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SOCIAL AND ECONOMIC IMPLICATIONS OF ENDEMIC MALARIA AND OF ITS ERADICATION

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THE ECONOMIC EFFECTS OF MALARIA ERADICATION *

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In this paper a method is presented for measuring the economic effects of malaria eradication, in particular the effects of eradication on per capita income in the long run. The method, which involves specifying a fairly detailed model of the entire economy, has been applied to the case of Ceylon, and some preliminary results are presented on what the course of Ceylonese per capita income would have been after 1947 if the successful eradication campaign of that year had not been undertaken.

These inquiries may be of interest to the economic historian, as providing an understanding of the far-reaching consequences of eradication programs which have been executed in the past. The inquiries may be relevant also to the decision-maker in government who must choose between alternative expenditure proposals in the context of a budget constraint. Considerations of the economic payoff of the alternative projects may properly influence the

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decisions which are made in those circumstances.

At the outset it should be stressed that in drawing attention to the economic consequences of disease eradication, the economist does not mean to belittle the noneconomic consequences. Many public health officials seem to feel that when the economist points to the possible economic losses resulting from eradication -- such as those implied by a population explosion -- he is callously arguing that people should be denied the benefits of modern medicine. The fact is that an eradication program, like all other government programs, ought to be judged by the contribution which it makes toward the several national goals. In most countries the growth of per capita income is a national goal which is accorded a fairly high priority, and therefore the effect of eradication on per capita income is a relevant consideration. It may of course be rational to adopt an eradication program even when it is known that per capita income will probably fall as a result. This may be so when the program makes large contributions to other goals, such as the diminution of suffering.

Malaria and Its Eradication

Malaria is a parasitic disease transmitted by certain species of the anopheline mosquito. The parasites invade red blood cells and cause them to rupture synchronously, thus producing the attacks of chills, fever, and sweating associated with the disease. These attacks cause temporary disability and are sometimes fatal. Those victims who survive the febrile attacks are left in a weakened state because of the massive destruction of their blood cells, and hence are more susceptible to death or disability from other diseases. Their debilitation reduces work efficiency. Eventually the blood cells are replaced and the body may develop some temporary immunity against a further infection. In many areas of the world, malaria has been endemic; in others it has appeared spasmodically or in epidemic form because of such factors as extreme instability in the size of the mosquito population. The annual number of cases on a worldwide basis has been reckoned in the hundreds of millions.

After the discovery some seventy years ago of the means whereby the disease was transmitted, the methods of control or eradication have multiplied rapidly. No universal panacea has been found, and one of the chief tasks in an eradication campaign is to choose from among the numerous possibilities that particular set of measures which is best suited to the local environment. The measures available include the use of mosquito netting, the location of dwellings at an adequate distance from the mosquitoes' breeding places, the use of insect repellents, the administration of drugs such as quinine which reduce or eliminate the parasite population in the human body, the installation of new drainage systems or the removal of vegetation to render the mosquitoes' breeding places unusable larvicidal techniques such as the oiling of ponds and streams, and (often the most effective of all) residual spraying of house interiors with DDT or other insecticides.

Before the Second World War attempts at controlling malaria were mostly localized and unambitious. In the years immediately following the war several campaigns were organized which made use of the new insecticides and anti-malarial drugs then becoming available and in many cases virtually complete eradication was achieved over extensive areas. The possibility therefore emerged that the disease could be rendered totally extinct, and in 1955 the World Health Organization formally established worldwide eradication as one of its goals. In the pursuit of that goal the World Health Organization and its affiliates have provided substantial technical and financial assistance to the national eradication campaigns. The proceedings have assumed a note of urgency as more cases of resistance by mosquitoes and parasites have been disclosed, and the possibility now exists that worldwide eradication will be indefinitely postponed unless it is accomplished quickly, before the resistant strains become established.

By 1966 the eradication campaigns have proceeded to the point where the population of territories freed from malaria exceeds the population of territories

where malaria still prevails. Since a campaign cannot succeed without money and some organizational resources, it is naturally the poorest and most backward areas of the world which still suffer from the disease. These areas include most of tropical Africa and parts of Central and South America, the Middle East, the Indian sub-continent, and Southeast Asia.

Malaria eradication is a half-finished task. In some countries the disease was virtually eradicated two decades ago or more, and these cases could provide abundant evidence on the economic and social consequences of eradication. Other countries are still malarial and are in a position to benefit from the experiences of the first group when they come to decide upon the timing, scale, and methods of their own eradication programs.

A Classification of the Economic Effects of Eradication

In the public health literature there is a consensus that malaria eradication is economically beneficial. Occasional misgivings are expressed about the implications of a population explosion; but even when these possible disadvantages are admitted, it is invariably said that they are far outweighed by the economic gains from eradication. These sanguine views have not been based on sound evidence. There have been several casual estimates purporting to demonstrate the economic advantages of eradication.[2] Some of these estimates have involved measuring the additional number of man-days of work which eradication has made possible in a particular country through reducing mortality and sickness, and then multiplying this number by an average daily wage. Other estimates have compared the costs of the eradication campaign itself to the extra hospitalization expenses which would have been incurred if malaria had been allowed to persist. All of the estimates have been incomplete: they have failed to take into account the multiplicity of economic effects.

