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Malthus Controverted: The Role of Capital and Technology in Growth and Environment Recovery in Kenya

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Summary. — Investment in technological improvements, coupled with management innovations and skills, are commonly held to lead to growth rates which outpace population growth. Although this applies to both industry and agriculture (Anderson, 1990) typical farm surveys in developing countries neglect to analyze fixed investments or the quality of management. This paper provides a nonmathematical case study and model from Kenya of the way in which investments in technological change, and especially in land improvement, have enabled rural incomes per capita to grow substantially, with improved environmental conservation, through the interactions of increased population density, improved information and market opportunities. Population density and investment are shown to be critical interrelated factors. Investments require maintenance expenditures. These are included in social cost-benefit analysis, but it is not always realized that labor on maintenance may have a rising opportunity cost, which farmers take into account when selecting technologies. Although the major part of expenditures are made and managed by farmers, government investments to stimulate and complement them are required. As on the farm, this requires wise management of recurrent and maintenance costs, if the benefits of investment are to be lasting.

1. THEORETICAL DEBATES ON ECONOMIC GROWTH, ENVIRONMENT AND POPULATION

This paper discusses the role of investment, innovation and the improvement of human capital in smallholder agriculture, and their association with population growth. It contends that increases in population density from a low base sets in train processes which can lead to environmental improvement as well as increased incomes per capita. The process can, however, be frustrated as well as assisted by government actions. It is illustrated by a case study of Machakos District, Kenya.

(a) *Investment and environmental improvement*

The pessimistic view of the impossibility of economic development and a sustainable environment when there is rapid population growth is influenced, knowingly or otherwise, by a neo-Malthusian view that resources are limited, and therefore, more people, anywhere, mean disaster. In agricultural terms, this is expressed by the belief that agro-ecological zones have a population-carrying capacity which must not be exceeded.

The theoretical basis for disputing a static view of carrying capacity was provided by Boserup (1965). She showed that a common response to increased need for food and land shortage under existing technologies is the adoption of intensification techniques, which combine more labor with the land resource, both to make permanent land improvements, (investment) and to raise output by more frequent cultivation accompanied by more careful husbandry (the recurrent

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activity). Additional people provide both the stimulus and the means to new types of land management. Her emphasis was on endogenous technology generation and the growth of internal markets and specialization.

Lele and Stone (1989) are among those who have questioned whether these mechanisms can cope with the unprecedented population growth rates experienced in Africa in this century. The necessary adjustments however, have been made in Machakos. Our thesis is that the successful response has been generated by the twin forces of necessity, as identified by Boserup, and opportunity, as offered by increased contacts with markets and information. Without the added force of opportunity, adjustment might have been slower and more difficult. The new opportunities are in part a function of increased population density,[1] but opportunities can be closed by unwise policies.

Unwise policies may stem from failing to realize that the greater part of the additional investments required are provided by the farmers themselves. Many economists assumed in the 1960s that taxation was necessary to provide for investment since peasants were too poor to save. They therefore approved the use of marketing boards to siphon off for governments a large proportion of the world price of agricultural commodities (e.g., Helleiner, 1966, for Nigeria). Since then, there has been disillusionment with the record of government investment. Nevertheless, investment remains the key; mathematical models have identified capital formation combined with technological progress as the means by which industrial output has stayed ahead of population growth, and raw materials have become cheaper rather than scarcer and more expensive, as human ingenuity has found ways to substitute new materials, or to economize in the use of old and to counter diminishing returns to capital by innovations (for example, Simon, 1986; Romer, 1989; Anderson, 1990; Scott, 1989 and 1991). Logically, this must apply to agriculture as well as to industry, and Anderson (1990) specifically applies it to both.

Despite the "generations of growth models [which] have emphasised the importance of technical progress and factor accumulation as sources of economic growth" (Doeringer and Streeten, 1990), the typical farm survey as carried out in developing countries neglects many items of capital expenditure which support present output.[2] For example, in Machakos, the coffee boom of 1976–79 led to an increase of coffee hectarage, from 5,500 hectares in 1976 to 14,000 hectares in 1982, entailing substantial costs for terrace-making, acquisition of planting material, digging of planting pits, initial manuring, etc. This was a nationwide phenomenon.[3] Simon (1977, p. 239) generalizes that these informal agricultural investments are rarely captured by national statistics. Nevertheless their accumulated total in smallholder economies is substantial.

While many farm surveys have neglected investment, the importance of agricultural innovation has been acknowledged at a more theoretical level, and through studies based on comparisons of more and less developed countries (for example, Hayami and Ruttan, 1985; Ruttan and Thirtle 1989). Because many Green Revolution technologies originated through national and international research, the organizations responsible for these have been considered the main source of agricultural innovation. To be effective, however, the fruits of official research have to be embodied in investments made by private farmers. Private farmers also have to make investments which embody innovations which they have themselves developed, or which have come through informal sources. As many investments and information sources are overlooked, the role of investment in new technologies such as higher value crops and livestock, land improvements and development, or new equipment, can easily be underestimated.

(b) *Investment, maintenance and management*

New investments generally require maintenance, and work on maintenance has an opportunity cost. Using social cost-benefit analysis to find the product of investment (Anderson, 1990, p. 1058), has an apparent advantage in that the maintenance expenditures are considered in the choice of technology, along with the capital cost. Maintenance expenditures, however, are discounted, since they take place in the future. Lack of weight given to these costs can lead to ill-maintained structures incapable of producing sustained benefits, as has been illustrated in irrigation (Tiffen, 1987 and 1991; Finney, 1984). Further, maintenance costs are often underestimated, for example by giving 'unskilled' agricultural labor a zero or low shadow cost, when, as Anderson (1990) points out, one of the effects of good investment should be the redeployment of labor into higher income activities. This *raises* the opportunity cost of the farmers' future labor on maintenance. Investments in, for example, higher yielding crops, call for increased recurrent labor inputs into weeding, harvesting, etc. which have an immediate impact on output. It therefore diminishes, or makes more expensive, labor for maintenance of buildings, trees, terraces, channels, livestock, equipment, etc. whose decay will gradually diminish output. Our thesis is that farmers are concerned with the real cost of their own or hired labor, and take this into account in selecting new investments and technologies. Maintenance costs are not insignificant: for bench terraces one farmer in Machakos District quoted a single maintenance as costing 20% of the original construction. A study in a neighboring district showed that farmers reckoned that about 30 man-days per year per hectare of cropped land is required (Holmberg, 1990).[4]

