Trade and Poverty in Rural Africa: The Role of Nutrition, Population Dynamics and Farm Productivity*

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The combination of limited trade and persistent poverty in Sub-Saharan Africa bring us back to one of humanity's oldest problems. Our earliest ancestors probably came from there, and chose to migrate across Eurasia. Populations elsewhere grew much faster and eventually became much richer, trading with Africans all the while. But from antiquity and slavery through colonialism to the present day, trade between Africa and the rest of the world has typically been highly concentrated in a few commodities and trading partners, and has typically occurred under heavy government control, often accompanied by military conquest.

To overcome the twin legacies of extreme poverty and limited trade, we would like to know to what extent limited trade is now a *cause* of Africa's poverty, and to what extent both poverty and limited trade might be caused by something else. It is clear that limits on trade could cause poverty, where large gains from trade remained unexploited. But it is also possible that trade expansion could result in relatively limited gains, where other constraints are binding.

This essay addresses the causes of persistent poverty in terms of aggregate data, characterizing long-term trends across all of Africa relative to other regions. Most readers will be familiar with at least one time and place where Africans have confounded the continent-wide trends described here, and any well-traveled specialist will have seen dozens of unusual cases. Those experiences are real, but may not have been frequent or extensive enough to outweigh the effects of other factors on a continent-wide scale.

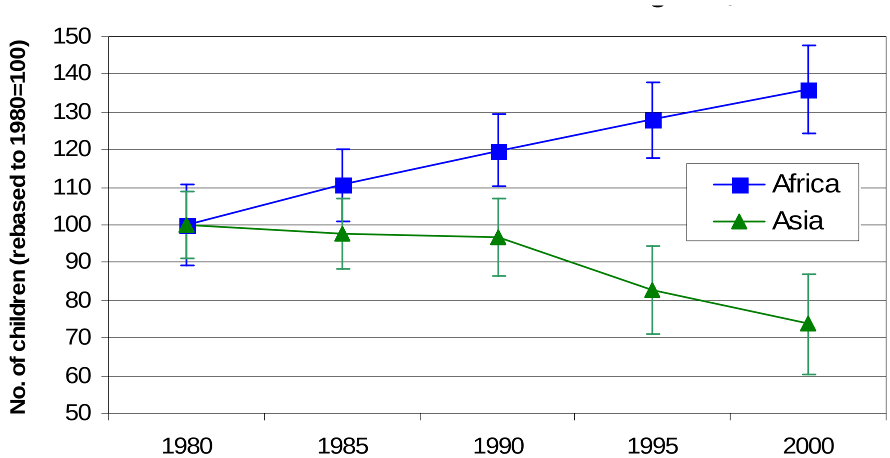
For the relationship between trade and poverty, a tentative conclusion from these data is that, for at least the next decade and perhaps the next generation, a large fraction of Africans will probably have little choice but to devote most of their resources to growing their own food and raising their children. Furthermore, unless food-crop productivity or aid inflows rise sharply, many Africans will still fall short of achieving the levels of nutrition, health and schooling that would be needed to rise out of poverty, and their persistently low productivity could severely limit the region's capacity to export much of anything.

The view presented here is not so pessimistic or deterministic as it may seem. In these data, Africa's situation is no more dire than the situation in much of Asia a generation ago. Africa also has at least one important advantage over other regions, which is an unusually equitable distribution of farmland. As a result, to the extent that foreign interventions are able to stimulate food-crop productivity growth, the resulting gains might lead to even faster poverty reduction than did similar interventions elsewhere. In sum, this essay suggests that foreign aid can play a dramatic role in poverty alleviation for Africa, particularly if it succeeds in accelerating agricultural productivity growth, through both larger and more effective real resource flows.

1. THE MAGNITUDE OF POVERTY AND UNDERNUTRITION

Figure 1 provides an illustration of the magnitude of Africa's recent impoverishment, based on data from a collection of household surveys compiled by WHO researchers. These data are expressed in index terms to show changes in the number of children whose growth has been severely stunted by undernutrition and disease since 1980. Those counted here have a stature that is less than two standard deviations below the NCHS/WHO reference levels of height-for-age. In other words they have suffered so much deprivation that they are physically shorter than about 97% of healthy children at a similar age. Like most data from Africa, there is considerable uncertainty about the exact numbers. Therefore, this figure presents not only the regional average but also a confidence interval around the point estimate shown derived from the variance in the survey data reported in the source cited.

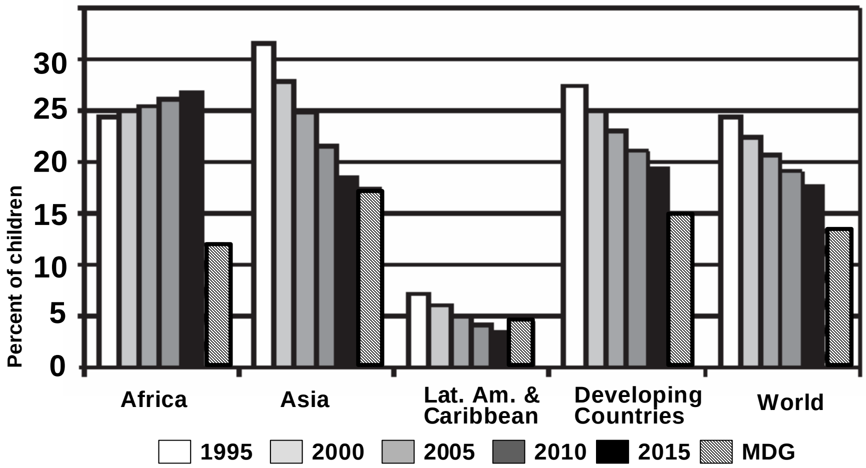
Figure 1. Number of stunted children in Africa and Asia, 1980-2000



Notes: Vertical bars are standard errors, computed from survey data in each period.
Scales are rebased to be comparable; the regions are very different in size.
Estimated totals for 2000 are 127.8 m. in Asia and 47.3 m. in Africa.
Source: Calculated from data in M. de Onis et al. (2000), "Is Malnutrition Declining?" *Bulletin of the World Health Organization* 78(10): 1222-33.

The number of children who are stunted is rising in Africa and falling in Asia, but Asia is a much larger region and so has a larger absolute number. And until very recently, Asia also had a larger fraction of its population affected by this kind of extreme deprivation. Figure 2 shows the incidence of undernutrition in percentage terms. Here the data are shown in terms of the proportion of children who are underweight, using weight-for-age as a combined measure of stunting (height-for-age) and wasting (weight-for-height).

Figure 2. Projections and MDGs for malnutrition by region, 1995-2015



Source: UN Standing Committee on Nutrition (2004), *Fifth Report on the World Nutrition Situation*. New York: UN SCN.
Note: Data show estimated percentage of children aged 0-5 who are underweight, defined as <2 s.d. below median NCHS weight for age.

By these projections, Africa will not only miss its Millennium Development Goal (MDG) targets in 2015; the nutritional status of its children is actually going in the wrong direction. Such deprivation is gradually being overcome elsewhere, but remains the world's most important underlying cause of illness and death as shown in Table 1.

Table 1. Worldwide disease burden attributable to undernutrition and to other factors (estimates for 2000)

	DALYs (M)	% total
Disease burden attributable to undernutrition		
Underweight	138	9.5%
Iron deficiency	35	2.4%
Zinc deficiency	28	1.9%
Inadequate fruit and vegetable intake	27	1.8%
Vitamin A deficiency	27	1.8%
Disease burden attributable to risk-factor exposure		
Unsafe sex	92	6.3%
Smoking and oral tobacco	59	4.1%
Alcohol	58	4.0%
Disease burden attributable to cardiovascular condition		
Blood pressure	64	4.4%
Cholesterol	40	2.8%
Body mass index	33	2.3%
Physical inactivity	19	1.3%
Disease burden attributable to environmental conditions		
Unsafe water, sanitation, and hygiene	54	3.7%
Indoor smoke from solid fuels	39	2.6%

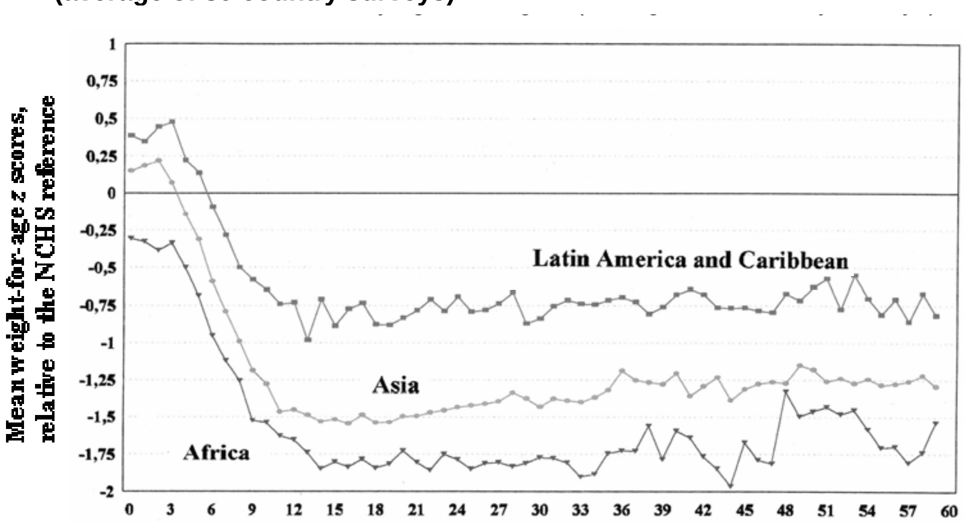
Source: WHO (2002), World Health Report 2002. Online at <www.who.int/whr>. Data shown are from web annexes at www.who.int/whr/2002/material/en.

The data shown in Table 1 are estimates from the WHO's most recent effort to assess the burden of disease attributable to various risk factors. Each factor is not mutually exclusive.

For example, those who are at risk due to being underweight are also at risk due to deficiencies in specific nutrients and exposure to pathogens. But the relative magnitude of each individual risk gives a good sense of its incidence. Astonishingly, despite the rise of HIV/AIDS, the severity of tobacco and alcohol-related risks, and increasing prevalence of cardiovascular conditions associated with excessive consumption relative to nutritional needs, by far the most important risk factor is simply being underweight.

