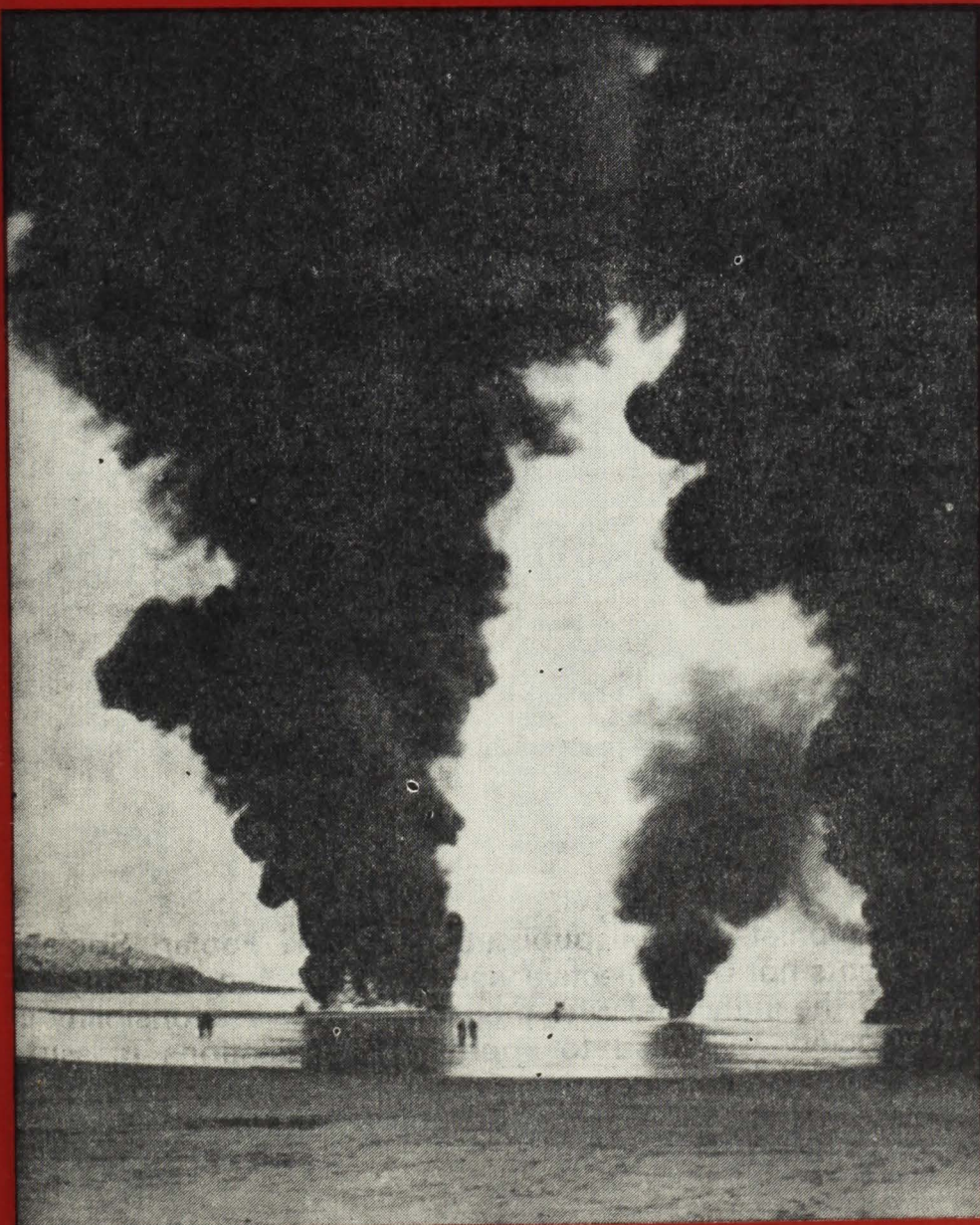


the politics of the environment

Jeremy Bray
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1. introduction

We are told the world is becoming overpopulated, economic growth is exhausting non-renewable resources, and the environment is becoming so polluted that the ecological balance necessary for survival is likely to be upset. This headlong rush will end in disaster within 100 years unless we halt the growth of population and industrial output and achieve a state of equilibrium in which we are told we can just hope to survive.