This leads us on to considerations of human capital. A second well-identified factor in accounting for economic growth rates is organizational innovation, and management skill in implementing change (Doeringer and Streeten, 1990). This calls for improving the organization of labor, evaluating technologies, assessing initial and recurrent costs and weighing benefits. In the few cases where management has been examined in smallholder agriculture, it is found to be important: Heyer found that good farm managers made three or four times as much as poor managers in Machakos District in the early 1960s (Heyer, 1966).[5] We shall show that increased population density facilitates the growth of institutions which support increased management capacity.

(c) *The importance of population density*

A longitudinal study, covering several decades, is needed to illustrate the longer term processes of growth. It allows us to take into account factors such as maintenance, and gradual improvements in human knowledge and capability. Another very significant long-term change is the effect of growth in population density.

Hagen (1975) plotted the rate of growth of per capita income for 32 countries, 1960–65, as a function of population density. As summarized by Simon (1977, p. 140) the results show 'higher density is not associated with lower growth except perhaps at the very highest densities, and low densities clearly are associated with low economic growth.' This suggests a possible S-shaped curve, with low or even declining growth when population densities are low, followed by rising growth rates in association with rising densities, and a possible, but unproven, leveling out or decline at very high densities. This lateral comparison across countries is in accordance with our longitudinal findings in Machakos.

Attempts to correlate national economic growth rates with population growth rates have failed to show significant relationships. If density, rather than growth rates, is the significant factor, the starting point will matter. High growth rates may have different effects, for example, on populations with current densities of less than 30/km^2 or more than 300/km^2. The effects of changes in population density are more readily observed at district rather than national level.

2. THE CASE STUDY: MACHAKOS DISTRICT, KENYA, 1930–90

(a) *Increased output and land conservation*

The study of Machakos District in Kenya, carried out by a team of physical and social scientists from the Overseas Development Institute, London, and the University of Nairobi, documented and as far as possible measured changes in rainfall, environment, population and productivity over a 60-year period, 1930–90.[6] The District stretches for some 200 km between Nairobi (about 50 km from its northernmost point) and Mombasa (about 300 km from its southern border in 1990[7]), in a mainly semi-arid region with very variable rainfall. The population (almost all Akamba), grew from under 250,000 in 1930 to just under 1.5 million in 1990. Most of the district has only a 60% chance of a successful maize crop in either of the two rainfall seasons. Maize and pulses are the predominant crops.

Figure 1 is based on points in time when data were available to calculate district output under representative climatic conditions. It shows that in 1930, when density in the medium-potential part of the then utilized area was about 54/km^2, the main output was of grains and livestock; the only other important crop, sugar cane, was used for local beer. Marketing opportunities were restricted both by government regulations and poor transport, but agricultural output does not seem to have kept up with expanding population. In combination with a series of dry years in the early 1930s, the expansion of arable areas and the concentration of livestock on communal grazing land without investment in land improvements led to a marked increase in soil erosion.[8] During 1942–62 famine relief and/or food imports were required in 14 years.

Growth in density in the highest potential agricultural areas increased from 80 to 380/km^2, and in the lowest potential areas from 2 to nearly 60/km^2 during 1930–90. Nevertheless, Fig. 1 demonstrates a nearly four-fold increase in the value of agricultural output per head, when all commodities are expressed in terms of their maize buying power at 1957 prices. Value, not volume, fell during 1977–87, when a move into horticulture did not fully compensate for the decline in the coffee price and increased inefficiency in parastatal management of cotton marketing. The value of output per hectare continued to grow in both current and constant price terms during 1977–87, and was in 1987 more than 11 times the 1930 level.[9]

Figure 2 shows the investment in land improvement which underlay this, in a typical area. It is derived from analysis of air photographs, which show both the conversion of bush grazing into arable, and the steady terracing of arable.[10] Terracing, in addition to conserving soil, conserves water, and in the conditions of Machakos, makes it possible to grow, at least in some parts of the district, higher value crops such as coffee, fruits and vegetables, as well as to improve the yield of grains and pulses. Terracing was accompanied by an increase in tree cover.