The enormous burden of undernutrition reflects not only the number of people affected, but also the nature of its effects. First, undernutrition strikes early: Figure 3 shows how African children, whose average weight at birth is only slightly below international norms, typically remain adequately fed during their first four months. But then, as they grow and need more nutrients than they can obtain from maternal breastmilk, the average African child fails to gain weight as quickly as they would if they were healthy. By 14 months of age, they are nearly two standard deviations below international norms, so the *average* African one-year-old is lighter than over 95% healthy children at a similar age. Their body size has been constrained by about ten months of inadequate nutrition relative to their needs. After 14 months we do not observe any further decline in the prevalence of being underweight, partly because the smaller children do not survive, and partly because the food needs of older children are more easily met from low-cost grains and tubers as opposed to the more nutrient-rich infant foods.

Figure 3. Children's nutritional status by age and region in the 1990s (average of 39 country surveys)



Source Shrimpto , R. et al., 2001. "Worldwide Timing of Growth Faltering: Implications for Nutritional Interventions," ***Pediatrics*** **107:e75. Reproduced with permission, © 2001 by the AAP.**

The health burden of undernutrition is closely linked to its early onset which causes not only early mortality but also later vulnerability to other conditions among the survivors. Fogel (1994, 2004) documents how improved nutritional status helped drive economic success in the now-industrialized countries, and Table 2 illustrates the channels through which undernutrition and other risk factors are still causing illness and death in the low-income countries. In addition to the directional arrows shown on the table, there is undoubtedly some reverse causality as well to the extent that specific diseases and injuries influence exposure to each risk factor.

Table 2. Attribution of disease burden to major risk factors (estimates for high-mortality developing countries, 2000)

Risk factor	% DALYs	Disease or injury	% DALYs
Underweight	*14.9*	HIV/AIDS	9.0
Unsafe sex	10.2	*Lower respiratory infections*	*8.2*
Unsafe water, sanitation and hygiene	5.5	*Diarrhoeal diseases*	*6.3*
Indoor smoke from solid fuels	3.7	*Childhood cluster diseases*	*5.5*
Zinc deficiency	*3.2*	*Low birth weight*	*5.0*
Iron deficiency	*3.1*	*Malaria*	4.9
Vitamin A deficiency	*3.0*	Unipolar depressive disorders	3.1
Blood pressure	2.5	Ischaemic heart disease	3.0
Tobacco	2.0	Tuberculosis	2.9
Cholesterol	1.9	Road traffic injury	2.0

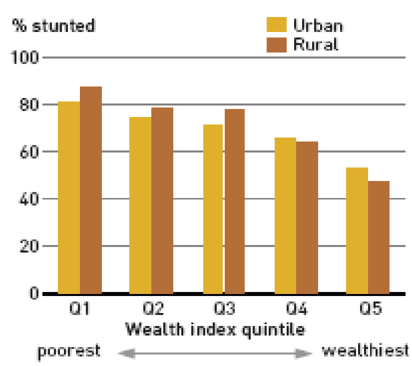
Notes: Arrows are roughly proportional to attribution rates. Risk factors and diseases associated with undernutrition are in italics. The selected risk factors cause diseases in addition to those relationships illustrated, and additional risk factors are also important in the aetiology of the diseases illustrated. Data shown are totals for the 69 countries defined by the WHO as having both high child mortality and high adult mortality, which includes all 46 countries of Sub-Saharan Africa.

Source: WHO (2002), World Health Report 2002, Annex Table 14 (p. 232). Available online at www.who.int.

A particularly challenging aspect of undernutrition in Africa is that most of its victims have no choice but to be farmers. The workers in their households lack enough education or other capital to support the household entirely from off-farm employment, so at least some workers must remain in the countryside to grow their own food. But their farms lack enough land, livestock and other assets to meet all of the household's nutritional needs. As a result, most African farmers earn a large fraction of their income from off-farm activities and remittances, and are net food buyers in most years. They grow some of their own food, but must supplement it with as much purchased food as they can afford.

The predicament of the rural poor is perhaps best captured by the evidence in Figure 4, which shows children's stunting rates by their families' wealth and location. The poorest three quintiles (60%) in rural areas are actually more malnourished than their counterparts in urban areas. Often their entire area is a net importer of food, so they might face higher real prices for food than the urban poor – and they may also have lower real incomes, even controlling for wealth quintile. It is only the very wealthiest rural people who have better nutrition than their counterparts in urban areas.

Figure 4. Stunting by residence and wealth



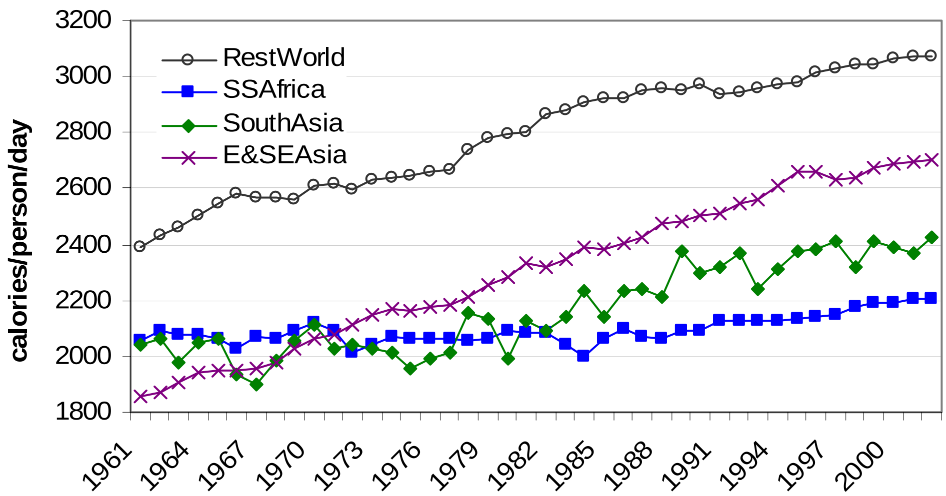
Source: FAO (2004), *The State of Food Insecurity in the World 2004*. Rome. FAO.

The data presented above describe the magnitude of chronic malnutrition associated with extreme poverty. A rising number of Africans lack the resources to buy or grow enough food. A key challenge for any poverty-reduction agenda is how to help them do so.

2. Markets, trade and the availability of food

The best aggregate data on food markets are compiled by the FAO from official national statistics. In contrast to the household survey data on nutrition presented above, the FAO data typically cover *all* countries rather than a sample, but their observations may be less accurate. Only the broadest trends can be considered meaningful, perhaps the most important of which is the reversal of fortune between Africa and Asia over the past forty years. In the 1960s, more food per person was available in Africa than in Asia, but since then Africa has fallen far behind.

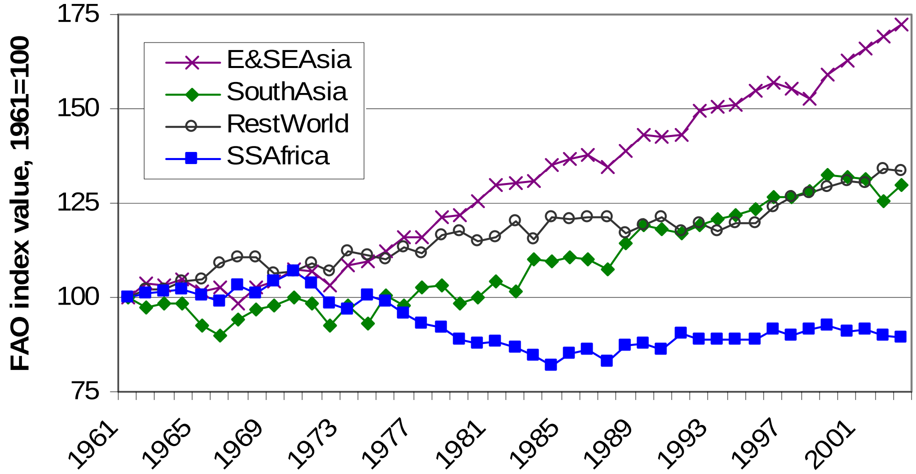
Figure 5. FAO estimates of total food availability per capita, 1961-2003



Source: Figures 5-14 are calculated from data in FAOStat (2004), except where noted. All data available online at http://apps.fao.org.

The food-production side of the story is illustrated in Figure 6, using the FAO index of total food output. The index is rebased to show percentage changes from 1961, and adds up various foods weighted by their economic value as opposed to their nutritional content as in the previous figure.

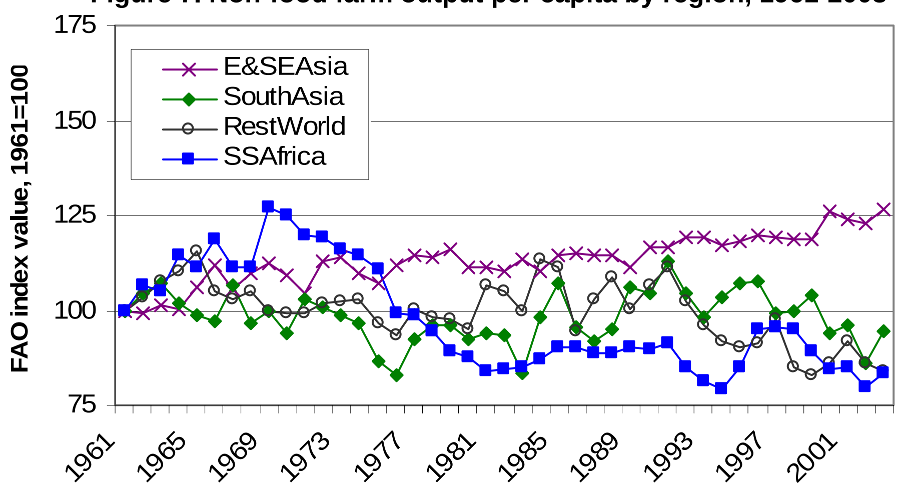
Figure 6. Food output per capita by region, 1961-2003



African food production per capita actually rose in the 1960s, but it declined precipitously from about 1970 to 1985 just as output per capita started to grow in Asia, first in East and Southeast Asia and then in South Asia. Africa's food output stabilized after 1985, but remains well below its level of the early 1970s.