In providing a more complete analysis, we can begin by stipulating that per capita national income is the economic variable whose fate concerns us. Eradication could affect income per capita by changing either the number of heads or the level of income. The level of income or output could be affected by changes in (a) the quantity and quality of labor inputs, (b) the quantity and quality of capital or nonhuman inputs, and (c) the manner in which these inputs are combined. Hence there are four categories of effects to consider. In our discussion of these effects we shall not dwell on the problems of measurement. These problems will be aired in the next section, where a model is outlined which incorporates the effects discussed below.

Effects on Population Size

Other things being equal, a rise in the rate of population growth will reduce per capita income. There is evidence that malaria eradication produces this result both by lowering death rates and by raising birth rates. The fall in death rates occurs not only because of a reduction in deaths directly attributable to malaria but also because the population acquires a greater resistance to other diseases.

The rise in birth rates which has often been observed to follow eradication can probably be explained by the fact that pregnant women attacked by malaria are more liable to suffer miscarriages. There is also the possibility that the rate of conception is lower in malarial conditions because of the reduced vitality of both men and women.

Effects on Labor Inputs

Other things being equal, a rise in the quantity or quality of labor inputs will cause per capita income to rise. Eradication can affect labor inputs by reducing mortality, morbidity, and debility.[3] The reduction in mortality will bring about an immediate increase in the quantity of labor inputs in cases where the fall in death rates occurs among those of working age. A fall in death rates among those in younger age groups will cause an expansion of the labor force after a lag.

A reduction in morbidity, which is defined here as sickness sufficient to cause absence from work, can bring about an immediate increase in the quantity of labor inputs. A reduction in debility, which is defined as affecting the worker's productivity on the job, can cause an increase in the quality of those inputs. A worker freed of the debilitating effects of the disease can improve his performance both physically and mentally; he may complete a given manual task in a shorter time and also undertake activities more imaginative and ambitious than before.

The economic payoff to disease eradication depends not only on the relative incidence of the disease in the labor force and the rest of the population. It depends also on what segments of the labor force are benefited by eradication. In the case of malaria we are dealing with a disease whose greatest impact is upon the low-income, low-productivity segment of the labor force, and the payoff to eradication is therefore less than would be the case with a disease which involved the same number of cases but which was concentrated among the most productive segment. Malaria is a low-income disease mainly because it is avoidable. Persons with higher incomes and higher levels of education are in a stronger position to take advantage of that characteristic: being better informed, they are more likely to avoid exposure, for example by staying away from mosquito-infested places during darkness; being wealthier, they are better able to afford prevention or curative measures, such as the use of quinine or mosquito netting. From the economic viewpoint, malaria therefore contrasts sharply with such diseases as cancer or heart disease, where the opportunities for prophylaxis are distinctly limited and where the incidence tends to be the greatest among the most productive members of the labor force.

Effects on Capital Inputs

Other things being equal, the higher the rate of capital formation, the more rapid will be the growth of per capita income in the future. We must

therefore examine the effects of disease eradication on the division of total expenditures between consumption goods and capital goods in both the private and public sectors.

In the private sector the larger population which results from eradication is likely to lower the rate of saving (and hence the rate of capital formation) attainable from a given level of disposable income. Moreover, when the population is growing more rapidly, what limited private saving does occur may tend to be invested in housing, which is a relatively unproductive form of capital stock. There will be some offsetting effects on the disposition of private income. After a government program of eradication, private expenditures for the prevention or treatment of the disease become unnecessary. The funds thus released may be devoted in part to saving and capital formation.

In the public sector the allocation of funds between consumption and investment is governed by political priorities which vary from country to country, and it is less easy to generalize about the effects of eradication. For our purposes, public investment should be defined as outlays which add to the stock of "productive" physical capital (like dams, roads, or government factories); all other resource-using governmental expenditures should be defined as public consumption, even when they provide long-lasting real assets (like police stations, schools, or sports stadia). One fairly common situation is for the highest budgetary priorities to be assigned to various traditional forms of public consumption, with any residual revenues being made available for new projects of physical investment. Other things being equal, the larger population resulting from eradication may necessitate an expansion of the traditional services and thus leave a smaller residuum for public capital formation. In this setting the direct expenses of the anti-malaria campaign itself cause an equivalent reduction in public investment. At the same time the lessened morbidity may permit the government to reduce its expenditures for medical care and funds would therefore be released for public investment as defined.