Most arable land was adequately conserved in

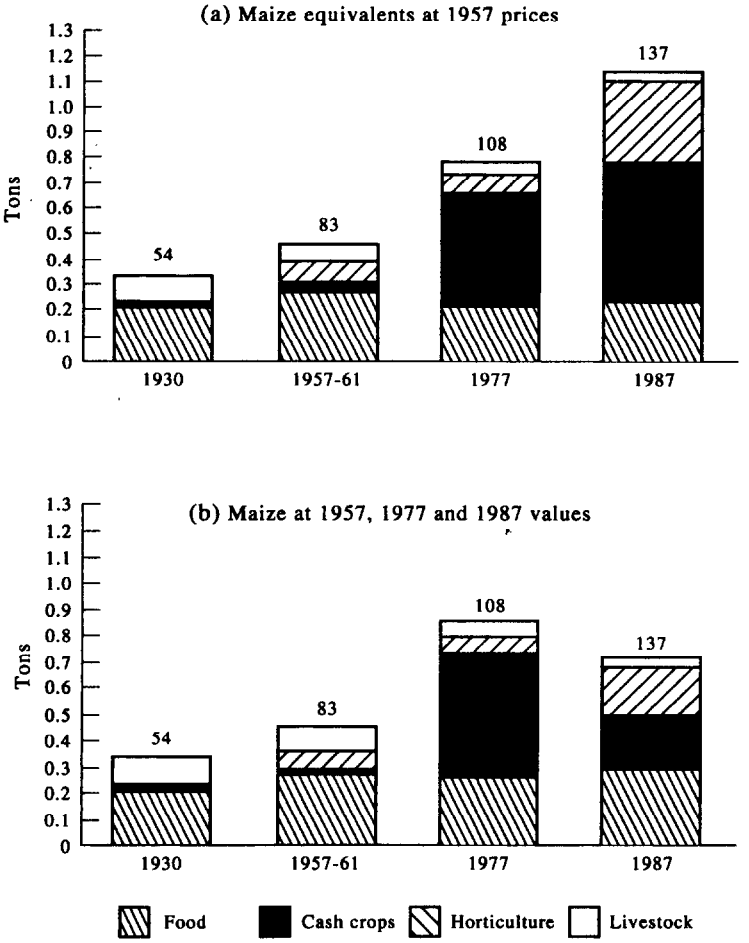

Figure 1. *Output per head, 1930–87.*

1990; there were still some bare areas in grazing land, some of which had been bare for a very long time. Grazing land, which is now all privately owned, is generally managed to provide a continuous supply of fodder and timber, although cover may suffer in droughts and management on larger farms may not be sufficiently intensive to prevent the increase of unwanted woodiness. Current intensively managed farming systems are undoubtedly more sustainable than the more extensive systems of the 1930s.[11]

The economy was also much more diversified than in the 1930s. By 1982 local nonfarm businesses and wages accounted for some 40% of rural incomes, and agricultural output for 51% (Kenya: CBS, Economic Survey, 1988). In the 1950s, farm output, the greater part for subsistence as Fig. 1 shows, accounted for about 80% of district income and local wages and businesses some 10–20% (Peberdy, 1961).[12] Figure 1 shows that food production per head kept up with population increase,[13] with the main growth in the value of production per head coming from cash crops such as coffee and horticultural crops. These crops generated jobs to meet the production and consumer needs of the farmers. The growth of the nonfarm sector means that income per head grew at a faster rate than the value of agricultural output per head shown in Fig. 1.

In this paper we use the terrace as an example of both new technology and fixed capital. While the terrace is the crucial investment, it is not the only one: Akamba farmers also invest in trees, fences, buildings, livestock, and equipment, and they require working capital. They have adopted innovations, in crops, husbandry, and livestock-keeping methods, derived

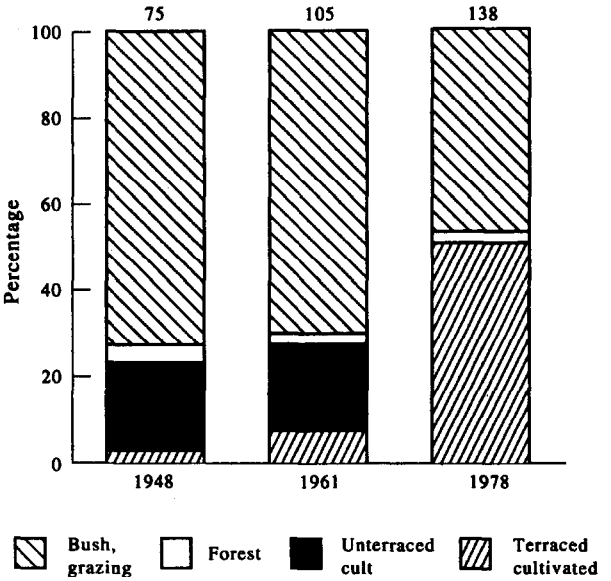

Figure 2. *Land use change in Masii (medium-potential agricultural area).*

from research institutions and other sources (see Mortimore and Wellard, 1991).

(b) *Investment sources*

Those who know Kenya and the district frequently assume that its increased productivity is mainly due to government investment and aid programs. Machakos received 36% of the investment funds and additional professional personnel provided for the development of African lands in Kenya 1946–62 (the ALDEV program, summarized in Kenya, 1962). This was equivalent in value to 89,000 tons of maize, or about 200 kg per person during the entire 15 years the program lasted, or 13.3 kg per person per year. A second substantial infusion of capital and skills was provided by the Machakos Integrated Development Programme (MIDP), 1978–87, funded by the European Community. Expenditure was equivalent, in current prices, to about 244,000 tons of maize, or about 205 kg per person over 10 years (20 kg per person per year). A small component was the provision of tools and advice to groups of farmers who undertook soil conservation work. This was also done by a Swedish-financed program in a northern section of the district beginning in 1978.

Our data show that in 1981–85 about half the new conservation works received assistance, either from the Swedish program (18%), MIDP (24%) or the local Catholic Diocese (12%). MIDP inputs, including expatriate technical assistance, cost the equivalent of 17,000 tons of maize, or about 3,000 tons per annum at the height of its activity. The larger share of costs—the digging cost—was borne by the farmers, who for 50% of the terraces built in this period received neither tools nor official advice.

We estimated the original digging costs of all terraces in place in 1985 at about 276,000 tons of maize.[14] This excludes maintenance costs, also borne by the farmers. Our 1990 field work showed most terraces had been maintained, unlike a large proportion of the terraces constructed by compulsory communal labor in the 1940–55.

The compulsory terraces were the type known as narrow-based. From about 1950 an alternative, the *fanya juu*, a type of bench terrace, spread from a few innovatory farmers to others, without compulsion. It was subsequently also promoted by extension officers, particularly for coffee.[15] During the late 1950s and early 1960s many of the narrow-based terraces were neglected to the point of disappearance; hence, Fig. 2 shows only a small net gain in terracing during 1948–61. Farmers state *fanya juu* were preferred, and always maintained, because they lasted longer. *Fanya juu* also appear to enhance yields by conserving more of the rainfall. These two qualities made their heavier initial labor cost worthwhile. It is significant that agricultural research has not investigated two qualities vital to the farmer, maintenance costs and water retention. Almost all the narrow-based terraces have been converted, under the farmer's own initiative, into bench terraces.