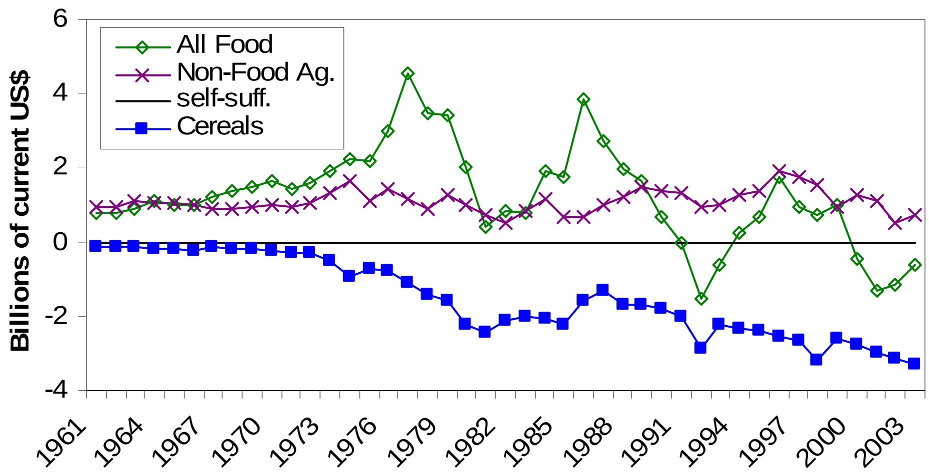
Low food output might not be a problem for farmers if they were producing enough other goods such as cotton, coffee, tea or tobacco. Figure 7 shows the trends in output of these non-food farm products using the same scale as Figure 6. Clearly, the distinctive success that occurred in Asia was specific to food output. Asian production of non-foods grew much more slowly. Within Africa, the swings in production are actually larger for non-foods, but this can be attributed mainly to the limited size and diversification of the non-food farm sector. In any case the timing of changes is similar, with growth in the 1960s giving way to over a decade of decline through the 1970s, followed by a limited recovery in the 1980s and 1990s.

Figure 7. Non-food farm output per capita by region, 1961-2003



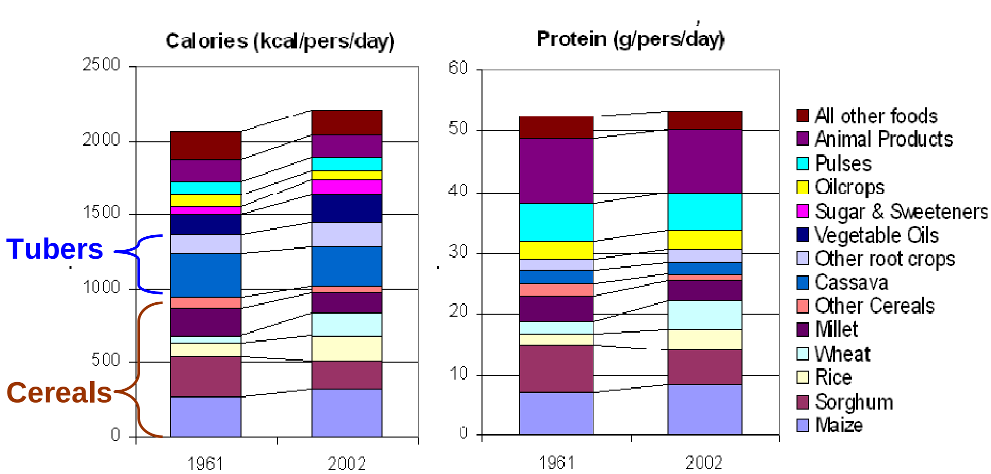
The data in Figures 6 and 7 refer to quantities produced. Households' access to purchased food is also influenced by prices and trade. Figure 8 summarizes Africa's net trade with the rest of the world in dollar terms. The figure shows that through the 1960s Africa was roughly self-sufficient in basic grains (cereals) and a steady net exporter of other farm goods, both foods and non-foods. During the commodity-price boom of the 1970s, Africa's earnings from those exports grew quickly but much of that earnings growth was spent on rising imports of basic foods, particularly cereal grains. Net exports oscillated but the trend was down, and Africa is no longer a net exporter of agricultural products.

Figure 8. Net agricultural trade of Africa, 1961-2003



Without the growing net imports of cereal grains illustrated above, food availability in Africa would have been even lower than it actually was– and those imports come first to the cities, which helps account for the better nutrition of the urban poor than of the rural poor. The rise in imports closely followed the fall in Africa's own production per capita between 1970 and the early 1980s when a limited but significant recovery in production, plus further growth in imports of cereals after 1987, helped stabilize then raise total availability of calories per capita – but not enough to prevent growing malnutrition among the poor, particularly the rural poor. The composition of these calories is shown in Figure 9.

Figure 9. Sources of nutrition in Sub-Saharan Africa, 1961 and 2002



The slight increase in aggregate food availability in Africa shown in Figure 5 consisted almost entirely of cereal grains. Cereals account for almost half of calories and an even larger fraction of all protein, and their availability grew only because of the very large growth in cereals imports shown in Figure 8.

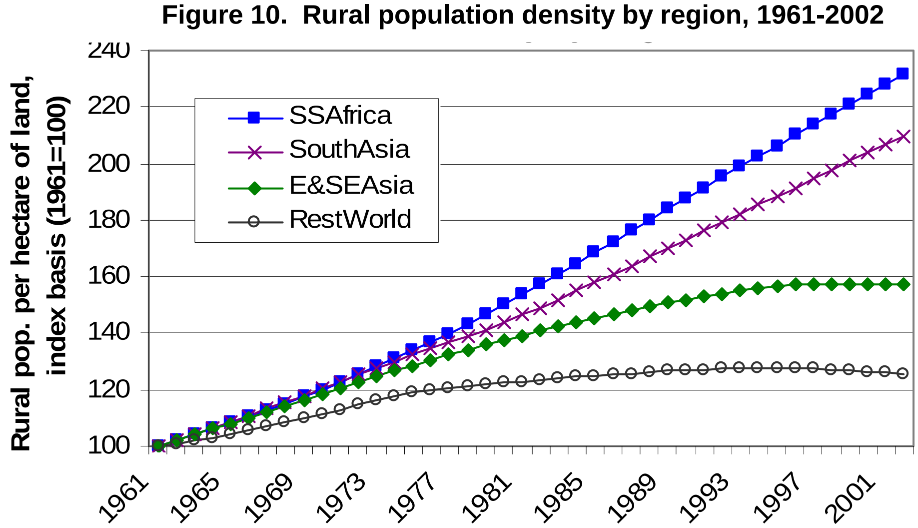
Clearly a significant improvement in nutrition and health cannot be sustained through imports alone, because Africans -- especially resource-poor rural Africans -- could not produce enough other goods to sell in exchange. Increased consumption would require a sharp and sustained increase in production, similar to that which occurred earlier in Asia. The following sections trace some of the key factors that underlie Africa's unusual circumstances, leading up to the specific interventions recommended in section 9 at the end of this essay.

3. Rural population and demography

A key element in the per-capita averages presented above is the number of people. In the 1970s and 1980s, Africa experienced unprecedented and uniquely high rates of rural population growth and a decline in what had been previously-abundant land area available per farmer. Africa's cities are among the fastest-growing in the world, and there is also out-migration to Europe and elsewhere, but the total size of both is too small to absorb all of the total population growth.

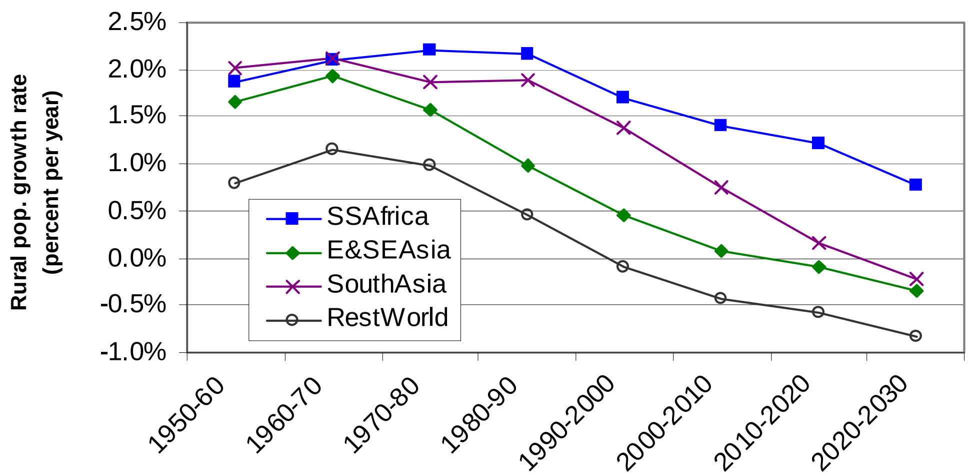
Changes in the level of rural population density are illustrated in Figure 10, in terms of population per hectare rebased to show proportional changes from 1961. During the 1960s, all low-income regions had roughly similar rates of increase in population density. But the increase slowed in Asia, first in the East and then in the South. By the turn of the millennium in 2000, Africa's rural population density had more than doubled and was still rising, whereas in East and Southeast Asia rural density had peaked at less than 60% above its 1961 level.

Figure 10. Rural population density by region, 1961-2002



A long-run perspective on rural population growth is provided in Figure 11, using the medium variant of the latest UN population projections. Rural population growth reflects the interaction of fertility and mortality with age structure and migration. In the 1950s and 1960s, a sharp decline in the mortality of children affected Asia and Africa similarly, generating a significant rise in the rate of rural population growth to around 2% per year. But Asia was able to reverse this decline in the 1970s, while Africa's rural population growth rates stayed above the 2% level for over 30 years.

Figure 11. Rural population growth rates by region, 1950s-2020s

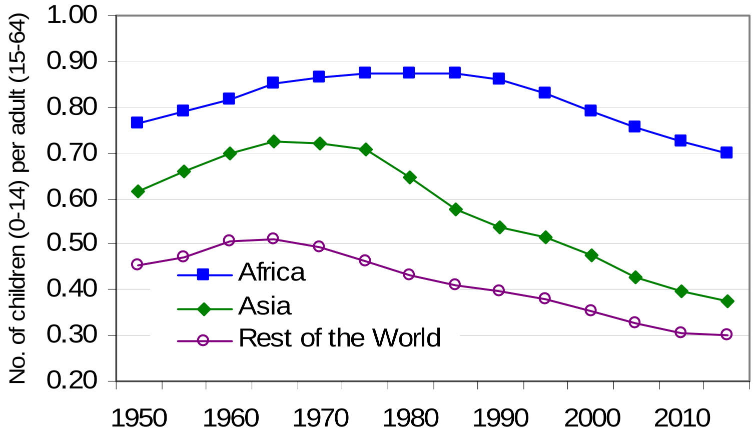


The uniquely rapid and sustained rural population growth that Africa experienced after 1960 occurred despite the world's fastest rate of urbanization. The FAO data on Africa's urban population show it growing more than eight-fold over the 1961-2003 period, while the urban population of Asia grew roughly half as much. But Africa's initial *level* of urbanization was so low, at only 12% of total population in 1961, that even very rapid urban growth could absorb only a fraction of the total number of new workers each year. Continued economic growth will eventually allow an absolute decline in the rural population, when its percentage rate of growth falls below zero, at which point there can be a rise in acreage available per farmer: Figure 11 projects that this transition will occur at some point during the next decade in East and Southeast Asia, and during the following decade in South Asia, but will not occur in Africa for at least another generation.