There is cause enough for concern already, with the teeming squalor of Calcutta, the dispossessed and exploited poor of South America, the hungry unemployed in the United States, and nearer home the drop outs and rebels from society mixing with the submerged poor in the cities of Europe. For the ordinary Western city dweller there is the pressure of commuter trains, the traffic jams on summer weekends, and the deafening noise of aircraft taking neighbours on holiday, with even the stars banished for ever from sight by the "pollution" of street lighting. Creeping havoc is threatened by lead and mercury poisoning from the operations of very powerful industrial corporations suspected of the ruthless pursuit of quick profits.

It is a heady message, full of foreboding. What truth is there in it? How can we tell the true prophets from the false, who have exploited every such movement from the dawn of history? What should we do?

the debate

Barry Commoner, Paul Ehrlich, Harrison Brown and many others have contributed to the debate. (A balanced summary of the non-population aspects is given in *The Biosphere* (1970), a Scientific American book. The most recent and authoritative survey of population prospects is *A concise summary of the world population situation in 1970*, UN 1971). I shall concentrate on the recent work of Professor Dennis Meadows initiated by the Club of Rome at the Massachusetts Institute of Technology, which attempts to bring different elements in the global situation together in a single systematic framework

(*The limits to growth*, Universe Books, New York, 1972).

The argument may be summarised briefly. World population is increasing exponentially at a pace which will double it in 32 years. Already about half the land suitable for agriculture is under cultivation. There will be a desperate shortage of land before the year 2000, and doubling or quadrupling food output per hectare will only delay the shortage by 30 or 60 years. Fish yields from the sea can only be doubled.

World industrial production in total and per capita has been increasing exponentially. At present rates of growth in the usage of minerals and fossil fuels, given the limited reserves, the great majority of these raw materials will be prohibitively costly 100 years from now, regardless of the most optimistic assumptions about undiscovered reserves, technological advances, substitution, or re-cycling, if our need for these materials continues to grow. Nuclear power will not be free or even cheap, and in any case energy will not be the limiting factor in extracting food and materials from the earth.

Pollution from radioactive wastes, lead and mercury poisoning, the accumulation of DDT in the oceans, carbon dioxide build up in the atmosphere, dust deposition and the rise in temperature from waste heat has locally reduced some living species, and may upset the ecological balance of the whole world and its ability to support human life at its future or even present level.

So the growth of population and output will inevitably come to an end for one reason or another. Professor Meadows and his collaborators at MIT put the interactions between population, land, food, industrial output, capital, natural resources, and pollution into a computer model to demonstrate the dynamics of the system as a whole. They argue that an individual involved in some element of a complex system has a good understanding of that element, but he is not good at analysing or predicting the behaviour of the system as a whole when all the

the politics of the environment

elements are put together. The computer programmer merely puts together the individual elements of behaviour, and the computer shows what happens for different assumptions about the particular form and parameters of the relationships describing each element. We shall return to Professor Meadow's conclusions and to technical questions which have to be asked about this model building method, but let us first examine the broad evidence used.

World industrial production is total and per capita has been increasing rapidly. At present rates of growth in the next 100 years, the world will produce enough to support 100 billion people. The most optimistic assumptions about industrial growth, however, technological advancement, education in developing countries, and the use of nuclear energy, will not be enough to support 100 billion people. The world will be unable to support 100 billion people.

Population from industrialized nations and many countries in the developing world is not in the normal state of equilibrium. It is in a state of disequilibrium. The world population is growing at a rate of 1.5% per year. This is a very high rate of growth. It is a rate of growth that is not sustainable. It is a rate of growth that is not in the long term interest of the world.

So the growth of population and output will continue to rise. It will continue to rise at an ever increasing rate. It will continue to rise until it reaches a point where it is no longer sustainable. It will continue to rise until it reaches a point where it is no longer in the long term interest of the world. It will continue to rise until it reaches a point where it is no longer in the long term interest of the world.

the world is becoming more and more dependent on non-renewable resources, and the world is becoming so polluted that it is becoming necessary to take steps to clean up the world. The world is becoming more and more dependent on non-renewable resources, and the world is becoming so polluted that it is becoming necessary to take steps to clean up the world.