Figure 2 shows that the bulk of terracing took place

in 1961–78, when there was no government program. Although the post-1978 donor-aided programs assisted the poorer farmers to build terraces quicker than they could otherwise, especially in areas of new settlement, in the older settled areas, most cultivated land was already terraced by 1978. The bulk of the investment was clearly financed by the farmers themselves.

As is general in Kenya, much investment is financed by off-farm jobs, either through remittances, or through the savings workers bring on their retirement.[16] Kenyan farmers' investment strategies are long-term: they frequently invest first in the education of their children, in the hope that these will help the family by securing a well-paid job. Alternatively, or in addition, they invest savings from their own wage-labor in nonfarm businesses, which are expected to yield profits more quickly than farming, and which provide resources to develop the farm. It is now realized that rural families frequently and intentionally have a member in a salaried job, and/or a nonfarm enterprise or craft. This provides a hedge against agricultural disaster, and cash for both long-term investments and short-term working capital for yield-raising inputs.[17] Agricultural investment is often the second or third stage in family investment strategy.

A second source of capital is livestock. In the 1930s and 1940s these were regarded as essential for hedging purposes, cash generation, income growth, and marriage. They are now one among alternatives. One group of village leaders explained, 'Now, coffee is the cow.' In a more arid area, we were told that a family with cattle were in the equivalent position to a family with a graduate. Livestock are often sold to finance hired labor for terrace construction or maintenance.

A third source is direct labor investment, or leisure foregone. Many terraces have been built by rotational work groups, predominantly female since many men have nonfarm occupations. The better-off farmer, however, prefers to have the work done at the time of choice by hired labor.

3. A MODEL OF GROWTH WITH SUSTAINABILITY

Figure 3 models a path from increased population density to higher incomes per capita, incorporating sustainable dryland management, which has been derived from the study, and which helps to illustrate why progress is slow and uncertain at low levels of population density, but picks up speed at higher levels, provided that governments support, or at least avoid impeding, the process. Autonomous processes are shown by continuous lines; those which governments can impede or assist by dashed lines. The central elements are the mutually reinforcing effects of investments (L) and new technologies (M). The model applies where smallholders predominate in the agricultural economy, and where their tenurial rights have evolved into a relatively secure form.

(a) *Direct consequences of increases in population density*

The four consequences of population density increase are shown as A: increased need for food (more mouths); B: increased labor supply (more hands); C: more idea generators (more brains); and D: reduced interaction costs. The main forces in the Boserup theory are the increased need for food (A), leading to additional inputs of labor (B) into current farm activities and land improvements, (F), thus increasing the frequency of cultivation. Although there is more labor, the new technologies demand more work than extensive farming methods, and output per hour may fall, although total output, through a greater total input of hours, rises to meet demand.[18] These labor investments tend to transform land tenure into secure, private, heritable and saleable forms (J).

In her 1965 exposition, Boserup showed how increased population density led to more efficient transport and the growth of small towns and labor specialization. This leads, although she did not state it clearly, to an increased demand for food and other agricultural products, in addition to the increased subsistence requirements of farm families. She later specifically linked this commercialization to the reduced per capita costs of roads (Boserup, 1981). We have generalized this as lower interaction costs, (D), since it applies to both physical and social infrastructure (G) and (H).

The original Boserup model relied mainly on the internal forces of growing subsistence demand and growing labor. Machakos was not, however, a closed economy. There were alternatives to accepting the lower rewards per hour of labor in intensive agriculture for subsistence. People could respond to demands for labor from other parts of the Kenyan economy, (thereby buying food if necessary) and this set the opportunity cost of their labor. There was also, while population density was low, some unclaimed land within the Reserve and much unoccupied land to which they thought themselves entitled, in the adjacent Crown Lands. After independence in 1963, they surged into the latter. The land effectively available to them doubled in size, although the natural agricultural potential of the additional land was poorer than that of the older settled areas. In consequence, the additional labor created (B) was not all available for the intensification of agriculture. Part undertook temporary migration for work (E) and part developed new farms, using the appropriate extensive methods for the settlement of an area with low population density. An