It should be recognized that many of the high-priority consumption expenditures of government promote the growth of income through improving the quality of the labor force even though they do not add to the stock of physical capital as defined. It would seem advisable to pay particular attention to the educational sector in assessing the economic effects of malaria eradication. In most countries of the malarial zone, education is a large-scale high-priority government service: the rapid increase which eradication produces in the population of school age therefore means that a large quantity of extra funds must be committed to education. These expenditures create a more productive labor force, but only after a substantial lag. If eradication did not occur, the funds in question could by assumption be invested to bring an immediate payoff.

Other Effects on Output

The level of output depends not only on the quantity and quality of human and nonhuman inputs but also on the manner in which those inputs are combined. It is possible for eradication to increase output by inducing a change in input combinations. The effect in question has been recognized and indeed exaggerated in the public health literature. It is said that malaria eradication permits the exploitation of new territories which previously were shunned because of the threat of disease. Very often the gross value of the output from the newly exploited districts is cited as a measure of the benefits from eradication. It is not acknowledged that the capital equipment and labor used in these districts presumably had some positive opportunity cost, and that the increase in output from the previously malarial districts is obtained at the price of reduced output elsewhere.

Nevertheless the phenomena in question may involve net gains for the economy. These gains are perhaps best analyzed as stemming from a spatial reallocation of resources which is induced by a localized decline in the disutility of labor. Eradication lowers the disutility of labor in the previously malarial districts; labor accordingly tends to migrate to those districts; the shift in labor raises the marginal product of capital in those districts relative to its

marginal product elsewhere, and in the long run a migration of capital will accompany the migration of labor. If, as seems likely, the marginal product of land in the malarial districts before eradication was higher than its marginal product elsewhere, eradication will have contributed to an expansion of output by causing labor and capital to be relocated in the districts where the marginal product of land was relatively high.

A Model for Measuring the Economic Effects of Eradication

If we wish to measure the impact of eradication on per capita income while allowing for all the effects discussed in the preceding section, it is clear that we must make use of a fairly detailed model of the entire economy. The relationships which appear to be relevant should be specified in the form of equations. The model should then be used to provide two simulations of the course of per capita income through a period of n years, the first simulation being based on the assumption that eradication occurs at the start of the period, and the second simulation being based on the assumption that no eradication campaign is undertaken during the period. The method could be used retrospectively, measuring the consequences of a completed program, or it could be used to predict the outcome of a proposed program. One particularly successful application of the method is to be seen in the measurement by Coale and Hoover of the economic gains from birth control in India.[4]

In specifying a model of the entire economy, this approach is somewhat more elaborate than that typically used in "benefit-cost" analyses of health programs. The typical analysis in this field has been of a partial nature, a legitimate approach when the program in question causes nothing more than marginal changes in the structure of the economy. But malaria eradication can cause quite marked changes. By using Newman's results concerning the effects of eradication on birth and death rates,[5] it can be estimated that the population of Ceylon in 1977, thirty years after eradication, will be 16.0 millions, whereas in the absence

of eradication the figure would be only 12.6 millions. It is estimated that in 1977, 27 per cent of the population will be in the labor force; without eradication the figure would be 29 per cent. In 1977 the education budget in Ceylon will be about 700 million rupees; the figure would be about 500 million rupees in the absence of eradication. The methods of partial analysis, which would essentially ignore the indirect repercussions of eradication, would probably yield misleading results in this situation.

A model has therefore been designed which allows for the major economic effects, direct and indirect, of malaria eradication. With some modifications the model would also be useful for evaluating any public health program which had important effects on demographic structure and labor supply, such as programs of birth control, programs causing substantial reductions in infant mortality, or the eradication of widespread debilitating diseases like schistosomiasis. The model may even be useful for evaluating nonmedical programs such as education.

The model has been designed with the case of Ceylon in mind, and is being used to estimate the effect of eradication on Ceylonese per capita income during the thirty-year period following the successful campaign of 1947, a period of this duration having been chosen as allowing for the adequate operation of all lagged effects. If other investigators wished to apply the method to other countries, they might find it desirable to amend one or two of the equations which reflect structural peculiarities of the Ceylonese economy.

In the first part of the model, age-specific birth and death rates have been used to generate the age-sex composition of the population year by year. No attempt has been made to allow for relationships between the vital rates and the various social and economic variables which appear elsewhere in the model: in a more sophisticated system it would be possible to incorporate, for example, the presumably negative relationship between birth rates and the level of educational attainment among females, or the presumably negative relationship between death

rates and lagged per capita income. It is assumed that the vital rates are affected only by eradication, and to the extent estimated by Newman. From Newman's analysis it appears that eradication had marked effects on fertility and infant mortality and therefore lowered the average age of the population. It can be estimated that by 1977 50 per cent of the Ceylonese population will be aged under twenty; without eradication the figure would be 45 per cent. From the population data thus derived, estimates have been made of the population of "equivalent consumers." The index of economic performance can then take the form of income per equivalent consumer instead of income per capita, which is a somewhat less refined measure.

