# THE CHOICE OF TECHNOLOGY IN STRATEGIES FOR AGRICULTURAL DEVELOPMENT: MECHANICAL INNOVATIONS IN EAST AFRICA

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FOREWORD

Roughly 1.6 billion people, 40 percent of the world's population, live in urban areas today. At the beginning of the last century, the urban population of the world totaled only 25 million. According to recent United Nations estimates, about 3.1 billion people, twice today's urban population, will be living in urban areas by the year 2000.

Scholars and policy makers often disagree when it comes to evaluating the desirability of current rapid rates of urban growth and urbanization in many parts of the globe. Some see this trend as fostering national processes of socioeconomic development, particularly in the poorer and rapidly urbanizing countries of the Third World; whereas others believe the consequences to be largely undesirable and argue that such urban growth should be slowed down.

Despite rapid rates of urban growth in many low-income countries, the persistence of high levels of fertility and the dominance of agriculture in their total labor force call for increased attention to agricultural strategies emphasizing labor-using innovations that permit a broad participation of the farm population in the gains in productivity and income achieved by such countries. This paper addresses the fundamental problem of agricultural innovations in low-income countries: those with a 1976 per capita GNP of $250 or less. In this subset of developing countries, which account for roughly a third of the world's population, the bulk of the population and labor force are still dependent on agriculture for employment and income. Much of the world's poverty is concentrated in the rural areas of these low-income countries. The design and implementation of agricultural strategies is therefore of central importance in achieving accelerated economic growth and the reduction of poverty.

Bruce Johnston, on leave from the Food Research Institute at Stanford University, has devoted many years to research on problems of rural development. In this paper, he argues that animal-drawn agricultural implements are of great importance to many low-income developing countries such as Kenya, Uganda, and Tanzania. He discusses the fact that the economic, demographic, and structural characteristics of these countries must be carefully analyzed in order to identify the "appropriate" technology for their agricultural development.

A list of related papers in the Population, Resources, and Growth Series appears at the end of this paper.

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I am grateful to Dr. James Ryan and his colleagues at the International Institute for the Semi-Arid Tropics for the opportunity to participate in the ICRISAT Workshop on Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture in February 1979. The numerous citations in the manuscript to papers presented at the Workshop give partial indication of my indebtedness, but the formal and informal discussions during the week at Hyderabad also contributed a great deal to clarifying my ideas about the important issues confronting low-income countries in their choice of technology for agricultural development.

Dr. Hiromitsu Kaneda and Dr. William C. Clark contributed valuable suggestions for improving this version of the paper, and I am indebted to Clark for advancing my understanding of the process of "policy analysis" which, I believe, is so relevant to the complex issues of policy design and implementation in developing countries. I am also indebted to Ms. Susan Riley, secretary for the HSS Population, Resources, and Growth Task, who typed the manuscript skillfully and managed to complete it prior to my departure in spite of the many competing demands on her time.

ABSTRACT

Agricultural innovations in low-income developing countries such as Kenya, Tanzania, and Uganda must be capable of increasing productivity as well as employing a growing labor force. A major thesis of this paper is that animal-drawn implements have a strategic role to play in these countries. The choice between animal- and engine-powered implements is discussed and an attempt is made to point out the principal obstacles to the identification and diffusion of improved farm equipment. Secion III of the paper emphasizes the problems involved in absorbing a rapidly increasing labor force into productive employment. In the concluding section, an attempt is made to apply "good policy analysis" to some of the more important and controversial issues that arise in the choice of technology for agricultural development.

CONTENTS

# THE CHOICE OF TECHNOLOGY IN STRATEGIES FOR AGRICULTURAL DEVELOPMENT: MECHANICAL INNOVATIONS IN EAST AFRICA *

Bruce F. Johnston

This paper examines certain issues related to the choice of technology for agricultural development which confront many of today's low-income countries. A fundamental problem faced by countries with the economic, structural, and demographic characteristics exemplified by Kenya, Tanzania, and Uganda is to identify and introduce combinations and sequences of agricultural innovations capable of increasing farm productivity and output by means which provide opportunities for productive employment for a large and growing farm labor force. A major argument of the paper is that expanded farm use and local manufacture of simple and inexpensive items of farm equipment have an especially strategic role to play in these countries and in many other low-income developing countries.

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*This is a revised and expanded version of a paper presented at a Workshop on Socio-Economic Constraints to Development of Semi-Arid Tropical Agriculture held at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India, in February, 1979.

# I. INTRODUCTION

The statistics in Table 1 briefly summarize some of the more important economic, demographic, and structural characteristics of the three East African countries together with average figures for the 34 developing countries with per capita GNP in 1976 of less than $250. This subset of developing countries accounts for about one-third of the total world population, and their share in the total can be expected to increase.

In addition to their low levels of income, the persistence of high levels of fertility and the dominance of agriculture in their total labor force are especially significant characteristics of the low-income countries. Because the crude death rates in the East African countries have been reduced to levels a little below the average for countries in the low-income category, their rates of natural increase, ranging from 2.8 percent in Tanzania to 3.5 percent in Kenya, were somewhat above the average for this subset of developing countries. In spite of rapid rates of growth of population in urban areas, the decline in the share of agriculture in the total labor force in the East African countries was small and more than 80 percent of their workforce was still dependent on agriculture in 1970. Again the situation in Kenya, Tanzania, and Uganda is typical of the low-income countries as a whole.

It is widely recognized that agricultural strategies which emphasize yield-increasing innovations as epitomized by the high-yielding, fertilizer-responsive plant varieties constituting the core technology of the "Green Revolution" have significant advantages for countries where the bulk of the population is still dependent on agriculture for income and employment. Being highly divisible, such innovations can be used efficiently by small farmers provided that the physical and policy environments are favorable.

The well-documented experience of Japan and Taiwan demonstrates that strategies which efficiently exploit divisible "biological-chemical" innovations of that nature can achieve rapid increases in output by a pattern of agricultural development that is economically efficient and which also has important social advantages. The progressive modernization of a country's existing small-scale farm

Table 1. Selected economic and demographic indicators: Kenya, Tanzania, Uganda, and low-income country averages

| | Kenya | Tanzania | Uganda | Average of 34 low-income countries |
|---|---|---|---|---|
| Per Capita GNP | | | | |
| 1976 | 240 | 180 | 240 | 150 |
| Average growth rate of per capita GNP (%) | | | | |
| 1960-1976 | 2.6 | 2.6 | 1.0 | 0.9 |
| Agricultural production growth rate (%) | | | | |
| 1960-1970 | 5.9 | 3.7 | 2.8 | 2.3 |
| 1970-1976 | 1.6 | 2.5 | 1.3 | 1.6 |
| Rate of Natural Increase (%) | | | | |
| 1975 | 3.5 | 2.8 | 3.2 | 2.7 |
| Crude Birth Rate (per thousand) | | | | |
| 1975 | 50 | 47 | 47 | 47 |
| Crude Death Rate (per thousand) | | | | |
| 1975 | 15 | 19 | 15 | 20 |
| Share of agriculture in total labor force | | | | |
| 1960 | 86 | 89 | 89 | 88 |
| 1970 | 82 | 86 | 86 | 85 |

Source: World Bank (1978) pp. 76, 78, 80, 102, 104.

units by a sequence of capital-saving, labor-using innovations permits broad participation of the farm population in gains in productivity and income. And the economic efficiency of the resulting expansion path for the agricultural sector is demonstrated by the relatively modest requirements for scarce resources because of the extent to which the increases in output are associated with substantial increases in total factor productivity, i.e., in output per unit of total inputs. This in turn is a consequence of the fact that the innovations and associated purchased inputs are highly complementary to the existing on-farm resources of labor and land.

It is also widely recognized, however, that many of the contemporary developing countries are experiencing a "dualistic" pattern of agricultural development in which increases in productivity and output have been largely concentrated in an atypically large-scale and capital-intensive subsector. And in part because of the concentration of resources in that subsector which preempts a large part of the domestic commercial market, a large fraction of the rural population has been essentially bypassed even in countries where average per capita GNP has been increasing at a rapid rate. Considerable attention has been given to the ways in which inappropriate policies, notably the protection of overvalued exchange rates by trade restrictions and the underpricing of capital available from official sources, have encouraged the adoption of capital-intensive technologies ill-suited to conditions where capital is scarce and has a high opportunity cost whereas labor is relatively abundant and cheap because of the lack of non-farm employment opportunities.

Much less attention has been given to the fact that the physical environment in many of today's developing countries also limits the scope for the expansion of farm output based on biological-chemical innovations. It is argued in the following section that because of those environmental factors, agricultural expansion in these countries requires a different balance between biological-chemical and mechanical innovations. In Kenya, Tanzania, Uganda, and most of the other countries of tropical Africa, the special importance of mechanical innovations is also a consequence of the fact that the overwhelming majority of farmers still

depend on the hoe which means that they encounter serious labor constraints even though the holdings which they cultivate are very small. It is emphasized, however, that there are formidable obstacles to the identification and diffusion of mechanical innovations adapted to the needs of small-scale farmers subject to a severe purchasing power constraint. Over the extended period from 1880 to 1965, the index of total input in Japan (which aggregates the conventional inputs of labor, land, fixed capital, and fertilizer and other nonfarm current inputs) increased at a rate equal to only about half the rate of increase in agricultural output (Hayami, 1975, p. 42). In Taiwan, crop production increased considerably more rapidly than in Japan as output responded to a higher rate of growth of effective demand associated with the expansion of sugar and rice exports in addition to the growth of domestic demand related to a much higher rate of natural increase than prevailed in Japan. Between 1911-15 and 1936-40 and again between 1951-55 and 1961-64 agricultural output rose at an average annual rate of about 3.5 percent which was associated with a remarkable rate of increase of total factor productivity of approximately 2.5 percent during both periods. This is based on estimates of the rate of increase in factor inputs in "stock terms"; it is noted later that a significant part of the growth of output is to be attributed to fuller as well as more efficient utilization of the available stocks of farm labor and of cultivated land (Johnston and Kilby, 1975, pp. 242-48).

The structural and demographic factors mentioned above have important implications for the problems of labor absorption that are examined in section III. A final section on Policy Analysis and the Choice of Technology in Low-Income Countries presents some conclusions that are necessarily tentative. It is asserted, however, that "hard conclusions" can be drawn from the implications of the structural-demographic characteristics of these countries concerning the formidable task which they face in expanding employment opportunities both within and outside agriculture. The evidence also seems persuasive that animal-drawn implements and other inexpensive items of farm equipment have an especially important role to play in achieving increases in farm productivity and incomes and in fostering the growth of local manufacturing output and employment.

## II. THE ROLE OF FARM EQUIPMENT AND TILLAGE INNOVATIONS IN EAST AFRICA

After examining certain characteristics of the physical envirnoment for farming in East Africa which influence the balance between biological-chemical and mechanical innovations in achieving increases in agricultural productivity and output, attention is given to the choice between animal- and engine-powered implements. This includes a brief summary of past policies and programs and a review of the evidence concerning the relative costs of animal- and engine-powered technologies.

The potential impact of alternative equipment innovations on the development of local manufacturing is then examined, and finally an attempt is made to identify the principal obstacles to the identification and diffusion of improved items of farm equipment.

### The Balance Between Biological-Chemical and Mechanical Innovations

There are three principal factors which suggest that agricultural strategies in East Africa should be concerned simultaneously with farm equipment innovations *and* with the introduction of yield-increasing innovations: (1) the relatively limited scope for yield increases under rainfed conditions; (2) factors which will limit the expansion of irrigated agriculture; and (3) the significance of interactions between tillage innovations to improve land and water management and yield-increasing innovations. This is in contrast with the pattern of development in countries such as Japan and Taiwan where growth of farm productivity and output has depended overwhelmingly on yield-increasing innovations together with complementary investments in irrigation and drainage. Gradual development and spread of a widening range of simple implements of good design made a contribution toward realizing the yield-potential of improved varieties and greatly expanded use of fertilizers (Johnston and Kilby, 1975, chs. 6,8). But it has been only since the mid-1950s in Japan and the late 1960s in Taiwan, when the absolute size of their farm labor force finally began to decline significantly, that engine-powered equipment in the form of single-axle power tillers became a major source of increases in productivity.