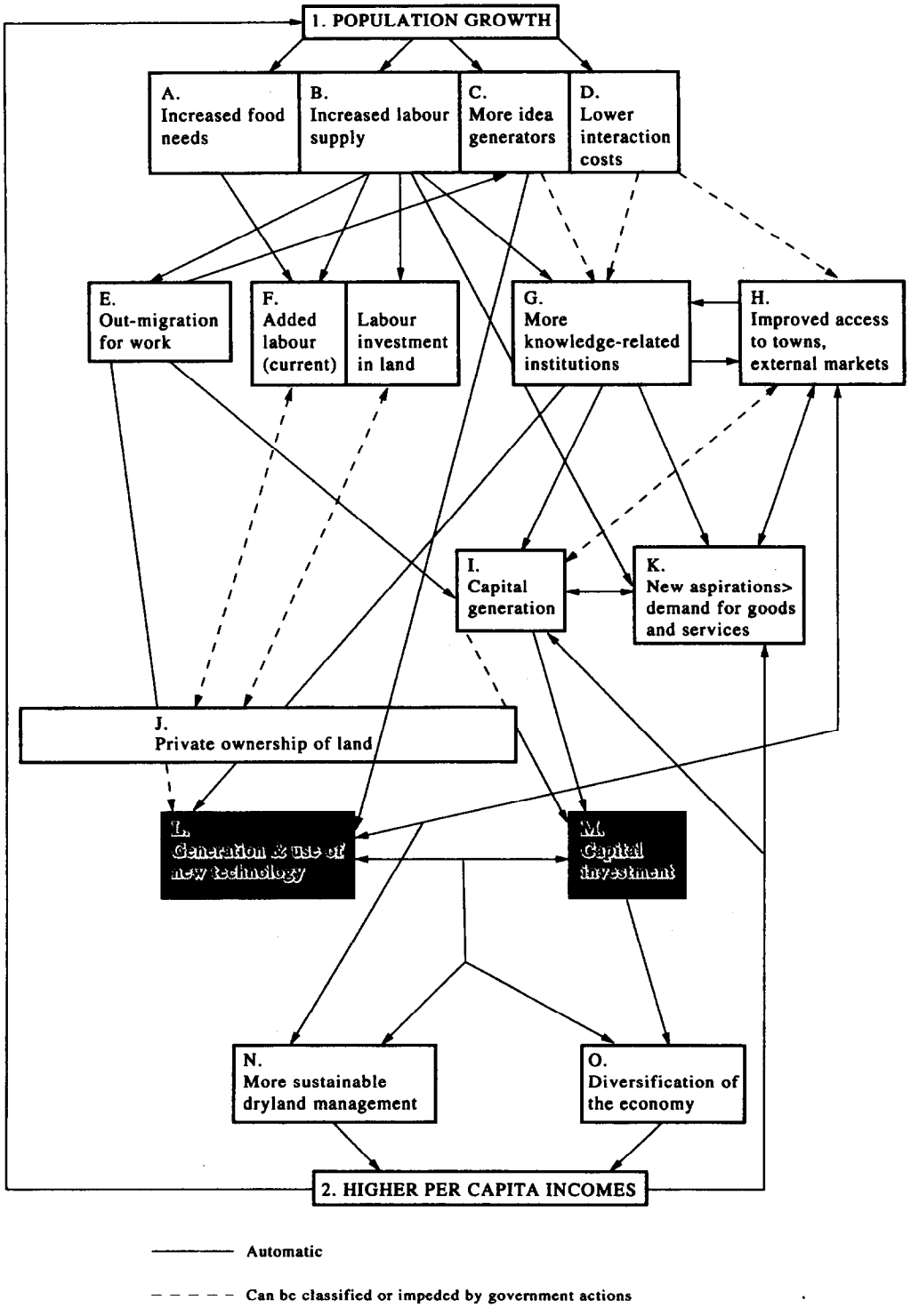

Figure 3. *Model of population and income growth with environmental conservation.*

increased amount of the time of the 15–24 age group was invested in education (G) to qualify for higher rewards to their labor in nonfarm work.

Intensification proceeded most rapidly in the small area of relatively high potential land which was the most densely populated originally, particularly in the areas with the best access to markets outside the District. Here, the rewards to labor in intensive farming were highest. The main intensification technologies (all embodied in investments), were the plough, the bench terrace and manure, and were first adopted in higher potential land closest to Nairobi, or having a feeder road to the Nairobi-Mombasa road or railway.

The plough can be used both for extensification or for intensification, and in the 1930s, in the north, it was used to expand the land under maize and beans, to create surpluses for sale. From the late 1940s the bench terrace and manuring were adopted, first for vegetable sales to Nairobi and abroad, then for coffee (when this crop was permitted), and, because of the evident benefits, also for maize and beans.

In areas somewhat further from the market, and in medium and low-potential land, with lower population densities, the production of a surplus of maize and beans above family needs remained unprofitable in the early 1960s (Heyer, 1966), fewer intensification technologies were adopted, and a high proportion of men found they could earn more by migrant labor than by farming. By the 1970s, however, the growing wealth and specialization of the coffee areas created new nearby markets for food crops and livestock, and stimulated the adoption of intensification technologies in the dryer areas.

(b) *Benefits of cheaper interaction costs and more brains per km²*

A most obvious advantage of higher population density is a reduced per capita cost of building roads by labor-intensive means, and a higher return to investments in road-building, because of a greater number of users (Simon, 1977; Boserup, 1981). Traders can amass worthwhile quantities more easily, and sell consumer and other goods to more people at lower cost. This leads to higher real farm-gate prices, cheaper nonfarm goods, and increased incentives for farm investments. While feeder roads, however, can be constructed by unskilled labor, only larger governmental units at the district or national level can amass the capital and skill required for trunk routes. Hence, the advantages of rising population density will only be fully realized if governments put a proportion of their resources into roads (the dashed line between D and H).

A denser population also reduces costs per capita of other types of social and physical infrastructure. It means that an extension worker can visit more farmers per day, a shop will have the prospect of more local customers, people can be gathered more easily to build a community amenity, and news will spread faster. Libraries, schools, and newspapers share with roads the benefit of lower per user cost. This is linked with (C); in every km² in a denser population there are more people with capacity to develop new ideas. New ideas are usually sparked by interaction with an existing idea, perhaps stocked in social infrastructure such as an extension service or a school, perhaps visible in the practice of a neighbor or heard of through a trader or a conversation in a bar.[19] Knowledge exchange and innovation-sparking occurs through both formal and informal institutions; the latter is particularly assisted by cheaper transport, which enables people to travel and bring back new ideas, creating the strong interaction between (G) and (H).

The importance of cheaper interaction costs was demonstrated in relation to villages in parts of Kenya and Uganda (including some in Machakos) by Mbithi (1971). He found that what he called village centrality (basically the existence of roads—at that stage created mainly by community labor), was associated with more specialized facilities such as various types of shop, bars, schools, banks, etc., and that this was in turn associated with an increasing or high rates of adoption of innovations by the surrounding farmers.

Much of this social infrastructure, such as roads, requires more than local investment. School buildings can be, and in Kenya are, raised by parents, the more easily where the population is dense. The effectiveness of education, however, depends on government, or supra-village organizations such as churches, making investments in teacher-training institutions, which are beyond the resources of a local community. An effective extension service requires investment in national research capacity.

(c) *The need for a more efficient agricultural labor force*

Despite population growth, labor continues to be in short supply. More of the over 15 age group remains in school—by 1979 in Machakos 74% of the 15–19 age group and 14% of the 20–24% age group were in school, according to the census. Further, part of the labor force is diverted into nonfarm activities. We were able to make rough estimates of the labor actually available for agriculture at different times, and to relate this to the land effectively available for Akamba settlement (Table 1). Line 6 shows the nearly sixfold growth in population during 1932–89. Labor available for agriculture however, only tripled (line 4)—while the land available for settlement (line 1) had doubled.