The main part of the model is devoted to the determination of income, defined as real gross national income. The relevant equations are listed in the Appendix to this paper. There is not the space here to explain the equations fully, and we must be content with mentioning a few of their salient features, along with a brief indication of some of the measurement difficulties encountered in estimating the equations for the case of Ceylon:

1) The production function is of the Cobb-Douglas form, a form chosen because of its relative simplicity and because the terms appearing in the function are readily measurable. The function differs, however, from the simplest Cobb-Douglas formulation in two main respects: (a) the labor input is disaggregated into two components, skilled and unskilled, skilled workers being defined as those with some secondary education; (b) each of the three inputs -- skilled labor, unskilled labor, and capital -- is characterized by a quality index. The purpose of disaggregating the labor input is to allow for the fact that malaria eradication has a differential impact on components of the labor force which differ greatly in their productivity. The introduction of the three quality indexes allows for various other consequences of eradication.

2) The indexes of skilled and unskilled labor quality are increased when malaria is eradicated, because debilitation is thereby reduced. The measurement difficulties here are acute, and an empirical investigation of the economics of debilitation must surely have high priority among future research projects in the area of medical economics.[6] In the present study the effect of eradication on the indexes of labor quality was estimated on the basis of opinions expressed informally by malariologists. Additional simulations are being performed on the assumption that the effects are much more powerful than initially supposed, the objective being to see whether the effects of eradication on income per equivalent consumer are highly sensitive to the extent of debilitation.

3) The index of the quality of the capital stock depends on the relative importance of three components of each year's investment: imported capital goods (assumed to have a high quality or productivity), housing construction (low quality), and other investment (average quality). The larger population occasioned by eradication causes a greater proportion of investment to take the low-quality form of housing construction, although only after a considerable lag. Imports of capital goods will be subject to a balance-of-payments constraint. In the case of Ceylon, the foreign-exchange receipts needed for purchasing imports are assumed to be independent of eradication. In particular, eradication is assumed to have no effect on exports: the acreage suitable for the major Ceylonese export crops (tea, rubber, and coconuts) lies mostly outside the previously malarial zone, and export production has not been limited to an important extent by labor shortages. In this context,

eradication may generate a larger volume of investment, but that volume is likely to be of inferior quality because it will contain a relatively small proportion of imports.

4) There is a fourth quality index in the production function, an index of allocative quality. Eradication can affect the level of this index by inducing a spatial reallocation of resources, as discussed above. Guesses are unavoidable in estimating the values of this variable, the only relevant information available in the case of Ceylon being that which describes the shift in the labor force between previously malarial and previously nonmalarial districts.

5) The exponents in the production function are the elasticities of output with respect to skilled labor, unskilled labor, and capital respectively. If, as seems reasonable, the sum of the three elasticities is constrained to equal unity, we can conclude on the basis of the Euler theorem that their values are approximated by the shares of the respective factors in total income. Data on the capital share in Ceylon are not available, and in the present study, simulations have been based on alternative capital-elasticity values of 0.5 and 0.3 (the latter being a normal value for Western economies). Data on the relative shares of skilled labor and unskilled labor are available from the Surveys of Consumer Finances undertaken by the Central Bank of Ceylon in 1953 and 1963. The Central Bank Surveys are also invaluable in providing data needed elsewhere in the model, such as data on private medical expenditures and on the proportion of each age-sex group who have received secondary education.

6) The quantity of labor inputs depends in part on morbidity rates. The reductions in these rates following the Ceylonese anti-malaria campaign can be roughly estimated from data collected by Cullumbine in a household survey of morbidity.[7] Cullumbine's data

suggest that eradication caused significantly greater declines in morbidity among the unskilled than among the skilled.

7) The value of the capital stock in the initial year, along with the value of the constant term in the production function, can be obtained by simultaneous solution of two versions of the production function -- one version containing the values for one arbitrarily selected year and the other containing the values for some later year -- in which these two terms are the only unknowns. The capital stock grows annually as a result of net investment. Net investment is assumed to be solely dependent on the supply of saving, an assumption which is justifiable for low-income countries although not for high-income countries. Most of the data needed for simuleting the growth of saving are to be found in a detailed set of national accounts. In the case of Ceylon these data are obtainable from the Central Bank's Annual Reports, the Census Department's Statistical Abstracts, the United Nations' Yearbooks of National Accounts Statistics, and in particular from a recent study by Snodgrass.[8]

8) Total saving consists of private saving, government saving (the excess of tax receipts over public noninvestment expenditures), and foreign saving (the current-account deficit in the balance of payments). Private saving is held to be a function of private disposable income per equivalent consumer. In the determination of government saving, it is assumed that the budgetary priorities are like those discussed above: the public noninvestment expenditures -- educational spending, other forms of public consumption, and transfer payments -- are dependent primarily on population size, and public investment is essentially a residual. Eradication causes

an expansion of public noninvestment expenditures but does not cause a corresponding increase in tax receipts, at least in the case of Ceylon. On the basis of the administrative realities in underdeveloped countries, it is assumed that tax receipts are a function of the size of the foreign trade sector. Since, according to our earlier argument, eradication has done little to increase the size of the foreign trade sector in Ceylon, it has also done little to increase tax receipts. In Snodgrass' words, "caught between..... rising service bills and the relative inelasticity of government revenues, capital expenditures suffered."[9]