Africa's rising rural population and hence falling land area per farmer help explain the continent's decline in food availability during the 1970s and 1980s, and represent an enormous hurdle for productivity growth to overcome in order to generate rising food availability per person. This rural demographic hurdle will remain higher in Africa than elsewhere for many decades, and is somewhat similar to the child-dependency demographic drag that is imposed by the age structure of the population.

As illustrated in Figure 12, Africa's child dependency rate was already high in 1950, and it continued to grow to nearly 90% during the 1970s and 1980s while Asia's child dependency rate started to decline after 1975. The decline in Africa's dependency rate did not begin until the 1990s. The survival of Africa's children is clearly a good thing, but the magnitude and duration of this change is such that the continent will remain dominated by young children for many decades to come. Looking forward, the eventual reduction in the number of children per worker, like the eventual reduction in number of rural workers, will help facilitate growth in output per capita – but the demographic burden will remain larger in Africa than anywhere else.

Figure 12. Past and projected child dependency by region, 1950-2015



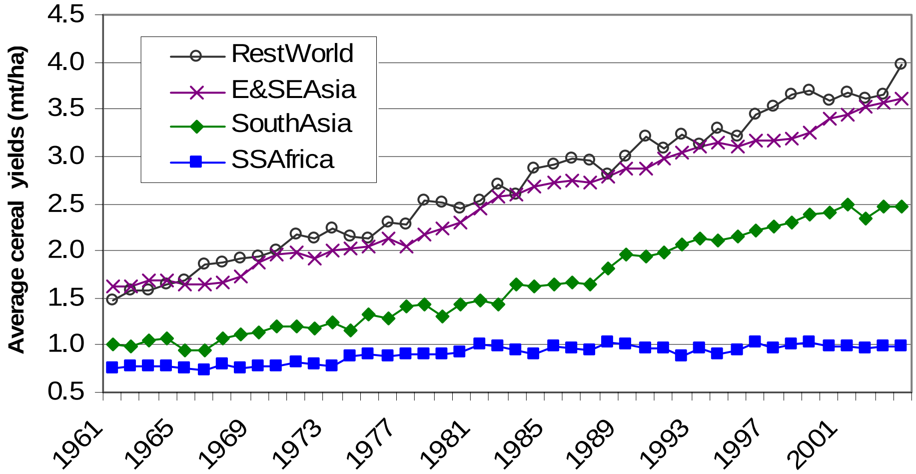
Source: UN Population Division, *World Population Prospects: The 2002 Revision*. Available online at <http://esa.un.org/unpp>.

Changes in age structure influence not only the fraction of people who are working, but also the fraction who are subject to childhood undernutrition and disease. And with a rising number of these children being in rural families, farm productivity in particular must rise all the more just to keep up. These trends can help account for Africa's dismal performance in the 1970s and 1980s, and continue to set a uniquely high hurdle for farm productivity to exceed in pursuit of any per-capita gains. Demography is not destiny, however: overcoming even the greatest obstacle is possible if people respond with even more powerful initiatives directed at the problem, such as the specific proposal sketched in section 9 of this essay.

4. Productivity: Farm output and input use

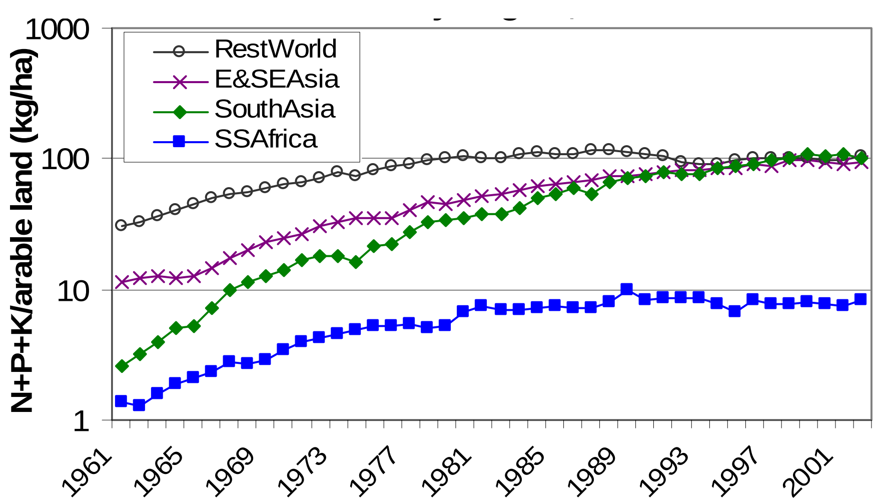
The recent experience of farm productivity in Africa is illustrated in Figure 13, showing the aggregate FAO data on cereal yields since 1961. At the start of this period, before the modern "green revolution" in Asia, Africa already had appreciably lower yields, reflecting the region's lower and more variable rainfall as well as its lower use of labor per hectare and more weathered soils. The productivity gap is actually understated by the graph, in that Africa's cereals are principally maize, sorghum and millet, whereas other regions grow more wheat and rice which have a higher economic value per ton. African farmers were able to raise their yields per hectare from about 0.75 mt/ha to about 1 mt/ha during the 1960s and 1970s, but Asian farmers achieved even faster growth rates, and more importantly, they were able to sustain their yield growth through the 1980s and 1990s.

Figure 13. Average cereal yields by region, 1961-2004



Beyond the farmer's own labor and water, a principal determinant of crop yield is soil nutrients; sustaining high yield levels requires soil amendments, if only to replace nutrients taken up by previous crops. Figure 14 shows the evolution of fertilizer use across regions, as a simple sum of the quantities of the three largest nutrients.

Figure 14. Fertilizer use by region, 1961-2002



The fertilizer data are shown on a logarithmic scale, to bridge the nearly hundred-fold gap between the lowest and highest rates of fertilizer use per hectare. The use of a log scale also helps reveal the remarkable convergence in fertilizer use between Asia and the rest of the world. Africa is the outlier, having had some growth in fertilizer use during the 1960s and 1970s, but no further growth after 1989.

Fertilizer is not the only factor in crop yields, of course, and in any case fertilizer application rates are not themselves a policy choice. Fertilizer use decisions are made independently by individual farm families, responding to their own circumstances. Key influences include relative prices, cost of credit and ability to bear risk. All of these can and should be improved by donor intervention and government policies. But the cost factors alone are unlikely to explain the fertilizer use patterns illustrated in Figure 14, because observed price responsiveness in Africa and elsewhere is much too small to explain the more than ten-fold gap in fertilizer use rates between Africa and the rest of the world. To close that gap, African farmers would need not just more favorable relative prices, but also higher and more stable physical productivity from increased fertilizer use.

Plants' response to fertilizer is constrained by a number of other factors, including soil moisture, soil structure, pests and weeds. Farming conditions in Africa differ from those of Asia and elsewhere, including higher peak soil temperatures as well as lower and more variable rainfall with fewer irrigation opportunities. These physical factors are associated with biological differences including more weathered, degraded soil structures, and relatively greater pest and weed pressure. Such differences limit African farmers' ability to use technologies developed in Asia or elsewhere, and they also limit the yield increases that can be obtained from more labor or fertilizer using traditional methods.

Although many inputs are needed to raise yields, many of the most widespread and sustainable external interventions to help African farmers have begun with new seed varieties. New varieties offer a different "blueprint" for plant growth, including particularly changes in plant architecture such as shorter stems, growth habits such as earlier maturation, and vulnerability to stresses such as pests and weeds. These changes in genetic potential then raise the payoff to farmers' own changes in husbandry practices – particularly the application of farmers' increasingly-abundant farm labor to soil and water conservation as well as pest and weed control.

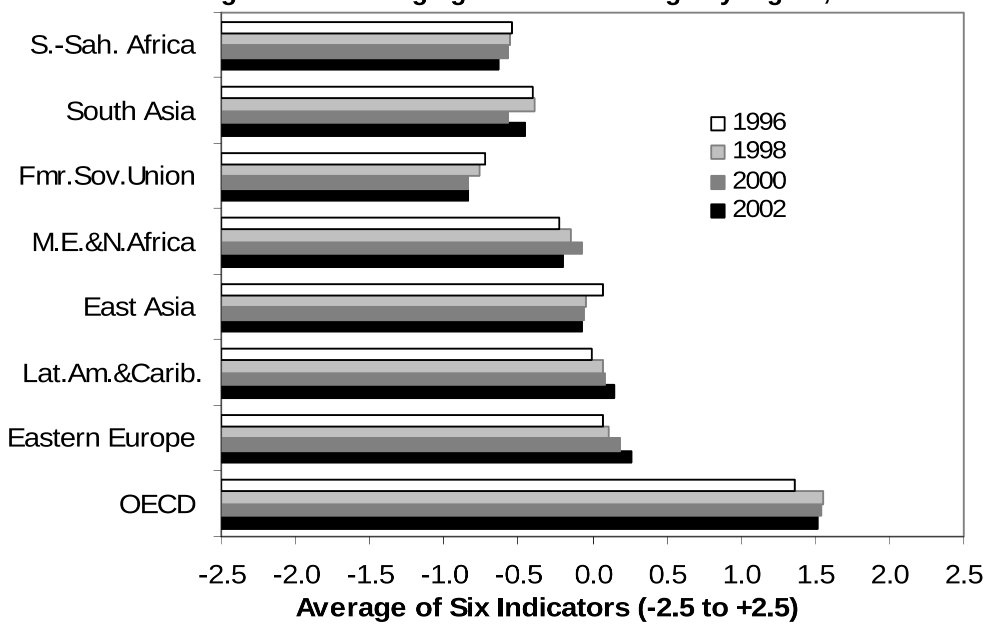
Farmers who attempt to apply increasing amounts of labor or fertilizer without complementary genetic improvements often find it difficult to sustain a yield response. Traditional plant varieties were selected for traits that suited their historical circumstances, such as tall stems to shade out competitors and slow maturation to maximize year-long growth potential. More intensive management of these plants typically has a low payoff, whereas new varieties make it worthwhile to invest more in the control of soil moisture, pests and weeds. The resulting increase in plant growth draws more nutrients from the soil, which in turn makes it profitable for farmers to replenish soil nutrients with fertilizer. This virtuous cycle between plant growth and farmers' use of fertilizer and other inputs underlies much of Asia's remarkable poverty-alleviation success story – and raises the question of how similar increases in crop productivity could be achieved in Africa.