There is cause enough for concern about the remaining surplus of California, the unexplored and exploited part of the world, the hungry unemployed in the United States, and hunger home the third world. The hungry unemployed in the United States, and hunger home the third world. The hungry unemployed in the United States, and hunger home the third world.

is a healthy message, full of foreboding. For truth is there in it. How can we be sure that the world is not being exploited every such movement from a dawn of history? What should we do?

the debate

very Commoner, Paul Ehrlich, Harrison Owen and many others have contributed to the debate. A balanced summary of the debate is given in the book "The Limits to Growth" by Meadows et al. The book is a very important contribution to the debate. It is a very important contribution to the debate.

2. the evidence

POPULATION GROWTH

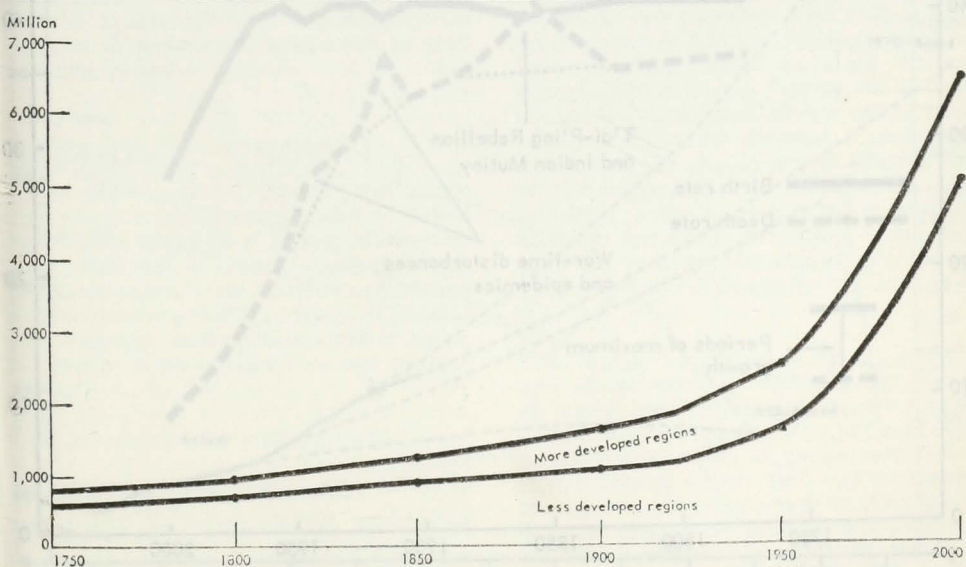
The latest UN estimates and conjectures of world population up to the year 2000 are shown below.

The expected increase from 3,600 million in 1970 to a conjectured 6,500 million in 2000 is enormous, and the graph shows no turning over beyond that point, giving credence to the idea of continued exponential growth. However, the graph overleaf gives a clearer impression of what is happening. In both the now more developed regions and the less developed regions up to about 1850 there were about 35 deaths and 40 births per 1000 inhabitants each year. From about 1850, as the former regions developed, the death rate dropped, to about 9 per 1000 today, to be followed some 30 years later by the birth rate, which has fallen to about 19 per 1000 today. From now on the death rate in the more developed regions is expected to rise as larger age groups begin to die, while the birth rate will continue to fall.

In the less developed regions the fall in the death rate was delayed by nearly a century, only gathering momentum around 1950, after the war. It will go on falling to below the level in developed regions because of the very skewed age distribution, before increasing again. The fall in the birth rate is already showing up in some developing countries, and is expected to appear in the total by 1980. The rate of growth of the population will continue to increase until past 1980 due to the fall in the death rate, but is expected to fall thereafter. If, as life expectancy settles down at upwards of 70 years in all regions, the birth rate approximates to replacement levels at an average of just over 2 children per family, the world population would settle down in the twenty first century at some level well over 7000 million, but not continuing to grow exponentially. How likely is this to happen?