9) Imports of both capital goods and noncapital goods are assumed to be a function of (a) demand considerations, and (b) the size of foreign-exchange reserves at the beginning of the year in question. When reserves become seriously depleted, it is common for the government to curtail imports by imposing tariffs or quotas. It was thought unlikely that the relationship between imports and prior reserves would be linear. To provide a more plausible relationship, the square root of the reserves was therefore used in the import equations.

Model Dynamics

It will be clear from the preceding discussion that eradication has numerous positive and negative effects on income per equivalent consumer. These effects do not occur all at once but in a staggered fashion, and the model therefore involves several lags. Some of the more important of these lags are listed in Table 1. On the positive side it is shown that there are some strong effects occurring in the first year after eradication. The lags in the negative effects can be best seen by following the career of the first cohort of "eradication babies" -- that is, those babies who would not be alive one year after the eradication campaign if the campaign had not occurred. One should add that the second

cohort is appreciably larger than the first: not only do infant mortality rates continue to fall in the second year after eradication (at least according to Newman's results), but in the second year birth rates begin to rise.

Table 1

SELECTED LAGS IN THE EFFECTS OF MALARIA ERADICATION ON NATIONAL INCOME PER EQUIVALENT CONSUMER

No. of years after eradication	POSITIVE EFFECTS	NEGATIVE EFFECTS
0		Resources are devoted to eradication campaign
1	Quantity and quality of labor inputs are increased due to reduced mortality, morbidity, and debility; private expenditures on medical care are reduced; spatial reallocation of resources begins	Population grows due to reduced mortality
2		Population grows due to increased fertility
6		Part of first cohort of "eradication babies" enters primary school
11		First cohort become "equivalent consumers"
15	Part of first cohort enters unskilled component of labor force	Part of first cohort enters secondary school.
16		Females in first cohort enter child-bearing age-bracket
20	Part of first cohort enters skilled component of labor force	Part of first cohort enters institutions of higher education
21		First cohort enters housing market
26		Females in first cohort enter age-bracket where fertility at maximum

The Model Applied to Ceylon

The model described in the preceding section and in the Appendix has been used to simulate the course of income per equivalent consumer in Ceylon on the assumption that malaria was not eradicated. Some partial results of the simulation are depicted in Figure 1. At the time of writing, the simulation had proceeded from 1947 through 1955. It can be seen that at the outset eradication had a strong positive impact on income per equivalent consumer. As the years progressed beyond 1947, the gap widened between the with-eradication values and the without-eradication values of income per equivalent consumer, until by 1953 the income figure with eradication, at Rs. 712, was 10 per cent higher than the figure without eradication, at Rs. 646.

Thus in the short run, malaria eradication in Ceylon proved economically beneficial. The explanation for this result can be found most readily by referring to Table 1. Eradication makes an immediate contribution to output by increasing the quantity and quality of labor inputs, primarily through reductions in morbidity and debility, and secondarily through reductions in mortality. In the short run the negative effects of eradication on income per equivalent consumer are weak. The direct expenses of the campaign itself are inconsiderable. During these early years, most of those who are alive because of eradication are infants: not until they are five years old will they begin to impose burdens on the educational sector; not until they are about ten years old will they become fully-fledged "equivalent consumers."