## Potential for Yield Increases

Under conditions of controlled irrigation, varietal improvement and high rates of fertilizer application have a very large and quite reliable impact on crop yields. In some of the farming areas of East Africa with ample and well-distributed rainfall, substantial increases in yield have been achieved. In fact, the rapid spread of high-yielding varieties of hybrid maize in Kenya has been the most significant example of technical progress affecting food production in East Africa (Gerhardt, 1975). There has also been considerable although more limited progress in diffusing high-yielding varieties of maize in Tanzania. However, in both Kenya and Tanzania progress has been much more limited in areas with less favorable environmental conditions in spite of the fact that food crop research in East Africa has been focused almost entirely on plant breeding and fertilizer use, to the neglect of research on improved farm equipment (Vail, 1973).

## Irrigation Potential

In the long run irrigation will make a significant contribution to the expansion of food production in East Africa, and attention needs to be given to accumulating better hydrological information and to building up experience and expertise in the demanding tasks of designing, constructing, and managing irrigation systems. But in the short and medium term it will be much more economical for research and development programs to concentrate on realizing the large potential that exists for expanding cultivation and raising yields under rainfed conditions. Moreover, there is considerable uncertainty whether the total runoff available will be sufficient to permit substantial expansion of irrigation.

In Kenya especially there is increasing recognition that water is becoming a scarce commodity and that priority should be given to "water-saving types of irrigation" (Ruthenberg, 1978, p. 13). The small irrigation projects undertaken in the past have concentrated a great deal of water on limited areas--and often low-altitude areas with extremely high rates of evaporation. Returns are likely to be greater if emphasis is given to supplementary

irrigation in areas of higher elevation where water effectiveness would be higher because of lower rates of evapotranspiration. Ruthenberg (1978, p. 12) also advances cogent arguments concerning the need to give much more attention in the future to intensifying production in valley bottoms where the water-logged soils now produce very little because of failure to develop drainage systems. He emphasizes that "valley-bottom development and farming is highly labour intensive and promises attractive returns per hour of work". In contrast with Asia, African farmers have no tradition of developing drainage systems, and the institutions and administrative procedures required to develop and maintain valley bottom farming systems do not exist.

Tillage Innovations and Improved Land and Water Management

Better and more timely weeding is an almost universal requirement for increasing crop yields in East Africa. Weeds grow vigorously in the tropics, and crop yields may be reduced by as much as 30 to 70 percent because the weeds compete for light, water, and soil nutrients. Under the traditional hoe cultivation weeding is typically late and poorly done. Farmers often prefer to plant a larger area than they are able to cultivate carefully because of the labor constraint, and this is probably rational given the low returns to labor employed in hand weeding. The introduction of animal-drawn cultivators can be expected to ease the physical constraint and also make weeding a more rewarding activity. That expectation is confirmed by the fact that farmers in Machakos District of Kenya are already making extensive use of ox-drawn plows for inter-row cultivation in spite of the fact that their moldboard plows are ill suited for that operation. Furthermore, with the higher yields obtainable with the introduction of improved varieties and use of fertilizers the returns to weeding are increased substantially.

The complementarity between equipment-tillage innovations and biological-chemical innovations is particularly high in the semi-arid "medium-potential" areas where crop cultivation has been expanding rapidly in recent years. Under these conditions the choice of implements and tillage methods is critical. This is because

land and water management practices that are well adapted to the soil and other characteristics of the local environment can increase substantially the extent to which crops are able to utilize the water available from limited and erratic rainfall. Improving infiltration, moisture retention, and the timeliness of planting and reducing weed competition all have a dramatic effect on the level and reliability of crop yields when moisture is the limiting factor.

Experimental work at ICRISAT (the International Crop Research Institute for the Semi-Arid Tropics) demonstrates that the really substantial improvements in net farm income are obtained with a set of innovations involving improved varieties and fertilizer in combination with improved soil and crop management, although under some soil conditions large increases in net returns are possible even with local varieties if the package of improved practices includes increased application of fertilizer and the improved soil- and crop-management treatments.

In the experiments conducted at ICRISAT, the soil and crop management innovations are implemented with a well-designed, animal-drawn wheeled tool carrier referred to locally as the "bullock tractor" (Ryan, et al., 1979). The estimated capital cost of the bullock tractor is about Rs. 6500 which is rather high even for a multipurpose animal-drawn implement. It has been calculated that the bullock tractor must provide yield advantages of some 200-400 kilos per hectare to justify its higher costs as compared to the traditional implements used by Indian farmers. Evidence derived from the trials at ICRISAT demonstrate that a yield advantage greater than that is possible on both the Alfisols and deep Vertisols in the experimental plots used by the Farming Systems Research Program. However, evidence of profitability at the farm-level is not yet available. It should also be noted that this animal-drawn tool carrier implies economies of scale which are naturally much less than those which apply to tractors but nevertheless make it particularly attractive for relatively large farmers operating about 15 hectares of land. The wheeled tool carrier with one large pair of bullocks can substitute for two or three smaller bullock pairs because the wider area covered by the bullock

tractor permits a drastic reduction of the distance that must be travelled in cultivating a hectare of land. This also implies the displacement of 1½ bullock drivers for each 15-hectare farm, thus illustrating that the direct effects of even a shift from traditional to improved animal-drawn implements can give rise to difficult problems of labor absorption. It is estimated that a simpler though less durable and less versatile wheeled tool carrier could be manufactured for about one-fourth the cost of the "bullock tractor", thus increasing the saving in resources possible with this mechanical innovation (Binswanger, et al., 1979*). The general implications of the *rate* and *bias* of technical change are considered in section III where it is emphasized that it is essential to consider both the direct and indirect effects of mechanical and other innovations on the problem of labor absorption.

## The Choice Between Animal- and Engine-Powered Mechanical Innovations

There has been considerable expansion of ox-cultivation in all three of the East African countries, beginning as early as about 1910 in Uganda (Anthony, et al., 1979, pp. 185-86; Uchendu and Anthony, 1975). But to a considerable extent this spread has been a spontaneous process based on the importation of either a standard moldboard or a ridging plow. Other than a modest expansion in the use of ox carts, there has been virtually no spread in the use of a wider range of animal-drawn equipment. This has, in fact, been the common pattern with the adoption of animal draft power in tropical Africa. Only in Mazabuka District in Zambia and in much of francophone West Africa and in Madagascar has there been substantial use of a wider range of animal-drawn implements (Anthony and Uchendu, 1970; Le Moigne, 1979).

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*In addition to the paper by Binswanger, Ghodake, and Thierstein cited in the text, I am indebted to Dr. Thierstein, Agricultural Engineer in the ICRISAT Farming Systems Research Program, for additional information about these tillage and equipment innovations and an opportunity to observe cultivation of some of the experimental plots. The bullock tractor is a locally manufactured version of the Polyculteur designed by Jean Nolle which is being used to a limited extent in francophone West Africa.

During the past two decades the governments in East Africa have given considerably more attention to promoting tractor cultivation, and the resources devoted to subsidized tractor hire schemes, subsidized credit for the purchase of tractors by individual farmers and to those undertaking contract cultivation (frequently the same persons), to training schemes for tractor drivers and mechanics, and subsidized or even free allocation of tractors to selected *ujaama* villages in Tanzania have greatly exceeded the funds allocated to the promotion of animal-powered technologies.

## Past Policies and Programs

In all three countries there is evidence of persistent ambivalence in government policies and in the priority to be given to animal-drawn vs. engine-powered equipment. At various times and in varying degrees the government of the three countries have recognized the advantages of promoting improved and expanded use of animal-draft power. There have, however, been substantial differences between the countries so that it is useful to briefly summarize experience in each country.

Uganda. A promising program to test improved equipment and to disseminate the "Indian Method" of training and controlling oxen, i.e., by the use of reins attached to a nose ring or a nylon rope passed through a hole punched in the nose of the animal, was initiated at the Serere research station in Uganda during the early 1960s. But that program was allowed to lapse because of the preoccupation of Prime Minister Obote and his government with promoting the use of tractors imported under aid programs. President Obote made a promise in the late 1960s to bring in 1,000 tractors over a three-year period. A first contingent of 250 were sent under a U.K. aid program, an additional 350 were financed by West Germany, and 270 were financed by the Uganda goverment (Minto, 1979). This total of 870 was less than the target but quite sufficient to involve the government in a much-expanded and costly program of heavily subsidized contract plowing and to bring a halt to earlier efforts to promote more effective use of animal draft power. This proclivity of policymakers to assume that farmers

could and should shift directly from the current predominant reliance on the hoe and human labor to tractor-powered farming systems has seriously weakened efforts to foster the use of animal draft power in all three countries.

Tanzania. The Tanzania Agricultural Machinery and Testing Unit (TAMTU), which was set up near Arusha in 1957, has carried out considerable testing and development work on animal-drawn equipment. On a number of occasions official statements have indicated that major stress would be placed on promoting ox-cultivation. President Nyerere has been especially eloquent in his endorsement of expanded use of animal draft power. In one forceful statement he declares:

> We are using hoes. If two million farmers in Tanzania could jump from the hoe to the oxen plough, it would be a revolution. It would double our living standard, triple our product. This is the kind of thing China is doing. (Quoted in Smith, 1971.)

Similarly, in his important statement on "The Arusha Declaration: Ten Years After", President Nyerere notes that

> .....the truth is that the agricultural results have been very disappointing. Modern methods have not spread very quickly or very widely; the majority of our traditional crops are still being grown by the same methods as our forefathers used... People still think in terms of getting a tractor for their farms--even when they are small--rather than learning to use ox-ploughs.

Tanzania's action--and lack of action--to foster wider and more efficient use of animal drawn implements is especially interesting. It might be assumed that as a socialist country with a strong commitment to an egalitarian approach to development, the political pressures which have elsewhere contributed to the encouragement of inappropriately capital-intensive technologies would have been almost non-existent. However, the gap between policy pronouncements and actual implementation has been wide. A recent monograph on *Agricultural Mechanization and Employment* asserts that "Tanzania is one of the few countries that adopted a policy

of both selective and appropriate mechanization during the last few years" (Bodenstedt, et al., 1977, p. 112). The authors support the statement by a reference to the Second Five-Year Plan (1969-1974) which proposed the widespread introduction of ox-cultivation, especially through the establishment of ox-training centers. A Food and Agriculture Organization Mission on agricultural mechanization which visited the country in 1974 reports, however, that they

> .....found it extremely difficult to find any concrete evidence in the regions of a concerted effort to promote a wider and more intensive use of animal power. The program of establishing ox-training centres, mentioned in the Five-Year Plan, appeared to be virtually non-operative...(FAO, 1975, p. 9).

My own enquiries and observations as a member of an ILO employment mission to Tanzania in 1977 seemed to confirm the conclusion of the FAO Mission and of a subsequent FAO/UNDP study by J. M. Beeney (1975). In addition there appeared to be renewed emphasis on large-scale tractor mechanization in state farms as a major element in the government's program to expand food production. I have suggested elsewhere that preoccupation with the problem of obtaining a marketable surplus for urban centers may partly account for this tendency to promote large, capital-intensive state farms (Johnston, 1978, p. 94). This is a problem which has caused concern in Tanzania because of the difficulties encountered by statutory monopolies in collecting and distributing food produced by several million small-scale production units. The lack of confidence in the "village sector" which this implies may well become a self-fulfilling prophecy. Priority allocation of scarce resources of capital and trained manpower to the state farm sector is likely to mean that the great majority of farm households will be deprived of the resources needed to achieve increases in productivity and output sufficient to feed a growing farm population and a small but rapidly expanding urban population. Because of the purchasing power constraint that is a consequence of limited structural transformation, low-income developing countries confront a fundamental choice between a dualistic agricultural strategy that concentrates resources in a large-scale,

mechanized subsector and a more broadly based strategy aimed at the progressive modernization of the small-scale farm units on which the great majority of its rural population depends for employment and income. That structural characteristic and the demographic factors which ensure that its effects will be a persistent feature of these economies are examined in detail in section III.

Kenya. Prior to about 1975, very little had been done in Kenya to promote ox-cultivation, and many policymakers and agricultural specialists in the government held the view that the country's farmers should shift directly from hoe cultivation to tractors. There are no doubt many factors that account for the especially strong appeal of tractor-based technologies in Kenya, including the pre-Independence preoccupation with European farms in the Highlands and the post-Independence interest of many senior government officials in large-scale farms in the former European areas. However, a psychological factor associated with the "modernity" of tractors and a tendency to look down on animal drawn equipment as an "inferior" and "backward" technology may have been especially strong in Kenya.*

It should also be noted, however, that neglect of animal draft power in Kenya was probably influenced considerably by the priority that was very properly given, beginning with the Swynnerton Plan in the 1950s, to achieving rapid increases in farm incomes by promoting smallholder production of coffee, tea, and grade cattle for milk production in Central Province and other "high potential"areas.