5. DETERMINANTS OF PRODUCTIVITY AND INPUT USE

The particular concern of this essay is how donor-country actions might help Africa's rural poor emerge from poverty: to what extent should donors focus on increasing trade, and to what extent should donors focus on increasing productivity. The two are not mutually exclusive, indeed they may be complementary, but they are distinct: trade facilitation aims primarily at institutions and policies to help people reallocate their resources among existing techniques, whereas productivity enhancement aims primarily at R&D and innovation to change the set of techniques among which people must choose.

To increase their productivity and input use, farmers certainly need both incentives and technologies. But it is not yet clear which has more often been the limiting factor in Africa as compared with other regions. Figure 15 shows the aggregate result of the World Bank's latest and most comprehensive attempt to measure the quality of market institutions around the world. These ratings have been widely used in attempts to determine the relative influence of institutions and incentives for economic performance. They show clearly that Sub-Saharan Africa and South Asia have similarly weak market institutions and show no marked improvement over the past decade. Under these conditions, individuals have limited incentives to invest in or choose more productive activities. In contrast, political institutions are much more favorable to market development in East Asia and in Latin America and the Caribbean, and are most favorable of all in the industrialized countries of the OECD.

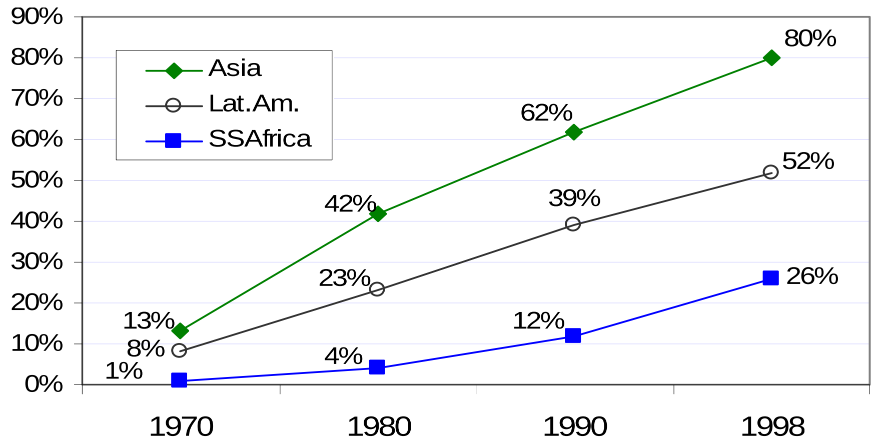
Figure 15. Average governance ratings by region, 1996-



Note: Data shown are average of survey data and other indicators reflecting six underlying aspects of national governance: Voice and Accountability; Political Stability and Absence of Violence; Government Effectiveness; Regulatory Quality; Rule of Law; and Control of Corruption.
Source: D. Kaufmann, A. Kraay, and M. Mastruzzi (2003), "Governance Matters III: Governance Indicators for 1996–2002," World Bank Policy Research Working Paper 3106. Data available online at www.worldbank.org/wbi/governance.

The figure above aims to summarize much of the available data on the quality of each region's institutions and incentives, while Figure 16 below aims to do the same for the contribution of modern science to the region's farm technology. The techniques whose adoption is shown here are the "green revolution" crop varieties developed through international exchange of materials, cross-breeding and local seed multiplication.

Figure 16. Adoption of new crop varieties by region, 1970-98



Source: Calculated from data in R.E. Evenson and D. Gollin, 2003. *Crop Variety Improvement and its Effect on Productivity*. Cambridge, MA: CABI.

The data shown in Figure 16 reveal a dramatic difference between Asia and Africa. The figures refer to all of Asia, which is shown to be at least 25 years ahead of Africa in their adoption of green revolution crop varieties. This lag reflects the number and appropriateness of the various new varieties released, as well as the size and quality of the seed multiplication sector.

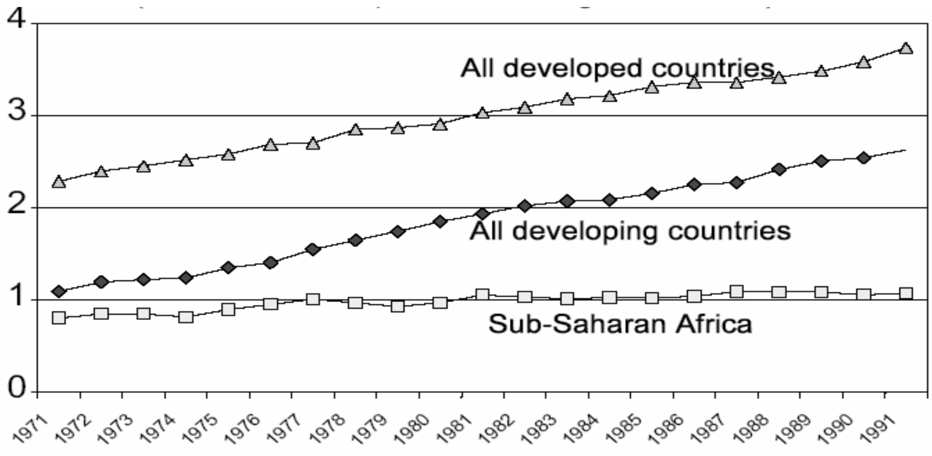
The new types of seed whose use is shown in Figure 16 originate in traditional varieties, which are then catalogued and exchanged among breeders looking for various traits such as plant architecture, disease resistance, and food quality that might suit local farmers' needs. An important international-exchange aspect of this effort is driven by transnational institutions funded through the Consultative Group for International Agricultural Research (GCIAR), while the local development and dissemination of new varieties is done mainly by national institutions.

6. Determinants of agricultural research effort

Where and when profitable new varieties have been available to farmers, they have quickly adopted them. What distinguishes Africa in this regard is not the farmers' response, but the fact that fewer and less appropriate new varieties have been available, either because the breeding system has not yet developed well-adapted varieties, or because the seed-multiplication system has not yet been able to disseminate them. The shape of the continent-wide adoption curve for new crop varieties is normal, but has been delayed a full generation behind Asia.

The delay in availability of new crop varieties in Africa can most readily be explained by much lower and slower-growing investment in agricultural R&D per unit of land. The best data on agricultural research efforts across countries have been collected by the Agricultural Science and Technology Indicators (ASTI) project at IFPRI in Washington DC. Figure 17 shows their estimates of expenditure, measured in comparable terms across countries and aggregated up to the regions shown. Clearly, at the start of its period of rapid rural population growth, Sub-Saharan Africa had less investment per unit of farmland than other regions, and that gap widened as other regions' investments grew much faster than Africa's.

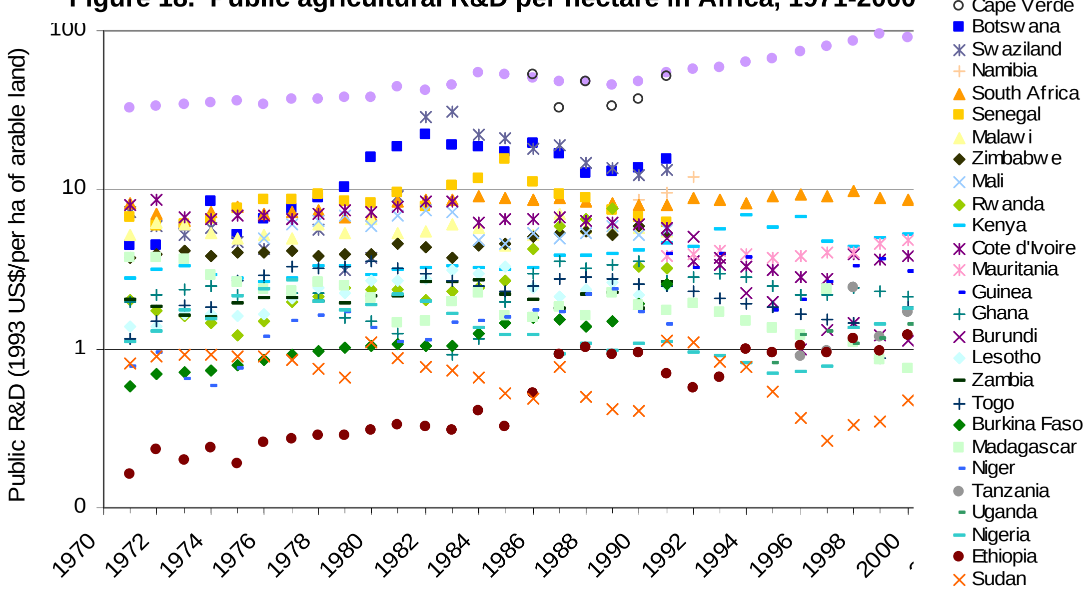
Figure 17. Public agricultural R&D per unit of agricultural land, 1971-91 (1985 PPP dollars per hectare)



Source: Calculated from IFPRI and FAOStat file data

The full time series of data shown above for 1971-91 is not available for later years, but investment levels have been estimated for some countries in some years. Figure 18 shows those data in detail, using a logarithmic scale to span the more than 100-fold difference between the highest-investment countries (Mauritius and Cape Verde) and the lowest (Ethiopia and Sudan). Of these countries, only Mauritius has had any significant increase in agricultural R&D levels per hectare, and several countries such as Madagascar have seen large declines.

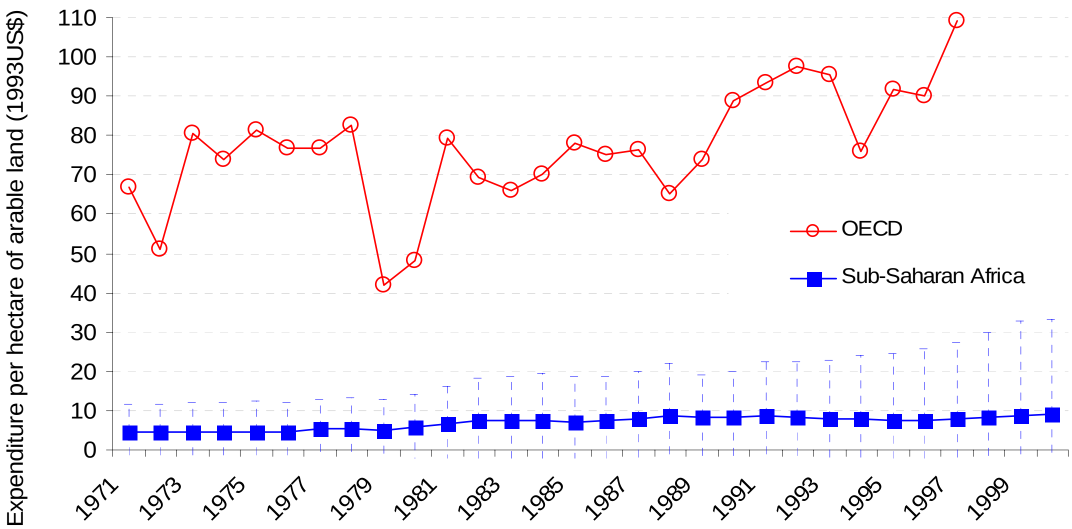
Figure 18. Public agricultural R&D per hectare in Africa, 1971-2000



Source: IFPRI (2003), Agricultural Science and Technology Indicators database. Available online from www.asti.cgiar.org.