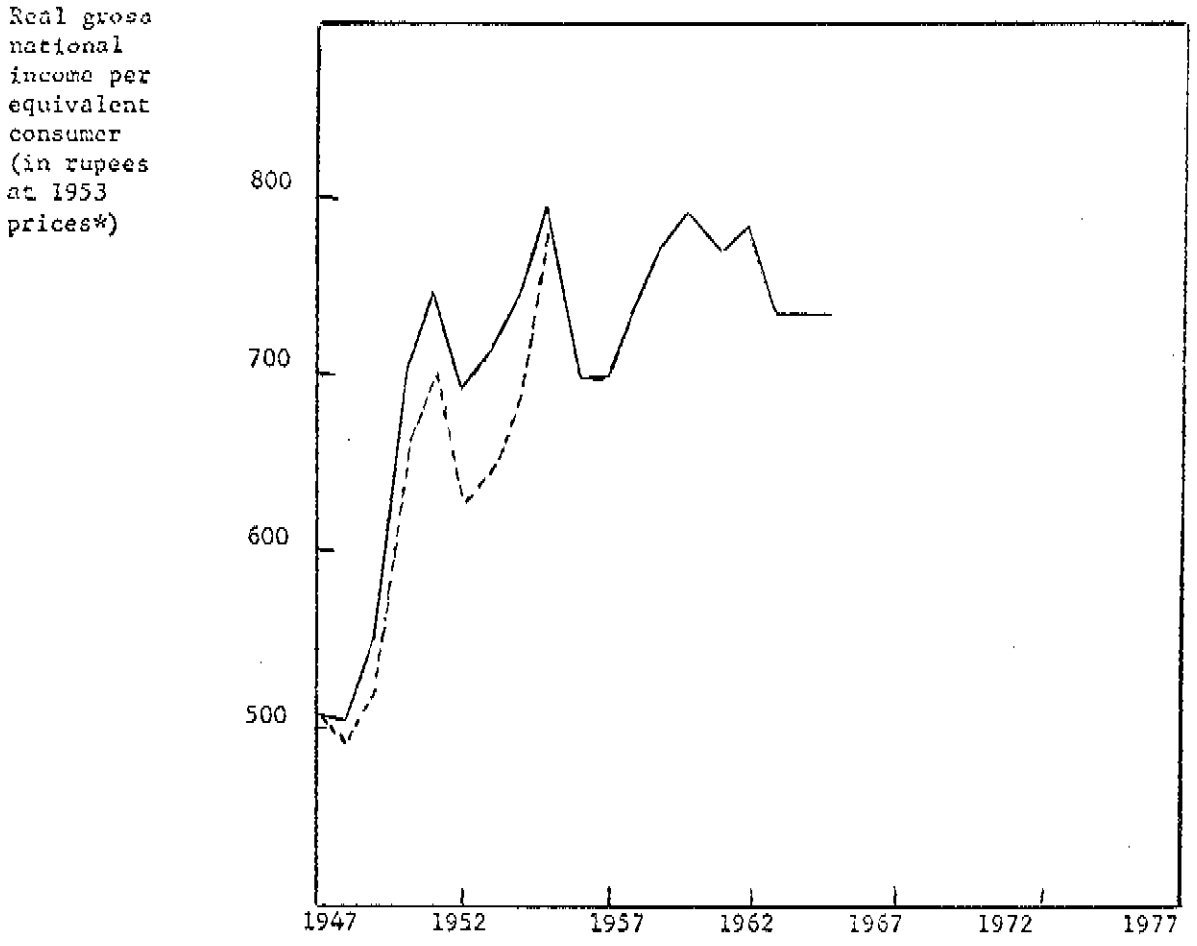
But the negative aspects of eradication gather strength as time progresses. Already by 1953 government saving, a major determinant of investment and hence of the future growth of output, was substantially smaller with eradication than without, even though gross national income was 14 per cent higher in the former case than in the latter. By that date the extra population

Figure 1

THE NET EFFECT OF MALARIA ERADICATION ON
NATIONAL INCOME PER EQUIVALENT CONSUMER IN CEYLON

____ With Eradication in 1947 (actual values 1947-65)

---- Without Eradication (simulated values 1947-54)



* In 1953 the official exchange rate was $1 = Rs. 4.76

resulting from eradication had begun to make demands on the public sector of such a size that government saving amounted to only Rs. 80 millions; without eradication the figure would have been Rs. 170 millions. Both in 1953 and in 1954 actual net investment fell short of the level it would have attained without eradication. As a consequence, by 1955 income per equivalent consumer, at Rs. 802, was a mere 3 per cent higher than the figure without eradication, at Rs. 779. It is likely that future results will show the two curves of Figure 1 crossing beyond 1955.

Further Analysis

Besides extending the two curves of Figure 1 to 1977, future calculations will show whether the results are highly sensitive to the assumptions made about the values of certain critical coefficients which are difficult to measure. Additional simulations will be based on the assumptions (a) that the capital-elasticity of output is 0.3 instead of 0.5 as assumed in obtaining the results shown in Figure 1, and (b) that the effect of malarial debilitation on labor quality is three times as great as initially supposed.

The main economic disadvantages of eradication are seen to lie in the rapid increase in the population of children resulting from the marked changes in infant mortality and birth rates. A final set of simulations will therefore be performed on the assumption that these disadvantages were avoided in Ceylon through the adoption in 1947 of a twin program of malaria eradication and birth control. It seems likely that the twin program would have made a dramatic contribution to the growth of per capita income.

APPENDIX

EQUATIONS FOR THE DETERMINATION OF INCOME

An asterisk attached to a variable expressed in money units (like gross national income) indicates that the variable is to be measured at constant prices

Definition of real gross national income

$$GNI^*_t = GDP^*_t + NFI^*_t + TTC^*_t \qquad (1)$$

Definition of real net foreign income

$$NFI^*_t = \frac{NFI_t}{pp_t} \qquad (2)$$

Definition of terms-of-trade contribution

$$TTC^*_t = \frac{X_t}{pm_t} - X^*_t \qquad (3)$$

Production function

$$GDP^*_t = A(qa_t)\left[(LS_t qs_t)^{es_t}\right]\left[(LU_t qu_t)^{eu_t}\right]\left[(K^*_t qk_t)^{ek_t}\right]V_t \qquad (4)$$