This slow increase in the agricultural labor force underlies other changes in land-labor relations. Table

Table 1. *Estimated land:labor relationships, 1932–89*

	1932	1948	1962	1979	1989
1. Total available ha, '000	636	692	782	1,360	1,360
2. Cropped ha, '000 (1)	56	90	126	291	323
3. Cropped ha, %	9	13	16	21	24
4. Agricultural labor, '000	112	160	214	277	378
5. As % of population	47	45	38	27	27
6. Total population, '000	239	358	566	1,023	1,400
7. Cropped ha/laborer	0.50	0.56	0.59	1.05	0.85
8. Cropped ha/person	0.23	0.25	0.22	0.28	0.23
9. Total ha/laborer	5.68	4.33	3.66	4.90	3.60
10. Total ha/person	2.66	1.93	1.38	1.33	0.97

Source: Tiffen, Mortimore and Gichuki (1994), Table 4.6

1 shows that the amount of cropped land per person resident in the district remained steady. Most cropped land remains under maize and pulses, and this area expanded to meet the increasing local food requirement. Cropped land per agricultural laborer increased slowly during 1932–62 (when the plough was coming into more widespread use); jumped in 1962–79 when the more arid lands were being settled, and decreased after 1979, since little unclaimed land existed by the 1980s.

Agricultural labor requirements in terms of hours per year increased not only because of the larger amount of cropped land per laborer, but also because of increased labor requirements per hectare, as Boserup indicates. The area under maize and pulses is now effectively cropped twice a year, with increased labor needed for row planting, weeding, manuring, fertilizing, and harvesting. At peak times, family members at school or in nonfarm activities help out, but farmers say they work harder than their parents did, and that they have to be better organized, in order to carry out all operations at the best times. Labor needs have also increased through the relatively small, but steadily increasing, amount of land under coffee, fruit and vegetables (all new technologies), land which demands very high labor inputs, both into its initial preparation and into current activities.

The requirement for more efficient use of labor led to management innovations such as the use of group labor (modernized from a traditional form with assistance from the community development service), hired labor, more flexibility in men and women's labor roles, coffee cooperatives and other innovations in marketing, including more use of banks. The increased use of cash and banks mean that literacy and numeracy became increasingly useful.

Labor had also to be better equipped. The purchased metal hoe replaced the digging stick. A plough and team of oxen became essential (except, now, on very small farms) if the crops were to be planted and weeded on time. Those who can afford it buy a cart for manuring and marketing.

(d) *Relationships with land distribution and land tenure*

We have limited the model to smallholder economies where secure ownership rights have developed. Many beneficial interactions in the model, particularly those which stimulate local small-scale nonfarm enterprises, do not occur where land is held by large estate owners.

Farmers are unlikely to make fixed investments without security of tenure. Farmers know some of the results will take a long time, and they work for their heirs as well as themselves. The fixed investments underpinning more intensive farming in Machakos include, in addition to terracing, hedging and fencing; tree planting (coffee, fruit and timber trees); grass planting, gully stopping and tree/shrub management on grazing land; more efficient grain stores; and housing improvement (particularly the use of brick with corrugated iron roofs that enable water storage). These investments are secure because Akamba custom had already evolved in the direction of private ownership by the 1930s; land registration has assisted the process, particularly on former Crown lands where Akamba custom was in conflict with the government's view of its own rights. It was noticeable in field visits that the explanation for a piece of land which remained degraded in 1990 was frequently the existence of a land dispute. Without secure private rights in land, it can be surmised that capital generated by temporary emigration would not have been invested in land improvement, and that labor investments would have seemed less worthwhile.

(e) *Why the process is slow while densities are still low*

It is only when population density increases to the point where there are substantially reduced interaction costs, leading to better contact with external markets and local market development, that the benefits of

increased population density are felt, and there is a move into higher value crops. The beneficial interactions pick up speed as population density increases further.

Figure 1, together with descriptive data, implies this slow growth between 1930 and the mid-1950s. Indeed, the acute food shortages of the 1940s suggest there may even have been some decline in output per head before recovery started. We are unable to confirm whether the curve is S-shaped, and whether growth will flatten out as densities increase still further, as population structure makes likely.[20] Figure 1 suggests hesitation in income growth in 1977–87, although investment in land if anything increased, and conservation practices began to move from cropped land to grazing land. Part of the decline in the value of agricultural production for 1977–87 was due to circumstances, at least some of which could be reversible. These include the decline in the coffee price at the end of the 1970s, deterioration in government services (especially roads, veterinary services, and cotton marketing), and failures to make some necessary investments in support of income diversification (for example, in electrification and other necessary infrastructure for small towns). Part may have been due to increased population pressure and the increased cost of land and water. In 1990, however, the increased scarcity of land seemed still to be stimulating investments in its improvement and there remained obvious scope for intensification of agriculture and income diversification.

4. IMPLICATIONS FOR GOVERNMENT INVESTMENT POLICIES

The implication of the model is that governments need to *facilitate* wise family farm investment as the main engine of agricultural growth, *complement* this with the key investments at national and district level which cannot easily be made by private investment, and ensure that there are resources to *maintain* the facilities publicly provided.