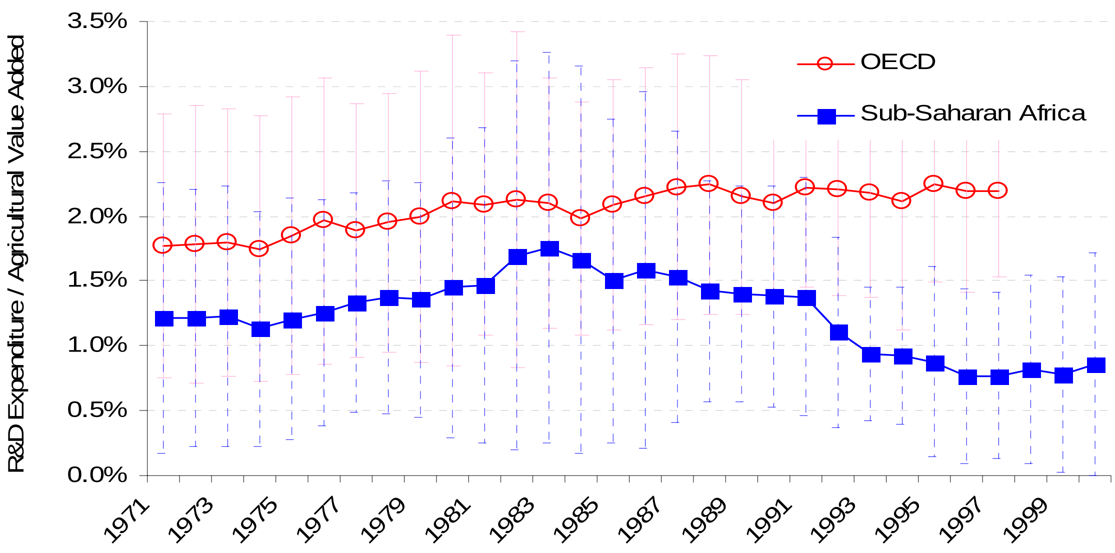
The average and standard deviation of the African observations, contrasted with comparable data for OECD countries, are shown in Figure 19. All values are expressed in constant PPP dollars. The change over time in Africa is not meaningful since the composition of the sample changes. What is remarkable is to compare the per-hectare data on Figure 19 with the percentage data in Figure 20, which shows public R&D expenditure as a fraction of agricultural value added.

Figure 20. Public agricultural R&D per hectare in Africa and the OECD, 1971-2000



Note: Error bars show standard deviation across the SSA sample. For OECD, the s.d. ranges from 68 to 210. Sample size varies from n=13 to 21 for SSA, and from n=8 to 15 for OECD.
Source: Agricultural R&D is from IFPRI (2003), available online at www.asti.cgiar.org; hectares of arable land are from FAOStat (2004), available online at apps.fao.org.

Figure 20. Public agricultural R&D in Africa and the OECD, 1971-2000



Note: Error bars show standard deviation across sampled countries.
Sample size varies from n=13 to 21 for SSA, and n=8 to 15 for OECD.
Source: Agricultural R&D is from IFPRI (2003), available online at www.asti.cgiar.org;
agricultural value added is from World Bank (2004), online at www.worldbank.org/data/wdi.

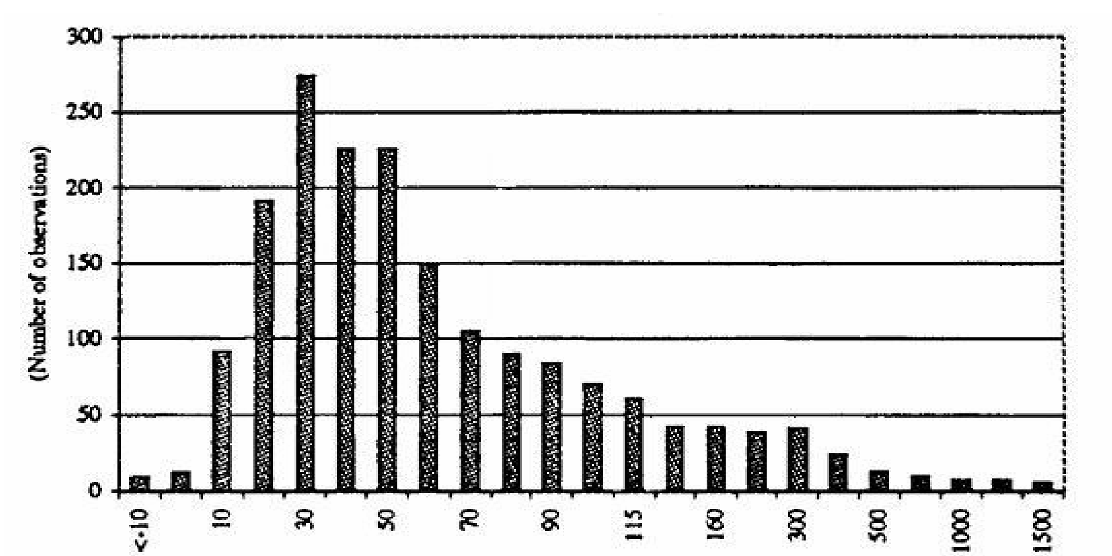
Africa's rate of reinvestment of agricultural value added in R&D is consistently one-half to one-third that of the OECD, and the resulting absolute level of investment per hectare is only one-tenth that of OECD countries. Even if Africa were to match the OECD's percentage rate of reinvestment of agricultural value added, it would still have less than one-fifth of the OECD's level of R&D per hectare.

7. THE ROLE OF PUBLIC FUNDS FOR AGRICULTURAL INNOVATION

To change the technologies available for African farmers, a key financing challenge will be to raise foreign support for agricultural R&D above what Africans could themselves afford, even if they reached the OECD's levels of reinvestment as a fraction of output. Scaling up foreign R&D investment in this way would have a large and sustained economic impact, as well as massive humanitarian benefit in the form of better nutrition. We know this because high levels of agricultural R&D have had high payoffs everywhere else, with no sign of diminishing returns in Africa or elsewhere.

Figure 21 shows the distribution of rates of return estimates found in a recent meta-analysis of the literature on R&D impacts around the world (Alston, et al. 2000); these findings are similar to and include the results of a previous survey of R&D impacts in Africa (Masters et al. 1998). The distribution shown covers a total of 1,852 estimates of the average annual percentage return on various kinds of research investments, research-and-extension programs, or extension activities undertaken around the world. Most of these programs were funded through government laboratories, universities and non-profit institutes, and the reported costs and benefits were computed using a wide variety of techniques. Having access to so many diverse studies allowed the authors of this meta-analysis to control for various possible influences on the estimates, and they found no significant difference in returns between R&D in Africa and anywhere else.

Figure 21. Estimated rates of return to agricultural research and extension (%/year)



Source: Alston, J.M., M.C. Marra, P.G. Pardey, and TJ Wyatt. 2000. "Research returns redux: A meta-analysis of the returns to agricultural R&D." *Australian Journal of Agricultural and Resource Economics*, 44(2): 185-215.

At the lowest end of the distribution there are some failed research programs, with returns below 10% per year. But most programs pay off handsomely, and a few offer blockbuster returns. Investment in agricultural research and extension offers sustained high returns first because there exist technological opportunities to raise productivity, and second because those opportunities are not fully exhausted under existing political institutions.

The technological opportunities with the highest returns often involve new varieties of crops and livestock, to which farmers and others respond with new management techniques involving land, labor and purchased inputs. The new varieties typically originate in research institutions, because the most successful breeding efforts involve controlled experiments and field trials. In contrast, new management techniques often originate with farmers themselves, who have more direct control over their own resources, and can observe the payoffs to various activities.

The institutions that generate new crop varieties are typically science-based enterprises, and they are mainly government-funded or non-profit organizations. Even in countries with extensive private R&D in other fields, the fundamentals of crop breeding remains mainly a public-sector enterprise with many public-good characteristics – whereas private firms often dominate specific fields of application and the multiplication and distribution of known crop varieties, as well as the development of new crop chemicals, machinery and other inputs.

The public-goods nature of crop genetics arises from the spillovers and externalities that new varieties often generate, both positive and negative. The US and UK have been most aggressive in extending patent law and upholding the legal rights and liabilities of private plant breeders, but even so the private firms involved remain closely tied to universities and public laboratories to capture positive spillovers, and they remain closely monitored by government regulators to limit negative externalities.

There remain high returns to agricultural R&D not only because of spillovers beyond private firms, but also because of spillovers beyond any other entity that might mobilize political support for more public funding. The aggregate economic gains generated by agricultural research can readily be measured using survey data, tracing its impact first in terms of the adoption of new varieties such as the evidence shown in Figure 16, then in terms of its result in terms of farmers' changes in input use such as Figure 14 and crop yields such as Figure 13, all the way back to food availability, household consumption and real income.

Household surveys can measure these impacts, but without a practical way for innovators to capture them in either financial profits or political support, underinvestment persists and each project continues to generate above-average economic returns. It is this situation that generates the data shown in Figure 20, with a large number of studies (1,852 distinct estimates!) that consistently point to unexploited opportunities for highly productive investment.