Skilled labor supply

$$LS_t = \sum_i P_{i,t}\, sk_{i,t}(1 - as_{i,t} - os_{i,t})(1 - ms_{i,t}) \qquad (5)$$

Unskilled labor supply

$$LU_t = \sum_i P_{i,t}(1 - sk_{i,t})(1 - au_{i,t} - ou_{i,t})(1 - mu_{i,t}) \qquad (6)$$

Definition of capital stock

$$K^*_t = K^*_{t-1} + I^*_{t-1} \qquad (7)$$

Investment-saving identity

$$I_t = SP_t + SG_t + SF_t \qquad (8)$$

Private saving function

$$SP_t = PC_t\left[\frac{SP_{t-1}}{PC_{t-1}} + sv_t\left(\frac{PDI_t}{PC_t} - \frac{PDI_{t-1}}{PC_{t-1}}\right)\right] \qquad (9)$$

Definition of private disposable income

$$PDI_t = GDP_t + NFI_t + TPFATI_t + TR_t - D_t - T_t - MC_t \qquad (10)$$

Transfer-payments function

$$TR_t = g_t PC_t \qquad (11)$$

Tax function

$$T_t = r_t(X_t + M_t) \qquad (12)$$

Private medical spending function

$$MC_t = mc_t\, GNI_t \qquad (13)$$

Definition of money gross national income

$$GNI_t = GDP_t + NFI_t \qquad (14)$$

Definition of government saving

$$SG_t = T_t + TPFATG_t - GC_t - TR_t \quad (15)$$

Definition of government consumption

$$GC_t = WF_t + ME_t + ED_t \quad (16)$$

Educational spending function

$$ED_t = ed_t \sum_i \$_i \left[P_{i,t} a_{i,t} + j(P_{i,t} a_{i,t} - P_{i,t-1} a_{i,t-1}) \right] \quad (17)$$

"Welfare" spending function

$$WF_t = wf_t \left[1 + j' \frac{PC_t - PC_{t-1}}{PC_t} \right] GNI_t \quad (18)$$

Definition of foreign saving

$$SF_t = M_t + TPTAFI_t + TPTAFG_t - X_t - TPFATI_t - TPFATG_t - NFI_t \quad (19)$$

Definition of imports

$$M_t = MK_t + MN_t \quad (20)$$

Function for imports of capital goods

$$MK_t = mk_t (I_t + D_t) \sqrt{R_t} \quad (21)$$

Function of imports of noncapital goods

$$MN_t = mn_t (C_t + GC_t + X_t) \sqrt{R_t} \quad (22)$$

Definition of foreign currency reserves

$$R_t = R_{t-1} - SF_{t-1} + B_{t-1} \quad (23)$$

Definition of capital stock quality

$$qk_t = \frac{K^*_{t-1} qk_{t-1} + IMN^*_{t-1} qm + IPN^*_{t-1} qp + IHS^*_{t-1} qh - D^*_{t-1} qd}{K^*_t} \quad (24)$$

Composition of real net investment

$$I^*_t = IMN^*_t + IPN^*_t + IHS^*_t - D_t \quad (25)$$

Definition of real imports of capital goods for nonhousing purposes

$$IMN^*_t = MK^*_t - MH^*_t \quad (26)$$

Function for real imports of capital goods for housing purposes

$$MH^*_t = mh\ IHS^*_t (1 - sh_t) \left(\frac{MK_t}{MK_{t-1}} \right) \quad (27)$$

Housing construction function

$$IHS^*_t = hs_t (P_{\text{males 20-54},t} - P_{\text{males 20-54},t-1}) \quad (28)$$