*A conclusion derived from a study in Nigeria by Winston (1977) appears to have considerable relevance to attitudes toward tractors in East Africa. On the basis of his discussions with plant managers, he identifies five sets of factors which appear to be important in explaining "the attraction of wrong technology" including commonly emphasized factors such as price distortions and lack of information about the equipment required for more appropriate technologies. Of interest in the present context is his suggestion that "A manager's choice of production technology is often in part a statement about cultural identity embodying his assessment of his people's characteristics and competence in dealing with technological sophistication..." (p. 14). Thus the choice of inappropriate technology was often "defined by the imperative 'We *must*'" which, Winston believes, "was an assertion, simply, that 'high technology' is the *sine qua non* of economic and cultural advancement, so if one wants those objectives, the way to get them is direct" (p. 15).

The steep slopes and the small size of farms in those areas alone are sufficient to limit the potential gains from introduction of ox-cultivation. But because such profitable alternatives exist, the opportunity cost of land for producing fodder for draft animals is high and this represents an important economic factor that reduces the profitability of introducing animal draft power in those high potential areas (Adelhelm and Schmidt, 1975).

Kenya's Development Plan 1974-1978 (1974) enunciated a policy of giving priority to increasing the productivity of Kenya's small scale farmers which included an emphasis on animal-powered equipment and other "appropriate technologies". This was followed by a considerable change in attitudes and policies with respect to the promotion of animal draft power. A 1975 Workshop on "Farm Equipment Innovations for Agricultural Development and Rural Industrialization" was organized by the Institute for Development Studies and the Faculty of Agriculture of the University of Nairobi and the National Christian Council of Kenya, but officials from the Ministry of Agriculture and other government agencies were active participants. The report on the Workshop (Westley and Johnston, eds., 1975) includes a report on a program initiated in 1975 at the Bukura Institute of Agriculture in western Kenya to instruct local farmers in the "Indian Method" of training and controlling oxen (Achiya and Udundo, 1975). The instructor, Gabriel Udundo, who had received training in the 1960s at Serere in Uganda, also trained staff members at the Faculty of Agriculture of the University of Nairobi and at Egerton College. Since that time the degree and diploma courses at those institutions have included training in the use of animal draft power as well as tractors. (Prior to 1975, the instruction in agricultural engineering at both institutions was limited to the use of tractor-drawn equipment.) In 1975 the Ministry of Agriculture entered into an agreement with FAO to undertake an FAO/UNDP Agricultural Equipment Improvement Project. Considerable progress has been made in identifying and testing a range of equipment and in devising evaluation procedures which include an assessment of an implement's "suitability for local manufacture". The Department of Agricultural Engineering of the University of Nairobi has also initiated research on animal-drawn farm equipment and associated tillage

methods which is described briefly in section IV. In its discussion of science and technology policy, Kenya's Development Plan 1979-83 (Kenya, 1979, p. 56) states that "on large farms, tractor ploughing may be appropriate" but then affirms:

> The greatest challenge and the greatest need, however, is to apply modern science to the development of technologies that can be used productively by small farmers and self-employed workers in the rural and urban informal sectors. Such technologies, if they are effective and appropriate to the small farm and informal sector settings must: (i) be more productive than the technologies now in use, (ii) be produced and sold at a cost that the intended user can afford, and (iii) cope effectively with problems confronted by the user in the setting in which he and his family work. That is appropriate technology, and its creation is a genuine challenge to the most sophisticated scientific knowledge. It is the first priority for Kenya's scientific and technological research programmes.

It is later noted that through the Agricultural Equipment Improvement Project there will be an intensified effort during the plan period "to produce appropriate technology suitable under smallholder conditions and which lend themselves to manufacturing in Kenya" (Kenya, 1979, p. 258). Finally, the program to promote small-scale industry will include efforts to facilitate local manufacture of simple implements identified as meeting the requirements of small-scale farmers (Kenya, 1979, p. 339).

## Relative Costs of Animal- and Engine-Powered Technologies

The evidence now available seems to be reasonably consistent in indicating that with prevailing labor/capital price relationships, reliance on animal draft power generally represents the most economical approach to overcoming the power constraint and labor bottlenecks which are major factors underlying the low levels of crop yield and labor productivity that characterize farming in semi-arid East Africa. On the basis of a number of farm management studies carried out in Sukumaland in western Tanzania in the early 1960s, Collinson (1965, p. 3) asserted that "There is no case for the introduction of tractors in areas where ox-plowing is established; these can perform the same function as tractors more cheaply".

A report on mechanization in Tanzania by J. M. Beeney (1975) includes a careful comparison of manual, oxen, and tractor cultivation using partial budgeting techniques and the best cost data available in 1974 when he carried out his FAO/UNDP study. He concludes that both for individual farmers and for communal cultivation in *ujaama* villages, animal draft power is more economical than tractor cultivation. The only exception, according to his analysis, is that in the larger and more successful *ujaama* villages, using tractors for minimum tillage might be superior provided that the equipment was well operated and well maintained. Even under those circumstances the use of a tractor in conjunction with ox-cultivation would offer the least costly option.

A linear programming analysis by I. J. Singh (1977) provides the most valuable evidence concerning the cost advantage of animal draft power over tractor cultivation. His LP models are based on input-output coefficients estimated from recent farm management surveys carried out in the Mwanza and Shinyanga regions of western Tanzania. They permit an assessment of how the farming system as a whole will be affected by different levels of mechanization, including both a tractor hire service and use of tractors in a communal *ujaama* farm as well as hoe cultivation with hand labor and ox-cultivation. Singh also examines the effects on net returns and on employment of various combinations of mechanical and yield-increasing innovations, viz. use of improved seeds, fertilizers, and pesticides. His analysis confirms the clear-cut economic advantage of animal draft power over tractors. When all land in a village is cultivated as a single operational unit so that the ubiquitous problem of under-utilization of tractors is minimized, the cost disadvantage of tractor cultivation is obviously reduced; but nevertheless net returns are higher with ox-cultivation than with tractors even when it is assumed that the price of labor is well above the levels that now prevail.

The examination of the structural and demographic characteristics of these East African economies in section III emphasizes that the present low price of labor is not merely a transitory phenomenon. Even with very optimistic assumptions about the growth of nonfarm employment and a slowing of the rate of natural

increase and growth of the population of working age, it will be two or three decades at least before these countries will experience a sufficient tightening of labor markets to raise the price of labor to levels that justify more capital-intensive alternatives than expanded and more efficient use of animal draft power. In fact, success in fostering the development of rural-based manufacturing firms through expanded production of simple farm implements can make a significant contribution to accelerating the growth of nonfarm employment and thereby reducing the time required to realize widespread increases in the productivity and opportunity cost of labor. Government measures such as minimum wage legislation can increase the price of labor for workers in the modern sector but at the price of encouraging the use of inappropriately capital-intensive technologies and thereby slowing the economy-wide expansion of employment opportunities.

## The Impact of Farm Equipment Innovations on the Growth of Domestic Manufacturing

There are a variety of ways in which a broad-based strategy for smallholder development can maximize the positive interactions between agricultural and industrial development. Widespread increases in farm income generate a pattern of rural expenditures that can provide an increasingly important stimulus to expanded manufacture of both farm inputs and consumer goods by relatively small and decentralized workshops employing labor-using, capital-saving technologies. By the same token, accelerated growth of employment in manufacturing and related service enterprises provides a continuing stimulus to the commercial production of agricultural products and makes possible continuing increases in the level of farm cash income.*

In contrast, a more dualistic pattern of agricultural development in which resources are concentrated in a subsector of relatively capital-intensive farm units generates a pattern of rural expenditure which tends to minimize the positive impact of agricultural development on industrial development. Particularly

*Economic policies which turn the terms of trade against the agricultural sector obviously diminish the positive interactions between agricultural and industrial development.

relevant to this paper is the fact that tractors are very cash-intensive which means that the net cash income retained by the agricultural sector will be considerably lower with tractor-based technologies than with ox-cultivation because the latter relies to a much greater extent on "internal inputs" of labor and farm-reared draft animals. Moreover, efficient manufacture of tractors requires large-scale, capital-intensive enterprises. But given the small size of the manufacturing sector and the limited development of technical skills in the East African countries, local manufacture of tractors and other sophisticated items of equipment would not only be uneconomic but would provide very little additional employment relative to the capital investment required. Establishing a domestic tractor plant which assembles imported components reduces the requirements for a wide range of technical skills and also reduces greatly the domestic value added. In fact, vehicle assembly operations in a number of developing countries are *negative* value-added operations. And the "leakage" which reduces the stimulus to the growth of local manufacturing is almost as great as with complete reliance on imported tractors and fuel.

A major thesis of this paper is that broadly based agricultural development can and should give rise to a growing demand for a widening range of simple, inexpensive farm equipment; and that "potential internal market can be used to foster the growth of a local farm machinery-manufacturing industry" (Swamy-Rao, 1977, p. 100). The magnitude of that potential market is suggested by the fact that an estimated 84 percent of Kenya's arable area is still cultivated with hand tools compared to 12 percent cultivated with oxen and 3.5 percent by tractors (Muchiri and Minto, 1977 p. 57); and the situation in Tanzania and Uganda would be roughly similar. Some of the cultivated land is unsuitable for ox-cultivation, but the potential for growth of effective demand lies as much in the adoption of a wider range of ox-drawn implements as in extending the area in which animal draft power is used.

Animal-drawn plows, cultivators, carts, and similar items of equipment can be manufactured with reasonable and increasing efficiency by small- and medium-scale workshops. Such firms employ

relatively labor-intensive technologies and they also have a strong incentive to minimize the import content of their products. The same considerations also apply to relatively simple types of processing equipment. Success in increasing the technical and entrepreneurial capacities of rural-based workshops manufacturing farm implements and processing equipment has wide ramifications because of the central importance of metal-working skills and of machines and fixtures made of iron and steel in the growth of a domestic manufacturing industry.

The experience of Taiwan and China provides strong support for the foregoing propositions. Their economic policies have been very different, but both Taiwan and China have had considerable success in reducing rural poverty and in transforming their overwhelmingly agrarian societies into more productive and more diversified economies. Recent experience in India and Pakistan also provides considerable support for these propositions in spite of the fact that government policies in those two countries have in general tended to discourage rather than foster the positive interactions between agricultural and industrial development.

Rural workshops in Taiwan have often progressed from the manufacture of relatively simple implements such as plows, cultivators, and carts to seed drills, grain driers, electric motors, diesel engines, and even power tillers. Moreover, production of one or more farm inputs has often led to the manufacture of consumer durables such as electric fans and bicycles or to producer goods such as oilseed expellers, lathes, and hand drill presses (Johnston and Kilby, 1975, Ch. 8).

A recent study of rural small-scale industry in the People's Republic of China provides further confirmation of the important ramifications of developing rural-based workshops for the manufacture of farm equipment. The report of the American Rural Small-Scale Industry Delegation asserts that "The agricultural machinery industry has been the major diffuser of technology to the countryside via a direct training effect and a considerable demonstration effect" (Perkins, et al., 1977, p. 72). It is even argued that the indirect effects in diffusing and upgrading metalworking and other technical skills may have been more important than the direct

impact of improved farm equipment on agricultural production. In China as in Taiwan, widely dispersed rural workshops manufacturing farm equipment have performed a crucial role as a technological training ground in developing the capacity to build machine tools and other capital goods. This steady upgrading of the processes and products of rural industry encourages the development and spread of technologies adapted to a country's factor endowment and thus stimulates continuing growth in the size and competence of its local manufacturing industry. Since manufacturing capacity in East Africa is now mainly confined to small urban enclaves, this impetus to the development and diffusion of such capabilities in the countryside is of special significance in fostering widespread increases in productivity, job opportunities, and income.

It is, of course, highly significant that those indirect effects of promoting evolutionary growth of rural workshops manufacturing farm equipment are linked with the direct effects on agricultural productivity resulting from expanded use of improved implements. The experience of Taiwan provides clear evidence of the variety of ways in which a gradually expanding range of simple but well-designed and well-adapted farm implements have eased labor bottlenecks and contributed to the increase in crop yields by improving the precision and timeliness with which various field operations are performed. Moreover, dispersed manufacture of such equipment facilitates feedback between farmers and manufacturers and thereby helps to insure that the implements that are produced are adapted to the needs of the local farming systems (Johnston and Kilby, 1975, pp. 356-59, 392-93).

