	4.99	-3.84	-6.87
Inflation	0.004	1.58	0.06	14.83	-0.07	-4.36
Environmental:						
Potential Dry Matter					-0.52	-8.82
Factor of Water Availability					0.53	9.94
Summary statistics						
Panel R-squares		0.309		0.997		0.975
Durbin-Watson statistic			2.597			
N=870						

Table A1: Average Ratio of Treestock and Livestock to Agricultural Fixed Capital

country	Treestock	Livestock
Australia	0.058	0.684
Austria	0.045	0.131
Canada	0.008	0.198
Cyprus	3.397	0.158
Denmark	0.008	0.231
Egypt	0.502	0.314
Finland	0.002	0.090
France	0.264	0.246
Greece	24.539	0.256
India	0.671	1.353
Indonesia	0.666	0.117
Italy	2.883	0.095
Kenya	6.353	3.578
Korea, Rep. of	0.072	0.057
Malawi	4.349	1.804
Mauritius	0.617	0.073
Morocco	10.799	2.219
Netherlands, The	0.021	0.229
Norway	0.009	0.076
Pakistan	0.280	1.573
Peru	0.464	1.123
Philippines	6.825	1.260
Sri Lanka	4.549	0.295
Sweden	0.004	0.137
Tanzania	2.660	5.920
Tunisia	5.845	0.234
Turkey	3.128	0.595
United Kingdom	0.015	0.348
United States	0.072	0.477
Uruguay	0.737	8.575

Note: average ratios for 1970-2000