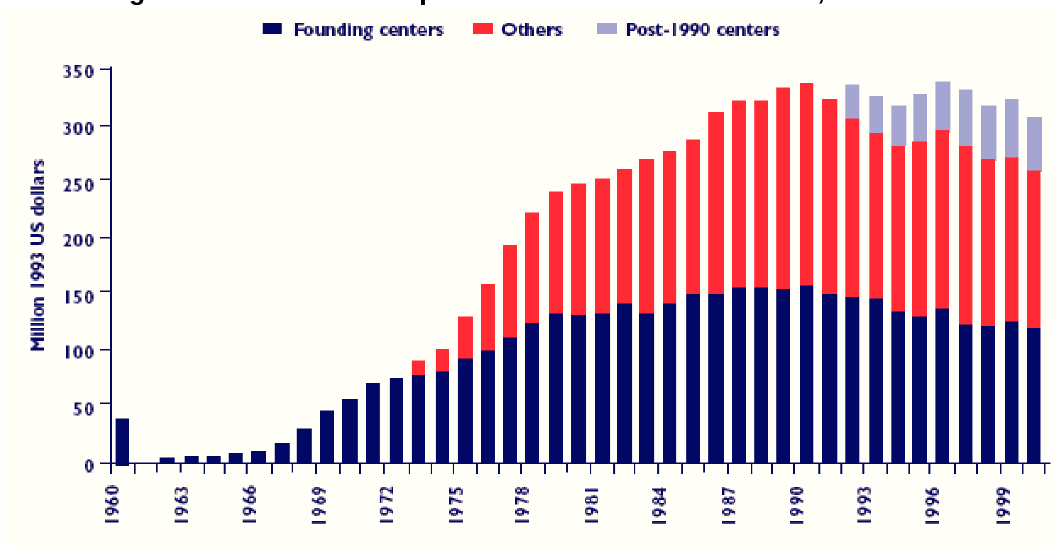
Public agricultural research has yielded high economic returns in all kinds of environments, but it is particularly effective at alleviating poverty in the lowest-income settings – first when it lowers the real cost of foods consumed by the poor, but also when it raises the productivity of their land and labor in production of other things. One recent study of this question found that the amount of public agricultural R&D investment needed to permanently pull one person out of poverty was about $144 in Africa and $180 in Asia, much less than in other higher-income regions (Thirtle, Lin and Piesse, 2003).

8. Institutional innovation and the funding of agricultural research

Opportunities for high-payoff agricultural research persist because existing political institutions consistently fail to exhaust the available opportunities for innovation. The central obstacle is that the gains from desirable new techniques would accrue mainly to widely-dispersed, low-income consumers. Those individuals typically have no way to connect a particular research investment with the benefits they might receive from it. And even if participants in the market knew all about the technologies from which they benefit, the possibility of a Pareto-optimal allocation of innovation is severely constrained by asymmetric information, free-ridership, and other market failures.

The political obstacles that limit agricultural R&D are occasionally overcome, often by visionary leaders who establish unusual institutions to internalize spillovers, set priorities and control free-ridership. A remarkable example of such institutions are the international agricultural research centers (IARCs), of which the earliest was the International Rice Research Institute (IRRI) founded in the Philippines in 1960. Such a center was not established for Africa until the International Institute for Tropical Agriculture (IITA) was founded in Nigeria in 1971, when the world-wide Consultative Group for International Agricultural Research (CGIAR) was established to sustain donor funding for all of the IARCs. The total expenditure of these centers over time is shown in Figure 21 below. Clearly, Africa came late to the party, and when it did it received much less support than the comparable Asian institutions – if only because in the early 1970s, Africa had relatively less need for new farm techniques than Asia. By the late 1980s and 1990s, when Africa needed it most, global support for the system had waned. There has been a substantial increase in funding to the CGIAR since 2000, with the system's total current-dollar budget probably now around $450 million, but comparable figures for the full time series are not yet available.

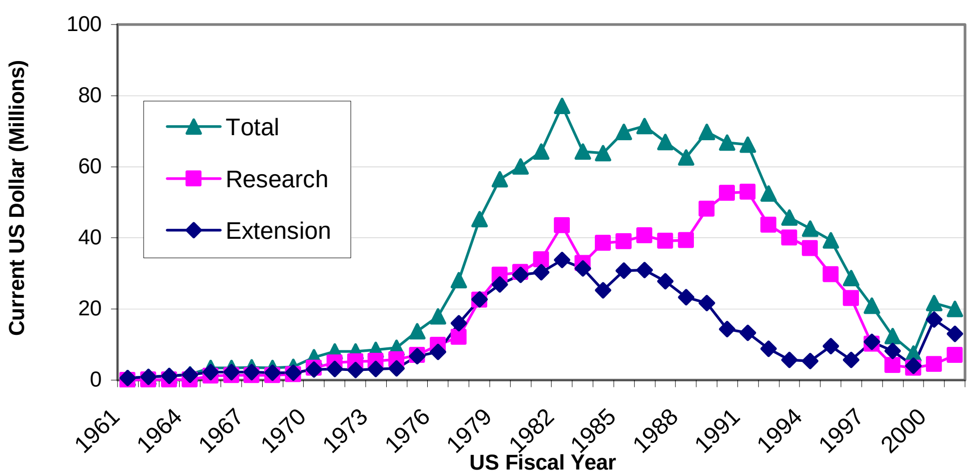
Figure 22. Worldwide expenditure of the CGIAR centers, 1960-2000



Source: P.G. Pardey and N.M. Beintema (2001), "Slow Magic: Agricultural R&D a Century after Mendel." IFPRI Food Policy Report 31. Washington, DC: IFPRI.

Investments in agricultural research and extension specifically for Africa did rise in the late 1970s, when the successes of IRRI and other green revolution institutions in Asia became apparent. Some of this occurred through the CGIAR as shown in Figure 22, and some of it was aid to other research institutions such as the USAID programs included in Figure 23 below. But USAID and other donors aimed first to import the successful technologies that had been developed elsewhere in previous decades, rather than conduct new research to develop locally-appropriate material, and they funded extension programs that had no appropriate innovations to extend. In any case, these fledgling investments in agricultural research soon fell afoul of the Africa's public-sector crises of the 1980s and 1990s, when most public services in Africa faced bankruptcy or privatization.

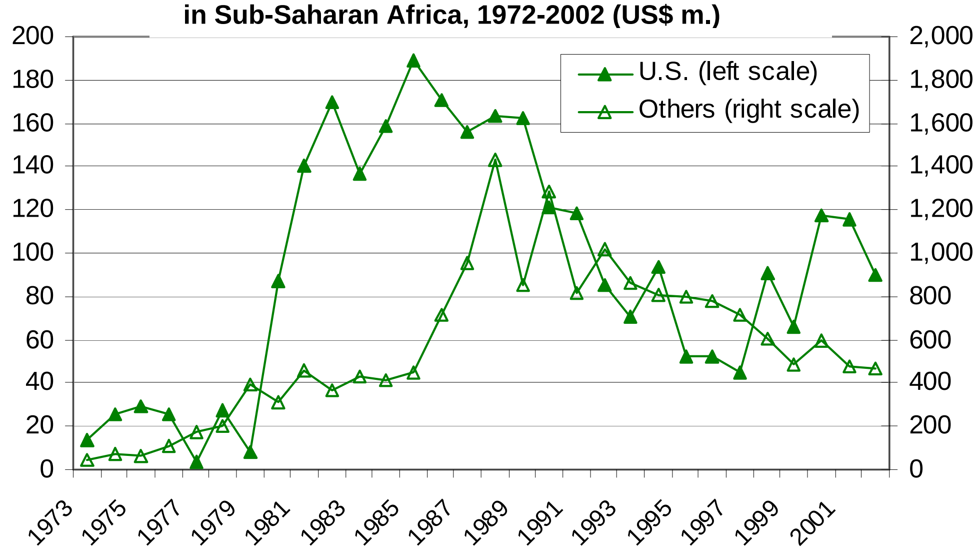
Figure 23. USAID Funding for Agricultural Research and Extension in Africa, 1961-2002



Source: USAID file data; Gary Alex, personal communication (February 2003).

The pattern of rise and then fall in financing of agricultural research and extension reflects a more general rise and then fall in support for all investments for agricultural production in Africa. Figure 24 shows data reported to the OECD, from a partial classification of donor expenditure by objective. USAID's investments in all projects related to agricultural production in Africa rose sharply after 1980, from near zero to a peak of US$180 million in 1985, while the sum of all other donors' similarly-targeted investments rose later to a peak of $1.4 billion in 1989. Both fell rapidly thereafter, and although US support recovered slightly after 1998 it remains only around $100 million, and an additional $400 million is coming from other donors.

Figure 24. Foreign aid for agricultural production in Sub-Saharan Africa, 1972-2002 (US$ m.)

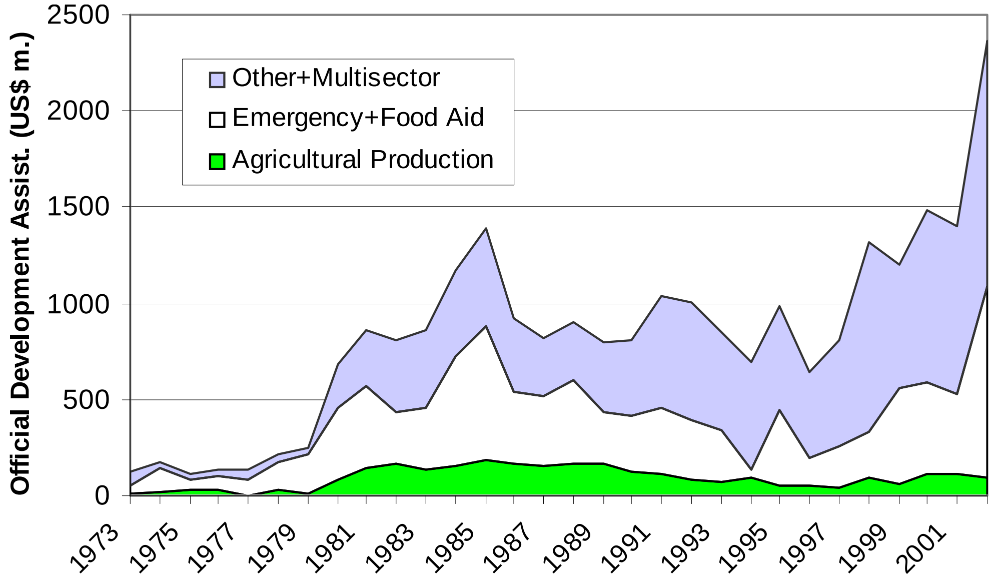


Source: Calculated from data in OECD Development Assistance Committee, *Geographical Distribution of Financial Flows to Aid Recipients 2004.* Online at http://sourceoecd.org

The combined total of donor support for all agricultural production is now less than one dollar per person in Africa. This situation is undoubtedly associated with a rise and then loss of support for public institutions in general, since many key agricultural services such as research are natural public goods that cannot profitably be provided in the private sector. But the rise and decline could also have been a response to the worldwide relative scarcity of food that emerged in the 1970s and was then alleviated during the 1980s and 1990s, thanks to farm productivity growth in Asia and elsewhere.