Clearly, success in promoting expanded use of inexpensive, well adapted farm equipment can make a significant contribution to two major objectives: increasing farm productivity and expanding employment opportunities outside agriculture. Moreover, the increases in farm productivity and income that can be realized by a sequence of equipment-tillage innovations can make possible the increases in cash income required to sustain the reciprocal interactions associated with rising productivity and income among farm households and those engaged in manufacturing.

## Obstacles to the Identification and Diffusion of Appropriate Mechanical Innovations

It has been argued at considerable length that promoting expanded farm use and local manufacture of animal-drawn implements and other inexpensive items of farm equipment can make important, even unique contributions to agricultural and industrial development in East Africa. Nevertheless, it has been noted that the actual progress in the three countries in spreading the use of such equipment is very limited indeed. And except for ox carts which are being manufactured in a number of dispersed rural workshops, local manufacture of animal-drawn equipment is confined essentially to one rather large factory in Dar es Salaam and a factory in Nairobi. Those factories are part of the modern urban manufacturing enclave, and they are contributing relatively little to development in Tanzania and Kenya other than in effecting a modest saving in foreign exchange through import substitution.

There appear to be three principal obstacles that are responsible for the large gap between the potential contribution of expanded use and local manufacture of simple and inexpensive farm equipment and the actual situation. The first is related to the ambivalence and inconsistencies that have characterized government policies for the promotion of animal- vs. engine-powered equipment. The second derives from the overall lack of resources for agricultural research which inevitably limits the research and development (R & D) activities that are needed to identify and promote improved equipment and tillage innovations adapted to local conditions. The third obstacle is the lack of an effective methodology for carrying out R & D activities to generate mechanical and tillage innovations.

### Ambivalence and Inconsistencies in Government Policies for the Promotion of Animal-Drawn Equipment

It has already been emphasized that during the past two decades the governments in East Africa have made a considerably greater allocation of resources for promoting tractor cultivation than for fostering wider and more efficient use of animal draft power. Because of their speed and other technical advantages

tractors have often been viewed as a symbol of a "modern" agriculture. Many government officials and foreign advisers have tended to assume that the striking *technical* superiority of tractors must also imply superiority in terms of *economic* efficiency. The relative ease with which tractor technologies can be transferred and the skillful promotional activities of large multinational firms exporting tractors have naturally reinforced that tendency.

It has been said "that in most cases the implementation of employment-oriented mechanization policies is essentially a political problem rather than a problem of the economic, administrative or technical feasibility of such policies" (Bodenstedt, et al., 1977 p. 108). The decision by Prime Minister Obote and the Ugandan government to shift emphasis from promoting animal draft power to tractors was related to a politically motivated desire to obtain a large allocation of foreign aid that was most easily available at that time for the importation of tractors. The essentially political decision in Tanzania to promote tractor cultivation under the block cultivation scheme of the 1960s also diverted attention away from ox-cultivation and other efforts to promote a broader and more progressive modernization of smallholder agriculture. In addition to its heavy demands on capital and foreign exchange, it is estimated that some 40 to 65 percent of all agricultural extension workers in the country were assigned to the scheme (Kline, et al., 1969, pp. 2-113). Subsequently, heavily subsidized distribution of tractors to selected *ujaama* villages had similar adverse effects, including the tendency noted by President Nyerere: "People still think in terms of getting a tractor... rather than learning to use ox-ploughs".

Perhaps the most fundamental problem has been a common failure to consider the structural and demographic characteristics of the East African economies which pose a fundamental choice between a broadly based strategy aimed at the progressive modernization of the great majority of a country's farm households and a "crash modernization" strategy which concentrates resources in atypically large and capital-intensive farm units. It is argued in section III that because of a cash income constraint and limited purchasing power for "external inputs" which are a consequence of the

structural-demographic characteristics of these economies, those alternative strategies are to a considerable extent mutually exclusive alternatives. A major commitment of scarce resources to a large-scale subsector which satisfies a large part of the domestic commercial demand for farm products inevitably reduces the possibility of successfully pursuing a strategy aimed at widespread modernization of smallholder farming based on fuller and more efficient utilization of their "internal inputs" of labor and land by a sequence of innovations which involves gradually expanded use of purchased inputs which complement those relatively abundant internal, farm-supplied resources.

## Scarcity of Resources for Agricultural Research

The failure to undertake adequate research programs to identify equipment and tillage innovations adapted to the agro-climate conditions in the semi-arid and other farming regions of East Africa has also been related to the general scarcity of financial and manpower resources for research. These countries face a formidable problem in achieving a transition from a resource-based to a science-based agriculture (Johnston, 1978). In past decades the agricultural economies of East Africa have been able to achieve substantial increases in agricultural output mainly by a "horizontal" expansion based on enlarged use of relatively abundant resources of unused land and a growing farm workforce. However, as a consequence of population growth, enlarged cultivation of export crops, and declining yields resulting from reducing the fallow period in the traditional bush fallowing systems, expansion of food production in recent years has not kept pace with the growth of demand. Hence, there is an increasingly urgent need to evolve more productive technologies based on scientific knowledge of improved varieties, increased fertilizer use, and locally adapted equipment-tillage innovations. That need is especially acute in the semi-arid areas. For reasons that are examined in the following section, there has been exceptionally rapid growth of population in Kenya's semi-arid farming areas as a consequence of outmigration from densely populated high potential areas. The migrants are using farming practices that are poorly adapted to these marginal areas, giving rise to serious problems of soil erosion and

an increase in the frequency and magnitude of the need for famine relief in seasons when there is a crop failure.

The strengthening of national agricultural research capabilities in these countries is a difficult task. The general difficulties faced by low-income countries are compounded because these countries are relatively small in terms of population and GNP, but their national boundaries encompass a great deal of diversity in rainfall, soil, and other agro-climatic conditions. Those ecological differences together with considerable variation in the dominant and secondary crops produced in different areas complicate the problems of crop improvement and of devising appropriate equipment and tillage innovations. The impact of past research on food production in these and other African countries has also been limited because both expatriate and national scientists have often lacked an intimate understanding of the conditions and constraints faced by farmers in various ecological zones.

It is noteworthy that agricultural research expenditures in African countries in 1974 represented only 1.4 percent of the value of their agricultural product in contrast to the countries of Western Europe and North America (and Oceania) where research expenditures were equal to 2.2 and 2.7 percent respectively of their much higher level of agricultural output. Probably more significant, however, is the fact that the 1974 figure of 1.4 percent in Africa represented a modest increase from 0.8 percent in 1959 whereas the increase in the countries of Asia over that period was from 0.6 to 1.9 percent of the value of their agricultural output (Boyce and Evenson, 1975, p. 8). It seems reasonable to infer that the threefold increase in the Asian countries reflected increased awareness of the value of agricultural research with the widespread introduction of high-yielding varieties of wheat and rice beginning in the mid-1960s whereas research programs in Africa have not yet yielded comparable results.

Lack of an Effective Methodology for R & D Activities to Generate Mechanical and Tillage Innovations.

The general problems which have limited the past impact of research appear to have been especially serious in the case of R & D activities aimed at providing the technical knowledge required

for achieving more efficient use of animal draft power. It has been noted that food crop research in East Africa has been focused almost entirely on plant breeding and fertilizer use to the neglect of research on improved farm equipment (Vail, 1973). It is not surprising that research stations have concentrated their efforts on varietal improvement since a powerful methodology exists for generating biological-chemical innovations. Furthermore, these divisible innovations can be used efficiently by the smallholders who account for the great bulk of the farm population in developing countries, and the achievements of the Green Revolution in Asia have enhanced the prestige of that research strategy.

In contrast, there are few examples of successful programs to identify and disseminate equipment innovations. In fact, there is reason to believe that the usual approach which has concentrated on the development and testing of equipment by agricultural engineers offers little promise. There appears to be much truth in the assertion that

> Machines to fit into farming systems cannot be designed by farm machinery research engineers working on their own. It requires a team effort of all those concerned with analytical research for the development of all aspects of appropriate farming technologies (Monnier, 1975, p. 224).

A conspicuous feature of the historical development of mechanical innovations in the U,S, has been the critical role played by local blacksmiths, tinkerers, and inventors working closely with innovative farmers. Frequently, it has been a local farmer who has defined "the problem" and has turned to a local workshop to translate an idea into a new or modified piece of equipment in a process that often involves much trial and error. However, the rudimentary development of local manufacturing capabilities in East Africa and the limited experience of farmers with mechanical equipment means that exclusive reliance on that sort of private R & D would be an unacceptably slow process. Thus there appears to be a need for publicly supported R & D activities such as those being carried out by the FAO/UNDP Agricultural Equipment Improvement Project in Kenya.

## III. STRUCTURAL AND DEMOGRAPHIC FACTORS AND THE PROBLEM OF LABOR ABSORPTION

The first part of this section examines several significant implications of the predominantly agrarian structure of the East African economies and of the high rates of growth of population and labor force that prevail. This is followed by an analysis of agricultural development and the choice of technology in which it is emphasized that both the rate and the bias of technical change in the agricultural sector will have a decisive influence on the expansion of better income-earning opportunities and the reduction of poverty.

### General Implications of the Structural-Demographic Factors

The structural-demographic characteristics of low-income countries such as Kenya, Tanzania, and Uganda have a number of implications with respect to the constraints that should be considered in the formulation of development strategies. First, and most directly relevant to this paper, is the fact that domestic commercial demand for agricultural products is inevitably small relative to the number of farm households when less than 20 percent of a country's labor force is employed in manufacturing and other non-farm sectors of the economy. Some farm households supplement their own subsistence production with purchased food, especially when they are earning cash income from the production of coffee, tea, or other export crops. In fact, most of the increase in farm cash income in these and other countries in tropical Africa has derived from expanded production of export crops (Anthony, et al., 1979, Ch. 2). Nevertheless, the monetary income accruing to the average farm household is still extremely small. Hence, the extent to which farmers can make use of fertilizer, farm equipment, and other "external inputs" purchased from outside the agricultural sector is extremely limited. Because of this cash income constraint that restricts the purchasing power of farm households, there are important economic as well as social advantages in a pattern of development which emphasizes certain types of labor-using, capital-saving innovations. These enhance the productivity

of the farm-supplied resources of labor, land, farm-reared animals, and other "internal inputs" while economizing on the especially scarce resources of capital and foreign exchange.

The second implication concerns the direct and indirect effects of a country's agricultural strategy in providing opportunities for productive employment for a rapidly expanding population of working age. The fact that agriculture weighs so heavily in the total labor force, in combination with the rapid rate of increase of the population of working age, means that agriculture will continue to account for the bulk of the total labor force for two or three decades or more. Even with highly optimistic assumptions about the growth of nonfarm employment, it is apparent from the "arithmetic of population growth and structural change" that the annual additions to the labor force must mainly find employment in the agricultural sector.*

In contrast, the effects of these structural and demographic factors are less pronounced in most of the middle-income developing countries. In Mexico, for example, the nonfarm sectors already accounted for 45 percent of the total labor force in 1960, and growth of employment in those sectors was sufficient to reduce agriculture's share in the labor force from 55 percent in 1960 to 45 percent in 1970 in spite of the rapid rate of increase in the country's population of working age. In fact, it is likely that Mexico's farm workforce has finally begun to decline in absolute

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*In a country where agriculture's share in the total labor force has been reduced to 50 percent, it would require a 6 percent rate of growth of nonfarm employment to fully absorb the annual additions to the labor force if the total labor force is increasing at an annual rate of 3 percent. A 6 percent rate of growth of nonfarm employment is extremely unlikely on the basis of past experience and the very high rate of investment that it implies. However, where agriculture still accounts for 80 percent of the labor force, even a 6 percent rate of growth of nonfarm employment would be sufficient to absorb only 40 percent of the annual additions to the labor force in a country with a 3 percent rate of growth in its total labor force. This follows from the definitional identity that the rate of growth of a country's total labor force will be equal to the weighted average of the rates of growth of its farm and nonfarm labor force. See Johnston (1969) for projections of the growth of a country's total, farm, and nonfarm labor force over a 50 year period with alternative initial conditions (80 and 50 percent of the labor force in agriculture) and alternative assumptions about the rates of growth of the total labor force and nonfarm employment.

size, and this is true of many of the middle-income developing countries. With average per capita GNP in 1976 of nearly $1,110 and a considerably higher level of incomes among the nonfarm population that depends on purchased food, the domestic commercial demand for farm products is fairly large in relation to the number of farm households.*

Low-income countries such as Kenya, Tanzania, and Uganda naturally face much more acute problems in achieving widespread increases in per capita income through generating opportunities for productive employment for a rapidly growing population of working age. Success in coping with those problems will require major efforts in three areas: (1) creating improved income-earning opportunities within agriculture; (2) expanding job opportunities in manufacturing and other nonfarm sectors; and (3) slowing their rates of growth of population which will, after a time lag, also slow the rate of growth of their population of working age.