(a) *Facilitating family farm investment*

Facilitating family farm investment has many facets, of which the first is acknowledging that investment, for production or conservation, requires the incentive of profit. This has implications for taxation policy, national investments in transport improvements that will raise farm gate prices, and the reduction of unnecessary marketing costs or hindrances. The second is the importance of the circulation of information on markets, technologies, finance and management. The humble rural post office that enables country people to keep in touch with urban relatives, and which is used to transmit both money and information, plays its role alongside traders, education, extension, community development services, and banks. The third is if farmers are willing to invest, it is important to help them save, and that since their savings are held in grain stocks and livestock as well as in cash, research and services which help minimize the losses in these are important. Farmers in risky, semi-arid environment such as Machakos already adopt various strategies to reduce the risk that not only their savings but also their current livelihood can be wiped out by a sequence of bad seasons; governments need to be conscious of these strategies, and supportive as far as possible of risk reduction. Assisting saving, and ensuring that money circulates quickly through efficient marketing services and prompt payment, is more important than providing credit. Credit in a risky environment usually leads to debt. It played almost no part in the Machakos transformation. The fourth requirement is security for investment, particularly for those fixed in the land, either through recognizing the evolution of tenurial custom, or by a carefully considered, once only, tenurial reform.[21]

(b) *Complementing farm investments and farmers' innovations*

Family investment requires complementary investments at the community, district and national levels to realize its full potential. Kenya's tradition of encouraging self-help, through the County Council's community development service and its active church and other nongovernmental organizations (NGOs), has assisted community-level investments. Cooperatives have also played a role, though on the whole these are successful in the environments where private traders also have incentives to provide services (Gyllström, 1991). Capability to organize and manage at community level has grown considerably in Machakos since the 1930s, as society has become more complex, with leadership roles open to women and younger educated people, as well as to male elders.

Some types of infrastructure and services are best planned and implemented at national or district level. These include transport infrastructure, higher education and types of scientific research. Other services can be provided privately, but often these will be stimulated if governments, or district-level authorities, have mechanisms for investing in, and maintaining, the infrastructure required by growing marketing and industrial centers. Without these national and district investments, farmers' investments are likely to be impeded, or to be less effective because they are less rewarding and are made less knowledgeably.

Representative institutions which enable people to influence the investment agenda, and to secure

accountability and transparency in the use of the investment funds, should assist in the selection of wise investments.

(c) *Providing for operation and maintenance*

Much of the above highlights the importance of investment, mainly by central or local governments, in physical and social infrastructure such as roads, electricity, water, schools, postal services, veterinary and extension services, and research services. Investment alone is not enough, however, since these facilities, to be useful, have to be operated and maintained, as farmers know with respect to terraces. Aid agencies have been blameworthy in encouraging policies that have led to staff expansion without considering revenue sources and limitations. The current situation in Kenya, and in many other countries, is that government servants have inadequate resources to operate a service (from paper to circulate information to fuel to visit an out-station), and almost no funds to maintain buildings, equipment, vehicles, roads, etc. There is an essential requirement for reconsidering investment policies and the methodologies of deciding on new investments, in such a way that the costs of operation and maintenance are given due weight. While the problem of funding maintenance is a familiar one, we emphasize it here owing to its impact on the long-term processes identified in our model, and the failures in much project planning to give it the weight it deserves in technology selection.

(d) *Increasing knowledge, management capacity and skills*

Anderson identifies *wise* investment as the source of growth. This means increasing access to sources of knowledge and secondly, increasing capability in using technologies, selecting and evaluating them, judging market opportunities and managing the institutions in which people combine to raise capital, organize trade, or provide services.

The Machakos story shows how the technologies in which investment has been embodied had many sources, including government research services, schooling, traders, missions, and farmers' observations while traveling. As farming becomes more diverse an ever more sophisticated research and extension service is required to keep up with the farmers' advance. Governments need to encourage commercial organizations and NGOs to join with it in listening to innovating farmers, evaluating needs and assisting in finding solutions to ever changing problems—a process facilitated by local representative organizations (Hayami and Ruttan, 1985, p. 88; Farrington *et al.*, 1993).

The bench terrace story is one illustration among many of the wisdom of offering farmers not one 'best' technology, but several, which they can evaluate and select in accordance with their needs. Diversity of technologies is supported by a policy of openness to outside influences.

The capacity to select, evaluate and manage can be increased by both formal and informal education. On the formal side, this means support to schools, adult education classes, agricultural extension, and a community development service that brings knowledge and management skills to groups who want to develop amenities or nonfarm businesses. On the informal side it depends on free movement, and internal peace and security. Policies that place restrictive licensing requirements in the way of enterprise establishment or trading movements diminish beneficial interactions. Those most likely to suffer are the poor, for whom petty trading is often the most feasible means of acquiring information and capital.

5. REPLICABILITY?

Machakos so far offers confirmation in a longitudinal study of the Boserupian hypothesis. It has shown that increased population density has also helped to make markets and information more accessible, thereby stimulating wise investments in new technologies, which have enabled output and incomes to rise faster than population growth, and which have restored and improved the resource base. This is despite a harsh and risky environment which periodically endangers savings.

Machakos is not unique. Collier and Lal (1986), and others, have illustrated intensification mainly by reference to the Kikuyu areas of Central Province (where population densities are higher than in Machakos, but so is land potential). Nor is Kenya unique. Around Kano, Nigeria, rural population increase has been accompanied by an increase in trees (Mortimore, 1993). In Indonesia, a study of farming systems in 1974 and 1987 found general and substantial improvement in the value of farm output, despite what was seen as the negative influence of continuing high population growth. The authors thought 'That the villages were able to absorb population increases in the order of 15–25% during the 14-year period and at the same time provide higher general living standards must be viewed as something of a minor miracle' (Prabowo and McConnell, 1993). We would say it was in accordance with our model.

While we know in general terms that there are other areas where both incomes and environment have improved as population increases, there are as yet few detailed studies of the processes of change over several decades. There are places where it is alleged that soil and water resources are being degraded as popu-

lation increases. We need, however, measurements of the condition of the resource base and the relationship of this to population density at different times. In the early stages of the movement from low population densities and extensive agriculture the resources for investing in commercialized, intensive and sustainable agriculture are scarce and market access is still difficult. At such a time some degradation of soil resources may be unavoidable before people begin to find solutions. In other cases, population may have built up to densities that would normally support better physical and intellectual communication, but governments may have impeded commerce and information exchange, or undermined security of tenure.