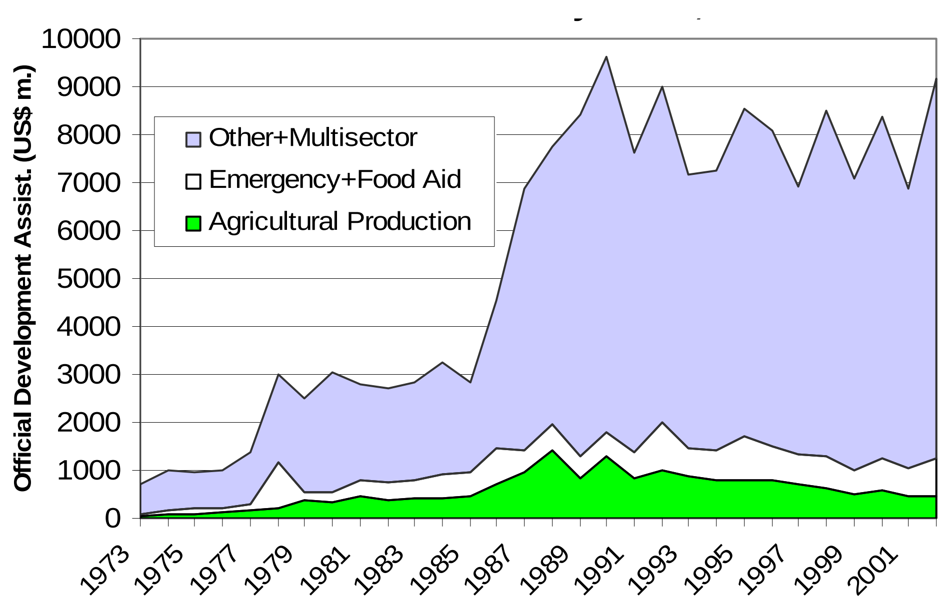
The rise and fall of U.S. and other donors' support for agricultural production in Africa is important, but is drawfed by other kinds of aid. The following two figures show total official development assistance (ODA) to Africa, first from the United States and then from other donors. The contrast is striking, as USAID gives an unusually large fraction of its assistance for emergencies and also food aid. In any case, since the 1980s all donors' aid has been dominated by programs, policy reform and institution-building, as opposed to aid for agricultural production.

Figure 25. US Official Development Assistance to Africa by sector, 1973-2002



Source: Calculated from data in OECD Development Assistance Committee, *Geographical Distribution of Financial Flows to Aid Recipients 2004.* Online at http://sourceoecd.org

Figure 26. Non-US Official Development Assistance to Africa by sector, 1973-



Source: Calculated from data in OECD Development Assistance Committee, *Geographical Distribution of Financial Flows to Aid Recipients 2004.* Online at http://sourceoecd.org

An old adage tells us to teach a man to fish so he can eat for a lifetime, rather than give him a fish so he can eat for a day. Perhaps that idea is so often repeated because it is so difficult to do. Many providers of foreign aid often find it much easier to mobilize funding to alleviate immediate suffering than to invest in long-term solutions – and when they can make long-term investments, they often find it easier to promote access to existing technologies through markets and trade, rather than try to develop new techniques.

For a donor to invest in the creation of new crop varieties for the poor requires first an understanding of the potential breakthroughs that might be achieved, and then a specialized science-based R&D effort directed at those targets. Farmers and others generate many different kinds of innovations, but by definition the particular kinds of innovations whose adoption is tracked in Figure 16 and whose economic value is measured in Figure 21 require some other kind of resource, beyond the existing toolkit available on the ground.

In practice, developing improved crops and better production practices typically involves the international exchange of materials and ideas, which are then recombined in new ways that are can be tested in thousands of local experiments across the target region, under target conditions. Experience in other regions provides examples of innovations that were successful elsewhere, but cannot provide the actual crop varieties, agronomic techniques and other innovations that would be needed in the target locations.

9. A NEW MECHANISM TO SUPPORT INNOVATION IN AFRICAN AGRICULTURE

The innovations needed for sustainable productivity growth in Africa *could* be developed and disseminated through existing contracting mechanisms. The scientific capacity exists for donors to scale up R&D efforts and to disseminate the resulting technologies. But existing institutions have been unable to sustain funding for enough of this type of activity, in part because they lack a reliable way to connect specific investments with specific results. Just as the CGIAR institutions were needed to fill an important gap in our technological capabilities in the 1960s and 1970s, a new kind of funding mechanism may be helpful for Africa today.

A specific proposal advocated here and in previous papers (Masters 2003, 2004) calls for donors to pay innovators proportionally to the social returns from the technologies for which they are responsible. A related strategy is advocated in Kremer and Zwane (2005). This approach would offer innovators a share of the returns that are documented in the studies shown on Figure 21. Donors would begin the process by authorizing lines of credit by which to pay for successful new technologies. At the same time, an independent secretariat would be established to invite applications for payment from eligible innovators. The prize secretariat would specify the kinds of evidence needed to document net benefits, undertake random field audits to assure the quality of the data, and conduct other kinds of due diligence on the applicants. Then, having helped overcome the market failures that limit R&D funding, the secretariat would submit its findings to the interested donors.

The proposal specifies a particular kind of research-prize system. Historically, prizes for technological achievements have often been used as a complement to patent rights and research contracts. A detailed analysis of past prizes as they inform the present proposal is made in Masters (2005). Since patents work only for marketable innovations, and research contracts require the donor to know in advance which R&D programs it is willing to support, prizes are useful to fill the gap, creating competition among innovators for an innovation that would not otherwise be marketable.

Most prize payments are triggered by the achievement of a pre-specified technological hurdle, from the 18th-century British prize for measuring longitude at sea to the recently-awarded X-prize for civilian space flight. Adapting the prize concept for African agriculture calls for an approach that specifies how value will be measured, but does not specify what technologies will be rewarded. This approach allows innovators to discover which kinds of technique will generate the greatest measurable economic gains. This is possible in agriculture where gains are relatively easy to document using a combination of field trials, adoption surveys and market data.

Controlled experiments can be used to document many kinds of quantity change, showing how a new technology might raise yields, save time, reduce pesticide use, improve food quality, or do anything else that can be replicated in an experimental setting. Asking for data from controlled experiments allows a wide range of solutions to farmers' problems to be considered and compared in a transparent and accountable manner. Of course not all innovations can be subject to controlled experiments, but the approach allows a wide range of important innovations to be rewarded proportionally to their value, and ensures that bundles of complementary innovations can be rewarded appropriately.

Using prizes and purchase guarantees for innovations that help the poor has recently been championed by Michael Kremer and others, particularly to create a market for tropical-disease vaccines (Kremer and Glennerster 2004). Kremer and Zwane (2005) discuss its application to agriculture. A popular book (Sobel 1995) recently drew attention to the importance of the Longitude prize, and awarding the X-prize for space flight was widely covered in the popular press.

The strengths and limitations of innovation prizes as a complement to patent protection and research grants has long been recognized in the economics literature, particularly Nalebuff and Stiglitz (1983) and Wright (1983). Clearly, as borne out in many historical precedents, a prize system is unlikely to replace local innovators' other sources of core finance and working capital. Even at their most successful, the function of prizes is mainly to help lubricate the market for innovations, providing some resources directly to successful groups and also complementing other flows. Prizes reveal information about what works and where, guiding funders and researchers towards successful strategies that are more likely to be rewarded.

The unique virtue of a prize program is to provide rewards *ex-post*, letting other institutions provide the working capital. The prize secretariat would have no comparative advantage in becoming yet another funding agency for research; donors should use their many existing contracting mechanisms for that. But the prize secretariat would have a strong advantage in providing technical assistance and small grants for experimental data and farm surveys, to build capacity in the new skills needed to produce high quality applications. By offering that assistance, prizes would be more likely to reach innovators who happen to be good at R&D or diffusion, but are perhaps not very skilled at documenting their work.

Offering technical assistance and small grants for data analysis and farm surveys will no longer be necessary once the prize criteria are well accepted for innovation programs. Innovators will collect and analyze similar data as a routine matter, because that will be the only way for them to know if they are succeeding. But many innovators do not now collect this type of data, and they are not funded in proportion to their success on the ground. Funding occurs for other things: either marketable innovations (pursuing sales as opposed to adoption), or through grants and contracts (pursuing proposals as opposed to results). Indeed, this failure to pursue economic gains for farmers is why there is a need for the proposed prizes.

When a prize system is first introduced, the first applications would be for innovations that have already been developed, with the only additional effort needed to win prize funds being the documentation of impacts. Some donors might wish to support such retroactive prizes, simply to draw immediate attention to these achievements, to channel funds to the successful groups, to inspire imitators and establish confidence in the prize mechanism. Other donors might prefer to look forward, for example specifying prizes for technologies that were first described, released or disseminated after the prize announcement. In such cases the awards would go first to new techniques that happened to be "on the shelf", with the prize offer providing stimulus mainly to the dissemination effort and the alleviation of adoption constraints. Over time, the prize award would help to pull technologies from further up the research pipeline, encouraging individuals and institutions to anticipate potential results, solve farmers' problems and thereby win prize awards. Prize awards would, as always, also play an important role in publicizing successes, encouraging innovators to pursue proven strategies and encouraging donors to provide direct contracts for successful lines of work. Clearly existing institutions are not able to complete the market for innovation. Large excess returns from the limited research funding that does occur are readily observable in the data, which is why the proposed prize system is needed now.

10. CONCLUSIONS

The post-1980 focus on trade as an engine of poverty alleviation may be gradually giving way to something else -- thanks partly to the extent of liberalization that has already occurred, but also due to the limited success of further openness in accelerating growth in the poorest regions. The goal of this essay has been to present publicly-available data in new ways, to improve our understanding of persistent poverty in Africa and the mechanisms by which donor agencies might be able to do something about it.

In the view taken here, the magnitude of potential gains from trade depends crucially on local productivity, particularly food-crop productivity, or aid and capital inflows to pay for sufficient food imports for labor, land and local capital to flow into production of other goods. The pace of that flow depends in turn on the nutritional status, growth rates and age structure of the population, particularly as they influence changes in the farm population. For Africa as a whole, the data shown here suggest that a sharp rise in productivity -- or huge capital inflows -- would be needed for sustained poverty reduction.

Twenty-five years ago a somewhat similar situation in Asia was met with an intense donor-country effort that included the creation of new institutions for international R&D, and the techniques they created underlie much of Asia's subsequent poverty-alleviation success. International agricultural R&D has begun to have similar effects in Africa, but so far has been done at a scale far too small to meet the continent's needs. For donors to scale up their efforts, new contracting mechanisms might be helpful. This paper briefly describes one such initiative, but a wide range of different institutional mechanisms are likely to be needed to help Africans overcome the many obstacles they face.

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