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*Because of Mexico's highly dualistic pattern of agricultural development in which increases in output, and especially of commercialized production, have been concentrated in a subsector of large-scale, relatively capital-intensive farm units, the great majority of farm households have nevertheless faced a fairly severe purchasing power constraint and their increases in productivity and income have been limited (Colosio, 1979; Johnston and Kilby, 1975, Ch. 6). Many factors have contributed to this failure to achieve a pattern of agricultural development leading to widespread increases in income among rural households, including the circumstances that encouraged the direct transfer of tractor-based technologies from the southwestern United States to the wheat- and cotton-producing areas of northern Mexico. The much more limited progress in the traditional farming areas which support the bulk of Mexico's rural population has probably also been influenced by a failure to evolve mechanical and other innovations adapted to the requirements of small farmers with limited cash income. In fact, it is now recognized that the initial emphasis on single-cross hybrids in the country's maize improvement program was not an effective strategy for reaching large numbers of farmers. Although Kenya and a number of other developing countries have recently demonstrated an ability to cope with the problem of annual replacement of seed, they have relied on varietal hybrids which are less location-specific. However, questions related to the choice of "appropriate" technology in Mexico are complicated by various implications of the fact that it has a long common border with the U.S., including large-scale migration of Mexican workers to the U.S. (Reynolds, 1979).

Income-Earning Opportunities for Farm Households

It has been noted that all three countries have made considerable progress in past decades in expanding farm incomes largely through enlarging the area under cultivation and by increasing production of high-value export crops such as coffee and tea. Tanzania still has substantial scope for expanding cultivation in areas with good soils and adequate rainfall. However, many of the sparsely populated areas are poorly served by roads and other types of infrastructure, so that substantial investment and organizational efforts will be required to exploit that potential. Many of Tanzania's settled farming areas which have a relatively good economic infrastructure, such as the regions adjacent to Mt. Kilimanjaro, are already experiencing considerable and increasing population pressure.

Of the three countries, the pressure of population is most severe in Kenya where only some 20 percent of the land receives sufficient rainfall for arable farming. And that includes the semi-arid "medium potential" areas where rainfall is only marginally adequate in a "normal" year. The population density on Kenya's arable land will increase from about 135 persons per square kilometer in 1978 to 250 in the year 2000 (Kenya, 1979, p. 65). But much of the population lives in "high potential" areas where the population densities are much higher and shortages of arable land are already acute. In addition to its effects on rural-urban migration flows, this growing pressure of population on the land in high potential areas is also giving rise to substantial rural-to-rural migration.

This is especially evident in Machakos District. The district-wide rate of population growth increased from about 2.5 percent in the 1932-48 period to 3.5 percent in the 1963-69 intercensal period. During the latter period, however, the rate of population growth in the densely populated high potential areas had already begun to decline because of outmigration induced by the lack of arable land. The major migration flow seems to have been to the less favorable medium potential areas of Marchakos. Because arable land was still available in those areas, the migration flow into the marginal zones between 1963 and 1969 was so great that

population grew by nearly 14 percent per year. In contrast, the rate of population growth in the high potential zone declined from 2.8 percent in the 1932-48 period, when it was a little above the district-wide average, to 1.6 percent between 1963 and 1969 or less than half the district-wide rate of population growth because the effects of natural increase were more than offset by outmigration (Lyman, 1978, Ch. 2).

This type of rural-to-rural migration provides some relief to population pressure in Kenya's most productive but densely populated farming areas, and the plight of the migrating families is no doubt improved as compared to being totally or almost totally without access to land. However, this influx of population into areas with low and erratic rainfall has magnified the demand for famine relief during the seasons when the level or distribution of rainfall is more unsatisfactory than usual. The hardship that is frequently experienced by the families that have settled in these marginal areas is accompanied by serious degradation of the land because of soil erosion that is aggravated by the cutting of trees and shrubs for firewood and for making charcoal in addition to the direct effects of expanded cultivation. The accelerated erosion also increases the silt load carried by rivers which means that downstream dams built for hydroelectric power and irrigation are being rapidly filled with silt, and turbines deteriorate so rapidly that repair and replacement costs are much higher than anticipated. Efforts to restrict the cutting of wood for making charcoal tend to be ineffectual because this is such a significant source of cash income--income that is needed acutely for food purchases when crops fail.

This Machakos example is being repeated on a lesser scale in Embu, Kitui, and other districts of Kehya. Extensive areas in Uganda and especially in Tanzania also face similar problems. Farming conditions in Dodoma Region and certain other areas of Tanzania may well pose even more difficult problems because the low and erratic rainfall is often associated with fragile soils with poor capacity to retain moisture. However, the effects of a high rate of natural increase on population pressure on the land is much less influenced by high rates of migration into Tanzania's semi-arid regions. There is an urgent need in all of these semi-arid

farming areas for the introduction of moisture- and soil-conserving farming systems, but the location-specific research required to evolve technologies adapted to the physical and socioeconomic conditions found in the different semi-arid zones of East Africa has been exceedingly limited.

## Expanding Job Opportunities Outside Agriculture

Success of efforts to improve income-earning opportunities within agriculture will become increasingly problematic as high rates of natural increase and labor force growth intensify population pressure on the land. There are, of course, many reasons why the governments in East Africa are determined to promote the growth of manufacturing and other nonagricultural sectors in order to transform the predominantly agrarian structure of their economies. However, a major consideration is that alleviation of the poverty that is still so widespread in these countries will depend increasingly on the creation of job opportunities outside agriculture. Kenya, Tanzania, and Uganda, in common with other countries in Sub-Saharan Africa, face special problems in generating expanded employment in their nonfarm sectors. As previously noted, this is partly a direct consequence of the fact that the nonfarm sectors account for such a small fraction of total employment that even a large percentage increase in employment does not represent a very substantial number of new job opportunities.

The small size and short history of manufacturing activity in the countries of tropical Africa also means that the experience, technical skills, and entrepreneurial capacities required for growth of local manufacturing are seriously deficient. It might appear that at least two of the East African countries were in a relatively favored position in this respect. In 1954 manufacturing already accounted for about 9 and 7 percent of national product in Kenya and Uganda respectively as compared to less than one percent in the Gold Coast (Ghana) and Nigeria (Acharya, 1978, p. 7).

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*The figure Acharya gives for Nigeria is 0.6 percent for 1950. His summary account draws heavily on an excellent monograph on "Manufacturing in Colonial Africa" by Kilby (1975).

However, manufacturing and commerce in East Africa were heavily dominated by Europeans and Asians until well into the 1960s. The problems that derived from limited practical experience in manufacturing and commerce were compounded by deficiencies in formal education which prompt Acharya (1978, p. 10) to remark that "the colonial heritage of trained indigenous manpower was abysmally small". In both Kenya and Tanzania only 2 percent of those of secondary school age were enrolled in secondary schools in 1960. Ghana with 3 percent secondary school enrollment and 59 percent enrollment for those of primary school age was exceptionally well endowed relative to other countries in Sub-Saharan Africa. Kenya with 47 percent of its population of primary age enrolled in 1960 had a relatively good educational endowment at the time of Independence in 1963; but Tanzania had only about a quarter of its population of primary age in school when it became independent in 1961.

There has, of course, been substantial expansion of manufacturing in the East African countries since the early 1960s when they became independent. In Kenya the share of industry in domestic product rose from 18 percent in 1960 to 23 percent in 1976, and the corresponding change in Tanzania was from 11 percent to 16 percent (World Bank, 1978, p. 80). In Uganda, however, it is estimated that industry's share in the domestic product declined from 13 percent in 1960 to only 8 percent in 1976, presumably reflecting the effects of the 1973 decision to expel all Asians and the disrupted state of the economy during General Amin's regime. But even for Kenya and Tanzania the figures on the share of industry in domestic product give an exaggerated impression of the economy-wide impact of the industrial development that has taken place. To a large extent, industrial development has been concentrated in relatively large firms located in a few major cities. Most of these plants in the modern or "formal" sector use capital-intensive technologies, and the number of job opportunities created has been very small relative to the magnitude of the investible funds that they have absorbed.

The growth of manufacturing activity outside the major cities and the development and diffusion of technical knowledge and skills and of entrepreneurial capacities has been extremely limited. Government initiatives such as Tanzania's Small Industry Development Organisation and Kenya's program for establishing industrial estates and Rural Industrial Development Centres have sought to foster a more decentralized expansion of small- and medium-scale firms using more labor-intensive technologies. However, those efforts have encountered many obstacles, including the predominance of semi-subsistence farm households and the cash income constraint which restricts their purchasing power and limits the effective demand for all types of goods and services produced by the nonfarm sectors of the economy.*

These considerations underscore the importance of rural development strategies which maximize the positive interactions between agricultural and industrial development. The potential that exists for promoting wider use and domestic production of simple and inexpensive items of farm equipment is therefore of strategic importance in stimulating the growth of manufacturing firms that employ capital-saving, labor-using technologies. Exploiting those potential interactions can lead to considerably more rapid growth of output and especially of employment in the nonfarm sectors than is possible when investible funds are concentrated in large-scale plants. Expansion of output by firms in the modern sector is constrained to a much greater extent by shortages of capital and foreign exchange because they are much more dependent on those scarce resources than firms in the informal sector which rely to a much larger extent on local resources of labor and raw materials.

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*In East Africa and in many other African countries policies with regard to trade, the exchange rate, prices, and taxation have been biased against agriculture and have had the effect of turning the domestic terms of trade against the agricultural sector. This "urban bias" has thus reinforced the structural and demographic factors that have limited the growth of per capita income among rural households. A detailed analysis by Jamal (1975) of the effects of these policies in Uganda indicates that they were major factors responsible for the negligible growth of per capita farm income during the 40-year period ending in 1967, and less detailed World Bank studies suggest that they have also been of considerable importance in Tanzania and Kenya (Acharya, 1978, pp. 25-26).

Slowing Population Growth

It has been emphasized that the present predominance of the agricultural sector in their population and labor force will be modified only gradually. This is, of course, a direct consequence of the "arithmetic of population growth and structural transformation" that applies to countries with the structural/demographic features that prevail in East Africa. This means that for another 25 to 50 years or more success in slowing population growth in these countries will depend mainly on the difficult and time-consuming task of reducing fertility among rural families.

Kenya was one of the first African countries to adopt a population policy, but it is apparent from the high birth rate that prevails and the country's 3.5 percent rate of natural increase that the efforts to promote family planning have not yet had much impact. There has been an appreciable increase in the practice of family planning in Nairobi and other urban centers and a small increase in a few agricultural districts, notably in Central Province, where the growth of income, expansion of education, and other aspects of modernization have proceeded very rapidly. But the change at the national level has been minimal. The Development Plan for 1979-1983 (Kenya, 1979, p. 130) expresses the hope that sufficient progress has been made in building up an infrastructure for the delivery of family planning services so that the current plan period will see the beginning of a reduction in the country's rate of population growth. Thus the population projections included in the Plan are based on a declining as well as a constant birth rate. The anticipated decline by 1983 is slight, but the projected population for the year 2000 of 28.2 million with a declining birth rate is nearly 6 million less than the projection which assumes a constant birth rate (Table 2). Because many of those who will be added to the labor force by the year 2000 have been or will be born before the anticipated increase in family planning will have its effect, the 118 percent increase in the "potential labor force" between 1978 and 2000 with a declining birth rate is only a little less than the 125 percent increase anticipated with a constant birth rate. On the other hand, the demand for public resources for education could be substantially

Table 2. Population in Kenya, 1978 and Projections for the Year 2000 (Million persons)

| | 1978 Estimate | Projected, 2000 | | Percentage Increase[a] with | |
|---|---|---|---|---|---|
| | | Constant Birth Rate | Declining Birth Rate | Constant Birth Rate | Declining Birth Rate |
| Total Population | 14.7 | 34.1 | 28.2 | 116 | 91 |
| Potential Labor Force[b] | 6.0 | 13.5 | 13.1 | 125 | 118 |
| Primary School Age (6 - 12) | 3.0 | 7.2 | 5.2 | 141 | 75 |

[a]Computed from unrounded figures.