Machakos cannot tell us the outcome if densities continue to increase rapidly in areas where they have already reached over 300/km^2. As yet only 8% of the population of the district lives in areas that can be defined as urban, and future progress may depend very much on enabling the existing small towns to expand the nonfarm sector in a symbiotic relationship with their hinterlands. A continued increase in local markets, services and industries can complement the stimulus coming from national urban markets such as Nairobi, and external markets.

While we need more case studies to make safer generalizations, the Machakos study illustrates that, even if there are instances in which, contrary to Boserup and other optimists, increased densities lead to degradation, in the right circumstances, people respond positively to the challenges posed by higher densities.[22] In drylands, much of the required investment is for land improvement which conserves soil and water resources not only for this but also the next generation. By far the greater part of this investment is made by the farmers and their families, in new technologies that come from formal and informal sources. These investments, however, can be stimulated and increased if government provides complementary investments and services. The selection of wise investments depends on the generation and circulation of information and on improvements in managerial skills, in governments as in farmers. In particular, it requires wise assessment of the maintenance costs of new investments, and a balancing of resources between the initial and recurrent costs, if the fruits of investment are to be harvested.

NOTES

1. This used to be well recognized (Hagen, 1975; Simon 1977). The expectation of an increasing population, and therefore, increasing demand, is "a fine thing for keeping up the spirits of entrepreneurs . . . [making it] easier to employ an expanding population than a contracting one" (Hicks, 1936, quoted by Collier and Lal, 1986).

2. In a survey of nearly 20 farm management studies in Machakos District, Kenya, we found Heyer (1966) to be the only one that included reference either to fixed capital in the form of terraces, or to management skills. Livestock and equipment featured in some, but not all studies, farm buildings in one, trees, hedges or fences, irrigation channels, etc. in almost none. Yet the quantity of output often depends essentially on the quality and maintenance of these capital assets.

3. Bevan, Collier and Gunning (1992) demonstrated the high propensity to save and invest the windfall profits of the coffee boom, using a survey of 800 farmers.

4. We did not establish with the farmer we interviewed how often he carried out maintenance. It seems likely, however, that the commonly used figure of 5% of capital cost is inadequate for the maintenance of terraces; Holmberg emphasizes that the terraces have to be maintained carefully, especially after heavy rains.

5. She used terrace maintenance as one of her indicators of good management.

6. See Tiffen, Mortimore and Gichuki (1994) for full details, including photographs of the environment in 1937 and 1990.

7. The district has since been divided, with its southern part forming the new Makueni District. Our study refers to the undivided district.

8. This is documented by reports and photographs of the time (Tiffen, Mortimore and Gichuki, 1994).

9. Although government agricultural statistics are unreliable, the order of magnitude of growth which they show is supported by our analysis of changes in farming systems as well as by the photographic evidence. Collier and Lal (1986:213) found a growth in mean real incomes of smallholders in Central Province during 1963–74 of 50%, and that over a longer period, 1949–79, national real smallholder incomes probably grew at around 2.5% per annum, allowing for population growth. Such a rate of growth would allow for a trebling in 50 years and quadrupling in 60 years, similar to our findings.

10. Full details of the five areas sampled are contained in Rostom and Mortimore (1991). Masii, shown in Figure 2, is typical of the older settled areas.

11. See Tiffen, Mortimore and Gichuki (1994); Thomas (1991) and Farah (1991) for changes over time in the status of erosion and natural vegetation. Thomas has studied erosion in the district since the 1950s.

12. Peberdy underestimated local businesses and wages,

since the only "informal" activity he recorded was wood carving. We know there to have been local shops and transport businesses, and the local nonfarm may have contributed 20% of income rather than the 10% he estimates.

13. Some commercial imports or famine relief were required in 1974–85, but they averaged about 7.5 kg per capita per annum, compared with 17.5 kg in 1942–62. There was no substantial famine relief program in 1985–90 (some food is regularly distributed to socially disadvantaged groups) but the rainfall record means that sequences of three or more bad seasons are bound to recur, and will probably still entail a degree of famine relief.

14. Details are in Tiffen, Mortimore and Gichuki (1994). It is preferred to give costs in terms of maize equivalent, in order to be able to compare the colonial program with the later ones, and because since the MIDP program began, there have been considerable changes in the Kenya shilling:US$ exchange rate.

15. The way in which the bench terrace, in its various forms, almost entirely replaced the narrow-based, is an interesting example of the variety of sources for technologies, formal and informal, (see Tiffen, Mortimore and Gichuki 1994, chapter 11).

16. Normally his. The majority of emigrants are male. Wives frequently remain at home to manage the farm. See Bigsten and Collier (1980); Collier and Lal (1986); Hughes (1991) for similar use of nonfarm earnings in other Kenyan areas.

17. See Hunt (1975); Collier and Lal (1986); Carter and Wiebe (1990); Livingstone (1991).

18. The historical data are inadequate to say whether, in Machakos, output value per hour rose or fell. A rise is possible given the great increase in the value of output per ha. It cannot however, be proven.

19. This discussion owes much to Simon (1986), where he develops a mathematical model showing the resultant continual expansion of new technologies which keep ahead of demand. He limits his discussion to developed economies because the model demands interaction with a large stock of existing technologies and ideas. We think it applies also to the less-developed countries which acquired a growing access to the world stock of ideas in this century. Tiffen (1993) considers its application to the Machakos case.

20. There are now signs that population growth rates are diminishing, and that smaller families are desired, but the current age structure means that many new families, even if smaller, will be created.

21. Land reform, even when beneficial in the long run, almost invariably has a disrupting effect initially. It is best undertaken at long intervals, and after careful consideration and consultation, taking into account effects on inheritance. Tinkering with it creates uncertainty, which is the enemy to investment.

22. We are grateful to Dennis Anderson for pointing out that there are two possible explanations of the successful adjustment in Machakos. One is that higher population density in itself explains growth, the other that in the right circumstances people can respond to the challenges of higher population density. We take the first view, although we think governments can frustrate the natural responses, but we accept that further case studies are needed for confirmation.

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