Definition of money gross domestic product

$$GDP_t = C_t + I_t + D_t + GC_t + X_t - M_t \quad (29)$$

Definitions of real gross domestic product

$$GDP^*_t = C^*_t + I^*_t + D^*_t + GC^*_t + X^*_t - M^*_t \quad (30)$$

$$GDP^*_t = \frac{GDP_t}{pp_t} \qquad (31)$$

Definition of real private consumption

$$C^*_t = \frac{C_t}{pc_t} \qquad (32)$$

Definition of real net investment

$$I^*_t = \frac{I_t}{pk_t} \qquad (33)$$

Definition of real government consumption

$$GC^*_t = \frac{GC_t}{pg_t} \qquad (34)$$

Definition of real imports

$$M^*_t = \frac{M_t}{pm_t} \qquad (35)$$

Definition of real imports of capital goods

$$MK^*_t = \frac{MK_t}{pk_t} \qquad (36)$$

Terms Whose Values Are Changed by Eradication

C	private consumption expenditures
ED	education expenditures
es	elasticity of output with respect to skilled labor
eu	elasticity of output with respect to unskilled labor
GC	public consumption expenditures
GDP	gross domestic product
GNI	gross national income
I	net investment (private and public)
IHS	housing construction expenditures
IMN	imports of capital goods for nonhousing purposes
IPN	expenditures on locally produced capital goods for nonhousing purposes
K	capital stock as of beginning of year
LS	number of skilled workers
LU	number of unskilled workers
M	imports
MC	private expenditures on medical care
mc	propensity to spend on private medical care
ME	expenditures on malaria-eradication campaign
MH	imports of capital goods for housing purposes
MK	imports of capital goods
MN	imports of noncapital goods
ms_i	morbidity rate among skilled persons in the ith age-sex group
mu_i	morbidity rate among unskilled persons in the ith age-sex group
P	population
PC	population of equivalent consumers
PDI	private disposable income
pp	implicit deflator for gross domestic product
qa	index of allocative quality
qk	index of quality of capital stock

qs	index of quality of skilled labor
qu	index of quality of unskilled labor
R	reserves of foreign currency
SF	foreign saving
SG	government saving
sk_i	proportion in the ith age-sex group having received secondary education
SP	private saving
T	tax receipts
TR	transfer payments from government to individuals
WF	"welfare" expenditures (public consumption expenditures excluding those for malaria eradication or education)

Terms Whose Values Are Independent of Eradication

A	constant term in production function
a_i	rate of school attendance in the ith age-sex group
as_i	rate of school attendance among skilled persons in the ith age-sex group
au_i	rate of school attendance among unskilled persons in the ith age-sex group
B	sum of balancing items in international accounts
D	depreciation
ed	education expenditures per standard pupil
ek	elasticity of output with respect to capital
f_i	ratio between per pupil expenditures in the ith age-sex group and expenditures per standard pupil
g	government transfer payments per equivalent consumer
he	housing construction expenditures per additional male aged 20-54
j	ratio between education expenditures per additional pupil when student population increasing and expenditures per pupil when student population unchanged
j'	ration between "welfare" expenditures per additional equivalent consumer when population of equivalent consumers increasing and expenditures per equivalent consumer when population of equivalent consumers unchanged
mh	import content of nonsubsistence housing construction when imports of capital goods unchanged from previous year
mk	propensity to import capital goods
mn	propensity to import noncapital goods
NFI	net foreign income from abroad
os_i	rate of nonparticipation as labor input for reasons other than school attendance and morbidity, among skilled persons in the ith age-sex group
ou_i	rate of nonparticipation as labor input for reasons other than school attendance and morbidity, among unskilled persons in the ith age-sex group
pc	price index for private consumption
pg	price index for public consumption
pk	price index for investment
pm	price index for imports
qd	quality of depreciation relative to quality of beginning-of-period capital stock
qh	quality of housing construction relative to quality of beginning-of-period capital stock
qm	quality of imported capital goods (for nonhousing purposes) relative to quality of beginning-of-period capital stock

qp	quality of locally produced capital goods (for nonhousing purposes) relative to quality of beginning-of-period capital stock
r	tax rate
sh	subsistence housing construction as a proportion of total housing construction
sv	marginal propensity to save out of private disposable income per equivalent consumer
TPFATG	transfer payments from abroad to government
TPFATI	transfer payments from abroad to individuals
TPTAFG	transfer payments to abroad from government
TPTAFI	transfer payments to abroad from individuals
TTC	terms-of-trade contribution to real national income
V	error term in production function
wf	propensity to spend on "welfare"
X	exports

FOOTNOTES

For a full treatment of these matters, see one of the standard works on malariology such as Emilio Pampana, A Textbook of Malaria Eradication (Oxford University Press: London, 1963) or Paul F. Russell et al., Practical Malariology, 2nd edition (Oxford University Press: London, 1963).

[2]For an account which describes many of these estimates, see C.-E. A. Winslow, The Cost of Sickness and the Price of Health (W. H. O. Monograph Series, No. 7: Geneva, 1951)

[3]These distinctions are discussed in Selma J. Mushkin, "Health as an Investment," Journal of Political Economy, LXX (October 1962), pp. 129-57.

[4]Ansley J. Coale and Edgar M. Hoover, Population Growth and Economic Development in Low-Income Countries (Princeton University Press: Princeton, N.J., 1958)

[5]Peter K. Newman, Malaria Eradication and Population Growth, With Special Reference to Ceylon and British Guiana (Bureau of Public Health Economics, University of Michigan: Ann Arbor, 1965)

[6]For several suggestions as to how the effects of debilitation could be measured, see Mushkin, loc. cit., pp. 141-42.

[7]H. Cullumbine, "A Survey of Disabling Illness in Ceylon," Bulletin of the World Health Organization, VII (1952), pp. 405-29 and "The Health of a Tropical People," The Lancet (May-June 1953), pp. 1090 ff., 1144 ff., 1193 ff., and 1245 ff.

[8]Donald R. Snodgrass, Ceylon: An Export Economy in Transition (Irwin: Homewood, Ill., 1966)

[9]Op. cit., p. 194.