[b]Estimated at about 85 percent of the population of working age (15 - 59).

Source: Kenya (1979), p. 63.

reduced. With a declining birth rate, it is projected that the number of children of primary school age would increase by 75 percent compared to a 141 percent increase in that age group with a constant birth rate.

The implications of continued rapid growth of a country's population and labor force obviously become more striking as the time horizon is expanded because of the "compounding" that charcterizes population growth. Projections made at IIASA by Mahendra Shaw and Franz Willekens trace the effects on population growth until the year 2024 of six scenarios of possible change in fertility and mortality that might take place between 1969 and 1999. Their "most likely estimate" is a population in 2024 of 64.3 million which is 18.5 million greater than their minimum estimate but more than 13 million below their maximum estimate. (See Appendix Table A1). The Shah-Willekens projections are broken down by rural and urban location. Consequently, their analysis directs attention to the fact that the structural transformation of the country's

labor force will be a slow process. According to their projections, the share of the rural workforce in the total would decline only from 87 to 65 percent between 1969 and 2024. A fourfold increase in the rural workforce would be associated with nearly a 16-fold increase in the active-age population in urban areas and a six-fold increase in the total population of economically active age.

The problem of generating sufficiently rapid expansion of job opportunities to cope with a 16-fold increase in the economically active population in urban areas is obviously a staggering one. It is estimated that even in 1975 more than a third of the urban active-age population was unemployed or "inactive". And the Shah-Willekens projections assume that that percentage would rise to 65 percent of the total urban active-age population in 2024 even on the basis of fairly optimistic assumptions concerning the growth of wage employment, the expansion of wage- and self-employment in the informal sector, and the increase in numbers receiving higher education (Appendix Table A2).

The magnitude of the labor absorption problem would, of course, be reduced with a slower rate of population growth. Thus the Shah-Willekens minimum projection, which assumes a 25 percent linear decline in fertility in rural as well as urban areas over the period 1979-1999, implies that the population of working age would increase 4.7 times by 2024 instead of the six-fold increase implied by their "most likely" estimate. Because of the momentum which characterizes population growth and the time lag before reduced fertility affects the rate of increase of population of working age, it is unmistakably clear that Kenya, Tanzania, and Uganda all face exceedingly formidable tasks in expanding employment opportunities both within and outside agriculture.*

*A joint IIASA monograph with William C. Clark (Johnston and Clark, 1979) and two earlier papers (Johnston, 1977 and Johnston and Meyer, 1977) give major attention to the possibilities of accelerating the reduction in fertility in low-income countries where the majority of the population is still dependent on agriculture.

## Agricultural Development and the Choice of Technology

The success of efforts to achieve widespread increases in income-earning opportunities in agriculture will be determined to a large extent by the *rate* and the *bias* of technical change. By reducing the resource requirements for producing a given level of output, technical progress opens up the possibility of reallocating resources to produce new goods and services as well as expanding the output of the existing mix of consumption and investment goods being produced. But given the structural and demographic characteristics which have just been examined, technical change in agriculture which has a labor-saving, capital-using bias will make it impossible for the great majority of the farm population to participate in gains in productivity and income and will perpetuate the widespread rural poverty that now exists. In addition, a capital-intensive expansion path for the agricultural sector will impede the process of structural change required to move toward a situation in which it is both privately and socially profitable to reduce total farm labor inputs by substituting capital for labor. By slowing the rate of increase in the demand for labor, such a pattern of agricultural development will also delay the tightening of labor markets which is the most reliable means of ensuring an economy-wide increase in returns to labor and of eliminating the nutritional and other deprivations caused by inadequate levels of income.

The concepts of rate and bias of technical change are well illustrated by a pair of diagrams reproduced from Binswanger (1978, pp. 19, 22). The outer production isoquant I-I in Figure 1 represents the production possibilities prior to technical change. The slope of the two parallel diagonals represents the relative prices of capital and labor. Thus point A is the economically efficient point of production because, being tangent to the price line, it represents the minimum cost combination of capital and labor required to produce a "unit" of output given the "state-of-the-art" described by the initial isoquant. The isoquants I'-I', I"-I", and I"'-I"' represent alternative possibilities after technical change has made available improved production possibilities resulting from research and development or

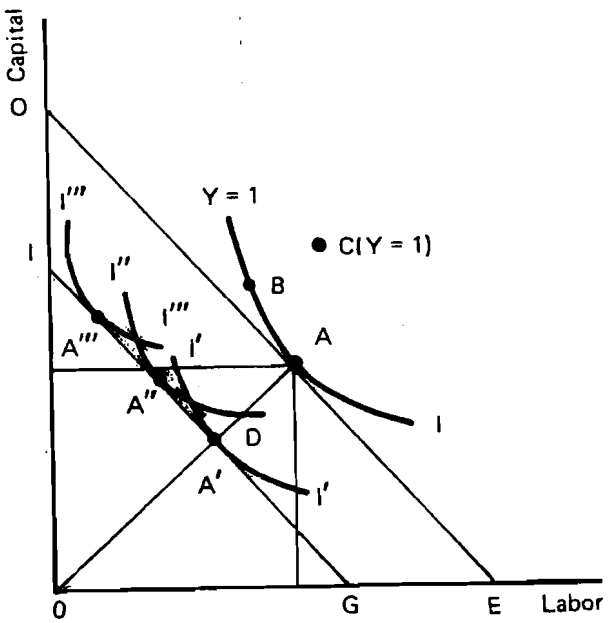


Figure 1. Rates and biases of technical change.
Source: Binswanger (1978, p. 19).

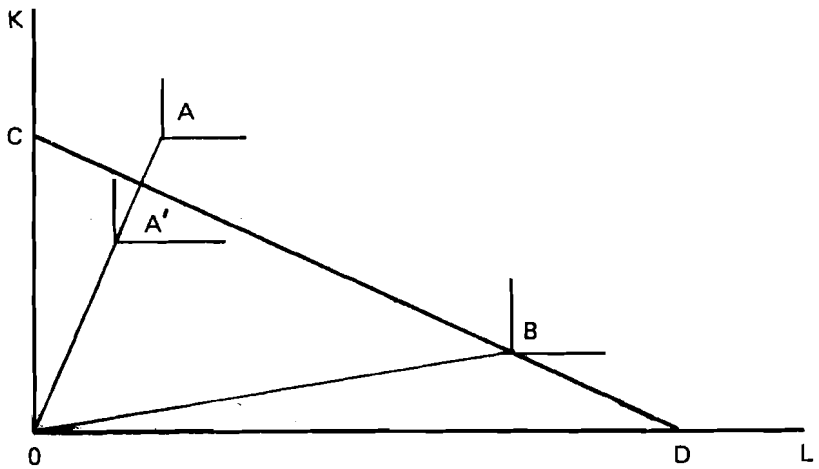


Figure 2. Neutrality and its reference point.
Source: Binswanger (1978, p. 22).

from learning by doing. The way that the isoquants are drawn, the same "unit" level of output can now be produced at points A' or A" using smaller amounts of both capital and labor or at A"' with a greatly reduced input of labor but a somewhat larger input of capital.

The technical change represented by the inward movement to I'-I' is "neutral" in the (Hicksian) sense that with no change in the relative price of capital and labor, the point that is economically efficient, A', results in the same proportional saving in labor as in capital. Technical change that led to shifts to A" or A"' would be labor saving because there is a proportional as well as an absolute reduction in labor requirements per unit of output. Figure 2 can be interpreted as describing an initial situation in which the capital-intensive technology represented by A and the labor-intensive technology at B co-exist. Even though point A is unprofitable as compared to B in terms of the "true" prices of capital and labor, represented by the price line CD, larger farmers might still find it privately profitable to operate with the capital-intensive technology represented by A. They might, for example, have access to credit from institutional sources at artifically low interest rates. (The three alternatives depicted in Figure 2 all represent fixed proportion technologies to sharpen the contrast between the capital-intensive and labor-intensive alternatives.) Technical change represented by A', i.e., an inward shift along the capital-intensive ray OA, would now be more profitable even with the relative prices represented by the price line CD.

Technical change that is relevant only to the relatively capital-intensive expansion path might occur with the availability of a more efficient imported tractor in a situation in which agricultural research is not generating any innovations that would permit technical change along a labor-intensive ray such as OB. Alternatively, one might interpret the capital-intensive ray OA as the historical pattern of technical change in U.S. agriculture and the labor-intensive OB ray as the labor-intensive pattern of technical change which characterized Japanese agriculture until World War II and which characterized Taiwan's agricultural

expansion path until the late 1960s. In Japan and Taiwan yield-increasing biological-chemical innovations led to increases in productivity of both land and labor whereas the mechanical innovations which were the major source of agricultural progress in the U.S. led to steady increases in labor productivity, but no appreciable increase in crop yield occurred until the 1930s when hybrid maize and increased use of fertilizer became significant sources of growth of output.

Because of the contrasting effects of mechanical and biological-chemical innovations, it is common to partition increases in farm labor productivity into two components: mechanical innovations which mainly increase the acreage cultivated per worker and biological-chemical innovations that mainly increase yields per acre. At a particular point in time this partitioning is merely an identity and output per worker (O/L) is equal to the product of acreage cultivated per worker (A/L) and output per acre (O/A). However, the rate of increase in O/L over time will, to a close approximation, be equal to the sum of the rate of increase in A/L and in O/A. Table 3 presents a summary picture of past changes in labor productivity in agriculture in the U.S. and Taiwan which illustrates several contrasts pertinent to the problems now faced by low-income developing countries such as Kenya, Tanzania, and Uganda. During the period 1901-50, increases in yield per acre (O/A) accounted for two-thirds of the increase in labor productivity in Taiwan, and increases in the acreage cultivated per worker (A/L) accounted for the remainder. But during the 1952-66 period, the rate of increase in the farm workforce was considerably greater than the increase in the cultivated area so that A/L declined. However, that decline was considerably more than offset by rapid increase in O/A resulting from improved crop varieties, expanded use of fertilizers, and improvements in irrigation which contributed to increased yields of individual crops and also permitted a substantial increase in multiple cropping. In the U.S., increases in A/L were considerably more important than increases in O/A in every period. However, the considerable increase in O/L between 1920 and 1940 and the rapid increase in O/L between 1940 and 1960 were largely a consequence of the accelerating decline in the size of the farm labor force. In Taiwan it was not until the late 1960s that growth of employment in the nonfarm sectors was sufficient

Table 3. Rates of change in output per worker (O/L), acreage per worker (A/L), and yield per acre (O/A), Taiwan and the U.S. (percent).

| | O/L | A/L | O/A |
|---|---|---|---|
| Taiwan | | | |
| 1901-1950 | 1.2 | 0.4 | 0.8 |
| 1952-1966 | 3.3 | -0.8 | 4.1 |
| United States | | | |
| 1880-1900 | 1.1 | 1.2 | -0.1 |
| 1900-1920 | .6 | .5 | .1 |
| 1920-1940 | 2.2 | 1.5 | .7 |
| 1940-1960 | 5.8 | 4.2 | 1.6 |

Source: Johnston and Kilby (1975) p. 143.

to permit a reduction in the size of the farm workforce. It is also noteworthy that in both countries a substantial fraction of agricultural output was exported so that the rate of increase in production and in O/L were a good deal more rapid than would have been possible if output expansion had been limited to the rate of increase of domestic demand for farm products.

Figure 3 (reproduced from Johnston and Kilby, 1975, p. 391) summarizes the principal factors influencing farm labor productivity based on this conventional partitioning into increases in acreage per worker and increases in output per acre. The figure also directs attention to the fact that changes in labor productivity in agriculture depend on the interacting influence of "farm level" and "socially determined" factors. In addition to the proximate factors that directly influence the acreage cultivated per worker and yields per acre, the level of farm output will also be influenced by the growth of effective demand as it influences agricultural prices and production incentives. As noted earlier, expanded production of export crops has accounted

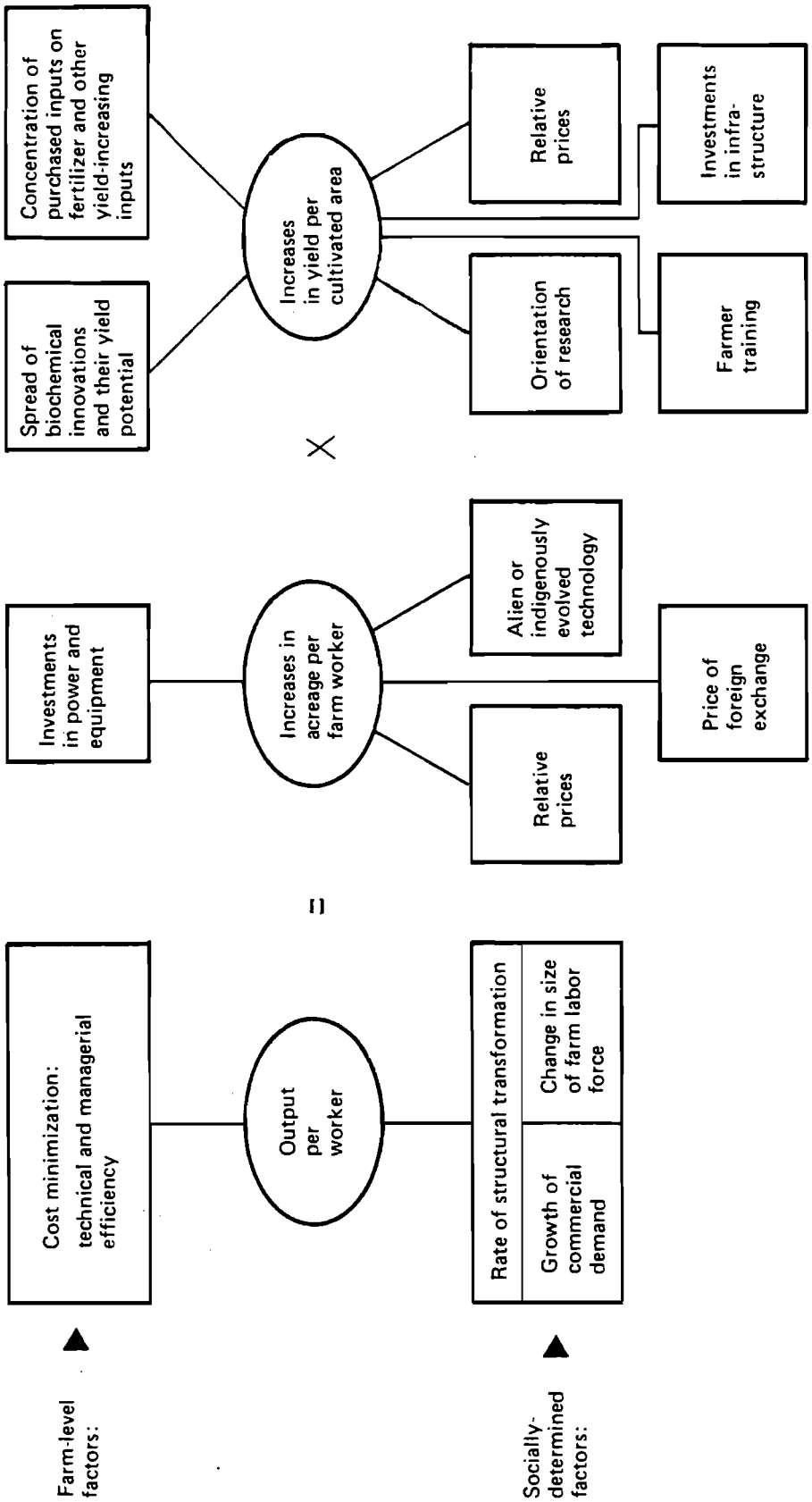


Figure 3. Schematic summary of the principal factors influencing changes in farm productivity.

Source: Johnston and Kilby (1975, p. 391)

for a substantial part of the increase in farm output and incomes in East Africa, but as structural transformation proceeds domestic commercial demand will become the principal source of farm cash receipts. The fact that the farm workforce in these countries is still increasing rapidly naturally means that the rate of increase in farm labor productivity is substantially less than the rate of growth of output. As has been emphasized repeatedly, it will be many years before these countries will reach the turning point which Taiwan reached in the late 1960s so that increases in farm labor productivity exceed the rate of growth of output because the farm workforce has begun to decline. In the meantime, any significant expansion of tractor-based cultivation by large-scale farm units will tend to limit opportunities for increases in output and labor productivity among the majority of small-scale farmers unless there is sufficient scope for enlarging the total cultivated area and for increasing agricultural exports so that expansion by the large-scale subsector does not preempt land and market opportunities that could otherwise be exploited by smallholders. In fact, in a relatively stagnant economic environment such as existed in northern Nigeria in the late 1960s, even the expansion of cultivation with animal-drawn implements by some of the larger farmers seemed to be contributing to a reduction in acreage cultivated by the smaller farmers (Anthony and Johnston, 1968).

This is not to suggest that technical change in agriculture should be stifled so as to avoid the problems of adjustment and reallocation of resources that are inevitable concomitants of economic progress. It is important to recognize, however, that mechanical innovations require more substantial changes in the allocation of resources than agricultural expansion based predominantly on biological-chemical innovations and expanded and improved irrigation. Although the latter innovations reduce labor requirements per unit of farm output, they generally increase labor requirements per acre. In Taiwan, for example, a more than threefold increase in farm output between 1911-15 and 1955-60 was associated with a 50 percent increase in the farm labor force which was almost twice as large as the percentage increase in the

cultivated area. But even so, because of higher labor requirements per acre associated with the higher yields and increased multiple cropping, there was a substantial reduction in the degree of underemployment in the agricultural sector (Johnston and Kilby, 1975, pp. 253-54).*

Discussions of choice of technology have frequently gone to opposite but equally untenable extremes. On the one hand, there is a tendency to emphasize technical efficiency and "modernity" rather than maximum economic efficiency even though the price of labor is low (because it is relatively abundant) and capital is scarce and dear. On the other hand, any technical change that eliminates income-earning opportunities of low-income households may be condemned on the basis of a partial, static analysis. That is, the potential for generating new employment opportunities as well as increased production of goods and services made possible by the resource-saving effects of technical change is ignored. Those tendencies are well illustrated by a clear and quantified analysis of alternative techniques for rice milling in Indonesia (Timmer, 1974). Timmer demonstrated that in the conditions prevailing in Indonesia, small rice hullers represented the economically efficient alternative, and this analysis seems to have helped to avoid sizeable investments in large bulk facilities that had been recommended by an international consulting firm. A subsequent critique of Timmer's analysis has emphasized that even the relatively labor-intensive small mills which he had shown to be economically optimal have meant a serious loss of income from hand pounding of rice which has traditionally been a significant source of cash income for poor households (Collier et al., 1974). It has been estimated that the introduction of the small mills results in an annual loss of some 125 million womandays of wage labor or earnings equivalent to about $50 million. In his reply, Timmer (1974, p. 20) emphasizes that

*There was a similar reduction in underemployment in Japanese agriculture during the period 1880-1920. Thus Hayami (1975, pp. 39-40) reports "that technical change in this period was of such a nature as to reduce the seasonal slack in the utilization of farm labor by facilitating the diffusion of arable cropping and of sericultural production..."

> .....banning small rice mills (thus forcing a return to hand-pounding) would be an enormously costly way of helping the displaced women... We must set the $50 million loss to these women against a gain to society of more than $450 million...

Timmer acknowledges that the benefits to the women directly affected are not sufficient to compensate them for their loss of income from hand pounding, but expresses the hope that a mechanism could be found that would redistribute enough of the social gain to compensate them adequately.

There is a serious question, however, whether schemes for the compensation of specific groups for loss of income as a result of specific technical innovations are a feasible alternative in a low-income developing country. Such schemes would pose difficult administrative problems in identifying the individuals who are affected adversely by a variety of innovations adopted by a large number of farmers and other producers in a complex and continuing process of technical change. There appear to be cogent arguments for governments to undertake labor-intensive rural works programs for the twofold purpose of providing supplementary income-earning opportunities for the most disadvantaged rural families and for improving the rural infrastructure through building roads and similar activities.

The more fundamental answer, however, lies in pursuing policies which ensure that the rate of increase in opportunities for productive employment in agriculture, in manufacturing, and in service activities exceeds the rate of growth of a country's labor force (see Binswanger and Ryan, 1977). In an economy characterized by fairly rapid and widespread increases in income, farmers will find many opportunities to itensify their operations in response to rising demand for vegetables, fruit, milk, and other products. This generates further increases in farm income and also expands the demand for both family and labor. Integration of livestock

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*An excellent analysis by Binswanger, Jodha, and Barah (1979) of the adverse effects of periodic drought in a number of rainfed farming areas in India indicates that rural works programs have played a critical role in somewhat mitigating the severe hardship and loss of productive assets during such periods. See also Chambers, et al. (1979) for a concise general account of the importance of seasonal factors in intensifying rural poverty.

rearing with crop production represents an especially significant opportunity in the semi-arid areas. One of the advantages of animal draft power is that instead of depreciating, the "power source" generally appreciates in value because farmers typically train young oxen that are sold for meat after some years by which time they are larger and fetch a better price. Those considerations also underscore the importance of maximizing the positive interactions between agricultural development and decentralized, labor-intensive, domestic manufacturing enterprises. They also emphasize the fact that resource-saving innovations and growth of rural incomes both enlarge the capacity of the economy to support social services and direct attention to the desirability of expanding rural education and health systems because of the need for such services and the expanded employment opportunities they provide. Finally, there is persuasive evidence which suggests that the spread of rural education and the introduction of integrated health schemes which make available a "composite package" of health, nutrition, and family planning services can make a major contribution to reducing fertility as well as improving the nutritional status and health of the rural population (Johnston and Clark, 1979 Ch. V). In the longer term, a slowing of the rate of growth of the population of working age is an essential requirement for eliminating the "labor slack" and low productivity of workers which underlie the miserably low returns to labor that now prevail.

In contrast, inappropriately capital-intensive technologies as represented by the large rice mills in Indonesia or tractors in East Africa can be criticized not only because they displace much more labor than a more "appropriate" technology that is economically efficient, but also they absorb excessive amounts of capital and thereby reduce the possibilities that would otherwise exist for creating new job opportunities.

## IV. POLICY ANALYSIS AND THE CHOICE OF TECHNOLOGY IN LOW-INCOME COUNTRIES

In his opening address at a "Rural Technology Meet for East, Central and Southern Africa" held in Arusha in 1977, Prime Minister Sokoine of Tanzania made the candid observation that "our own efforts to develop appropriate technology... have been isolated, patchy, uncoordinated and sometimes have lacked a sense of seriousness" (1977, p. 31). This paper has sought to apply "good policy analysis" to an examination of the complex and important issues which confront the East African countries in the choice of mechanical innovations and other appropriate agricultural technologies.

In a brief but exceptionally lucid editorial in *Science*, Morgan (1978) states that the objective of good policy analysis

> .....is to evaluate, order, and structure incomplete knowledge so as to allow decisions to be made with as complete an understanding as possible of the current state of knowledge, its limitations, and its implications. Like good science, good policy analysis does not draw hard conclusions unless they are warranted by unambiguous data or well-founded theoretical insight. Unlike good science, good policy analysis must deal with opinions, preferences, and values, but it does allow different people, with different opinions and values, to use the same analysis as an aid in making their own decisions.

I have also been influenced by Majone's (1975) argument that preliminary analyses of government policies and programs should concentrate on investigating their *feasibility* given the relevant *constraints* on their adoption and implementation. His conclusion that a major source of failure in policy design stems from the fact that "many otherwise competent and reasonable people tend to equate the desirable with the feasible" seems especially applicable to much of the debate about development policy options.

It should be made quite clear that the feasibility of government R & D programs to promote wider and more efficient farm use of animal draft power and local manufacture of simple and inexpensive items of farm equipment has not yet been effectively demonstrated. Given the obstacles examined in the preceding section, it is fairly easy to explain the limited effectiveness of past efforts.

It can be stated with considerable confidence that future efforts to promote expanded use of improved but inexpensive farm implements and dispersed local manufacture of such equipment will also fail unless this effort is taken seriously and given a high priority. Solutions will not be forthcoming unless determined and persistent efforts are made on several fronts: (1) technical and socioeconomic research to identify profitable and feasible sequences of equipment and tillage innovations adapted to the needs of small farmers in different agroclimatic regions; (2) design and implementation of programs to promote expanded farm use of the most promising innovations; and (3) measures to upgrade the technical capabilities of rural-based workshops and to foster local manufacture of farm equipment in response to the growth of effective demand.

Up to the present time the action taken on all three fronts has been very limited. It is probably safe to assume that fairly little has been done in Uganda since the promising work at Serere in the 1960s. Considerable work has been done by the Tanzania Agricultural Machinery and Testing Unit (TAMTU) in testing and developing certain types of animal-powered equipment, including a well-designed ox cart. But the unfortunate location of TAMTU precludes R & D activities aimed at a sequential and balanced introduction of farm equipment linked with tillage innovations and improvements in farming systems capable of raising crop yields by easing labor bottlenecks and by better soil and water management. Only three tillage trials were mentioned in Tanzania's National Agricultural Research Programme for 1976-77, and one of these involved wheat production based on very large and sophisticated tractors of 140 and 160 h.p. The other two related to minimum tillage trials for maize to be carried out at the Uyole Agricultural Centre where an agricultural engineer had just been appointed to initiate research on implements and tillage techniques based on animal draft power (ILO, 1978, p. 58).

There are now some promising indications that Kenya is beginning to undertake the serious and sustained effort required to make more efficient utilization of animal draft power. Reference has already been made to the FAO/UNDP Agricultural Equipment Improvement Project, and the Department of Agricultural Engineering at

the University of Nairobi has initiated research on equipment and tillage innovations with particular emphasis on Kenya's semi-arid farming areas. This latter work began with an attempt to offer some tentative suggestions with respect to research priorities on the basis of a literature review and ideas solicited from knowledgable scientists with experience in a number of countries (Muchiri and Johnston, 1975). The principal requirements for equipment and tillage innovations were examined in relation to six problem areas: (1) improved equipment and tillage systems for seedbed preparation and weed control; (2) improved practices for seeding and planting; (3) use of narrow-based terraces, level terraces, bench terraces or other land development measures to conserve moisture and soil; (4) improved techniques for training, handling, and maintaining draft animals; (5) measures to secure the most effective utilization of the limited mechanical power currently available and likely to become available in the short and medium term;* and (6) various crop production innovations that need to be considered concurrently with tillage and equipment innovations in order to devise more productive farming systems. Work is now in progress to identify the implements and tillage methods best adapted to semi-arid areas in western Kenya (Muchiri, 1978). This research merits the high priority it is receiving because there is a strong presumption that the moldboard plow, the only implement now being used, is not well-suited to conditions where conserving soil moisture is a more important objective than covering weeds by a soil-inverting plow.

The difficulty of determining a mangeable set of equipment and tillage innovations to receive priority in the initial phase of an equipment improvement program derives in part from the large number of factors involved in the efficient use of animal draft power and the interrelatedness among those factors. For example, introducing improved methods of training and controlling oxen is in itself a fairly demanding undertaking if only because it must begin with a program to "train the trainers". On the other hand,

*The technical superiority of tractors is greatest in earth-moving operations. This suggests that during the short- and medium-term periods when only a limited number of tractors will be available, the private and especially the social returns to their use might well be maximized by using them on mainly (subsidized) contract work preparing level or bench terraces or other land shaping activities to improve moisture utilization and reduce soil erosion.

it is problematic whether much success can be achieved in promoting the use of oxen for inter-row cultivation unless oxen have been trained to plow straight furrows and control is adequate to avoid damaging the growing crop. It is also argued that oxen trained according to the Indian method pull steadily instead of with an inefficient, jerking motion so that a pair of oxen are sufficient instead of the four or six oxen commonly used in East Africa for primary tillage. A related problem concerns the need to introduce techniques for making hay or silage to keep animals in good condition at the end of the dry season when they are called upon to perform the heavy work of plowing.

The lack of an effective methodology for carrying out R & D activities concerning equipment and tillage innovations naturally complicates the task of identifying the most profitable and feasible sequence of innovations. It seems clear, as was noted earlier, that agricultural engineers working alone on equipment design problems will not provide answers to the important problems related to the modification of farming systems based on improved tillage methods. On the basis of their experience in francophone West Africa, Monnier, Tourte, and others argue for a "systems approach" which involves several phases of research and an integration of research and extension which incorporates feedback information from farmers (Monnier, 1975; Tourte and Moomaw, 1977). In an "analytical phase" various components of a farming system--soil and plant improvement, equipment, tillage, etc.--are studied separately but with careful attention to the labor requirements and other costs and to the returns associated with various alternatives. The goal is to design and test systems which are profitable and feasible given the constraints faced by farmers.

> These systems to be extended are then demonstrated to farmers as a factor having relevance to their farming operations. It is not intended that they should apply the whole new package of innovations in one go, but rather that they should themselves decide on the intermediate steps they should take to arrive finally at a system of production that is logical and appropriate to their conditions (Monnier, 1975, p. 226).

Although fairly impressive progress has been made in Senegal and several other francophone countries of West Africa in fostering expanded and more efficient use of animal draft power, the "systems

approach" that has been used appears to be rather demanding in its requirements for trained manpower. An approach evolved at the Instituto de Ciencia y Tecnologia Agricola (ICTA) in Guatemala seems especially promising as a methodology for generating technical innovations suited to the needs of small farmers (Hildebrand, 1976). An agrotechnical and socioeconomic reconnaissance survey of existing farming systems and of the principal constraints faced by farmers provides the starting point for determining research objectives and priorities. Trials carried out by research staff on farmers' fields help to verify the suitability of the innovations under farm-level conditions, and subsequent "tests" of the more promising innovations by representative farmers provide further verification of the profitability and feasibility of the innovations which are to be promoted by coordinated action by the staff of regional research stations and extension workers. Up to now the work in Guatemala has given little attention to mechanical innovations because the policy is to emphasize initially innovations that involve little or no requirement for purchased inputs. Although much remains to be learned about methodologies for identifying and promoting equipment and tillage innovations, two generalizations can be made with considerable confidence. First, it is essential to involve local farmers in the process at an early stage. And secondly, it is important to establish close links between research workers and extension staff because little can be accomplished unless extension field staff as well as farmers become involved in an ongoing learning process.

After this somewhat tedious discussion of a few of the detailed problems related to the difficult task of promoting expanded and more efficient use of animal draft power, two obvious questions arise: Why bother? Why not make the transition directly from the hoe to tractors?

In part, the answer lies in the constraints imposed by the nature of the physical environment for farming. For the reasons examined in section II, a combination of biological-chemical and mechanical innovations have much more favorable benefit-cost ratios than a strategy which neglects improvements in land and water management which are not feasible with hoe cultivation. The advantages of animal-powered as compared to engine-powered mechanical innovations derive from the structural and demographic factors that

were examined at length in section III. It will be recalled that Morgan stressed that "good policy analysis does not draw hard conclusions unless they are warranted by unambiguous data or well-founded theoretical insight". A major thesis of this paper is that "hard conclusions" can and should be drawn from the implications of those structural-demographic features of the low-income countries of East Africa. And that if those implications are ignored, there is a high risk that efforts to cope with the formidable problems of reducing poverty and of absorbing their rapidly growing population into productive employment will fail. And this is no idle concern.

In a major address to the recent World Conference on Agrarian Reform and Rural Development, President Julius Nyerere (1979, p.14) has emphasized that "rural areas must be diversified" and stressed the importance of providing the funds required for the expansion of rural industries and rural services. But other statements in his address suggest an insufficient appreciation of the implications of the constraints that derive from the structural and demographic characteristics of a low-income country such as Tanzania and the need to make hard choices. Thus he asserts:

> Rural development, for example, requires greater use of fertilisers--both organic and chemical--with the consequential need for a fertiliser plant or a phosphate mine, or both. It needs a factory to produce animal-drawn ploughs, harrows, seeders--and another producing tractors and bulldozers.

President Nyerere is clearly right in emphasizing the requirement for greater use of fertilizers. But it does not follow that that automatically implies a need for a fertilizer plant. The fertilizer plant built in Tanga in Tanzania was predictably too small to realize the economies of scale that are so important in the manufacture of nitrogen fertilizers. Hence, the heavy investment of resources in that plant has not only made a very minimal contribution toward expanding opportunities for nonfarm employment but has also obliged Tanzanian farmers to rely on unnecessarily expensive fertilizer. Very large subsidies have reduced the price of fertilizers to levels comparable to the much lower price of

imported fertilizer; but to a large extent the heavy cost of those subsidies has been paid by farmers through levies imposed on the marketing boards through which their products are sold.

More directly relevant to this paper is the assertion that a developing country such as Tanzania "needs a factory to produce animal drawn ploughs, harrows, seeders--and another producing tractors and bulldozers". The importance of local manufacture of aniaml-drawn implements is obviously not at issue. However, the experience of Taiwan and China that was cited in section II suggests strongly that to concentrate such manufacture in a single factory rather than a number of dispersed machine shops using labor-intensive technologies, making maximum use of local materials, and catering to the local needs of farmers in different farming regions is to forego much of the potential impact of farm equipment innovations on the growth of domestic manufacturing capabilities and nonfarm employment.

On the other hand, economies of scale are so important for efficient manufacture of tractors that it is extremely doubtful whether a country of Tanzania's size and stage of economic development justifies even a single factory "producing tractors and bulldozers". To be sure, tractors have a role to play in Tanzanian agriculture in spite of the general cost and other advantages of animal draft power. Wheat production in Tanzania was developed as an enterprise of large-scale farmers, formerly European farmers and now mainly state farms; and it is doubtful whether it would be feasible or desirable to try to organize the country's wheat industry on the basis of small-scale farms employing the sort of labor-using, capital-saving technologies on which the agricultural sector must principally rely until considerable structural transformation has been achieved.* The production of maize, which is

*The sugar cane industry in Tanzania has been created on the basis of large, mechanized operational units, and a shift to reliance on small, labor-intensive farm units would probably be even more difficult than in the case of wheat production.

a smallholder crop well suited to the use of animal draft power, is more than 10 times as large as Tanzania's production of wheat.

It will be a good many years before the annual requirements for tractors will justify investing scarce capital resources in a plant which would contribute so little to the expansion of job opportunities and to the growth of domestic manufacturing competence. Given the magnitude of the problem that these East African countries face in reducing widespread poverty and generating employment for an expanding labor force, allocating investible funds and foreign exchange to inappropriately capital-intensive investments is bound to have a high opportunity cost.

The examination of the role of farm equipment and tillage innovations in section II suggests strongly that expanded farm use and local manufacture of simple but well-adapted items of farm equipment can make a significant contribution to increases in farm productivity and incomes and to the growth of rural-based manufacturing and the expansion of nonfarm output and employment. However, much remains to be learned in order to realize that potential, and the prospects for success are not good unless determined efforts are made on several fronts and are pursued with "a sense of seriousness".

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APPENDIX

Table A1. Projections (million persons) of total population and of economically active population, Kenya.

A. Alternative projections of total population.

| | "Most likely estimate" | Maximum estimate | Minimum estimate |
|---|---|---|---|
| 1969 Baseline | 10.9 | 10.9 | 10.9 |
| 1999 | 24.5 | 32.0 | 25.6 |
| 2024 | 64.3 | 77.6 | 45.8 |

B. Projection of economically active age (most likely estimate of population, 15-59).

| | Rural | Urban | Total | Rural as % of Total |
|---|---|---|---|---|
| 1969 | 4.6 | 0.7 | 5.3[a] | 87 |
| 1999 | 9.3 | 2.6 | 11.9 | 78 |
| 2024 | 20.7 | 11.1 | 31.9 | 65 |

[a]Error in original corrected per Frans Willekens, 24th July, 1979.

Source: Shah M. and F. Willekens (1978, pp. 28,29).

Table A2. Employment projections in the urban areas, Kenya.

| URBAN AREAS | 1975 | 2024 |
|---|---|---|
| Total active-age population | 876,000 | 11,100,000 |
| Urban wage employed | 387,210 | 2,151,600 |
| Informal establishments | 74,100 | 1,097,000 |
| Higher education | 100,000 | 556,000 |
| Unemployed/inactive | 315,000 | 7,195,400 |
| % Unemployed/inactive | 36% | 65% |

Sources: Shah, M. and F. Willekens (1978) p. 38.
The 1975 estimates are from Kenya, *Statistical Abstracts*, 1976, p. 271; and Kenya, *Economic Survey*, 1977, p. 40.
The projections for 2024 are based on the following assumptions:

1. The annual growth rate in wage employment in urban areas in Kenya was 3.5 percent for the period 1966-75. This rate of growth is assumed to continue to 2024.
2. Informal establishments are assumed to grow at 5.5 percent annually over the period 1975-1999 and 1975-2024. This is equivalent to half the growth rate of 11.0 percent over the period 1974-76.
3. The active age population receiving higher education is assumed to grow at 3.5 percent annually up to 2024.

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