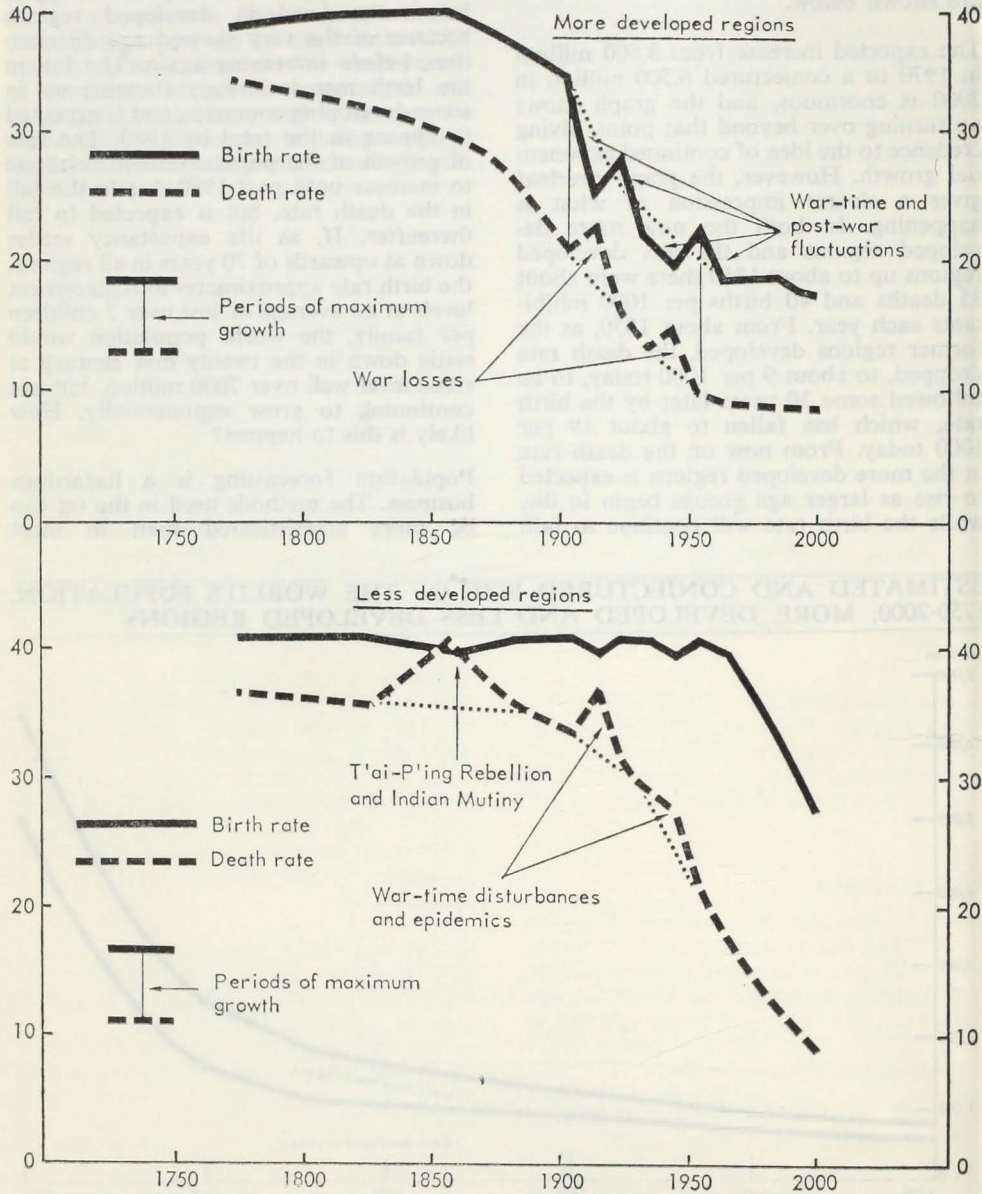
Population forecasting is a hazardous business. The methods used in the UK can be more sophisticated than in most

ESTIMATED AND CONJECTURED SIZE OF THE WORLD'S POPULATION, 1750-2000, MORE DEVELOPED AND LESS DEVELOPED REGIONS



source: *A concise summary of the world population situation in 1970*, United Nations 1971.

ESTIMATED AND CONJECTURED TRENDS IN BIRTH RATE AND DEATH RATE, 1750-2000, MORE DEVELOPED AND LESS DEVELOPED REGIONS



source: *A concise summary of the world population situation in 1970*, United Nations 1971.

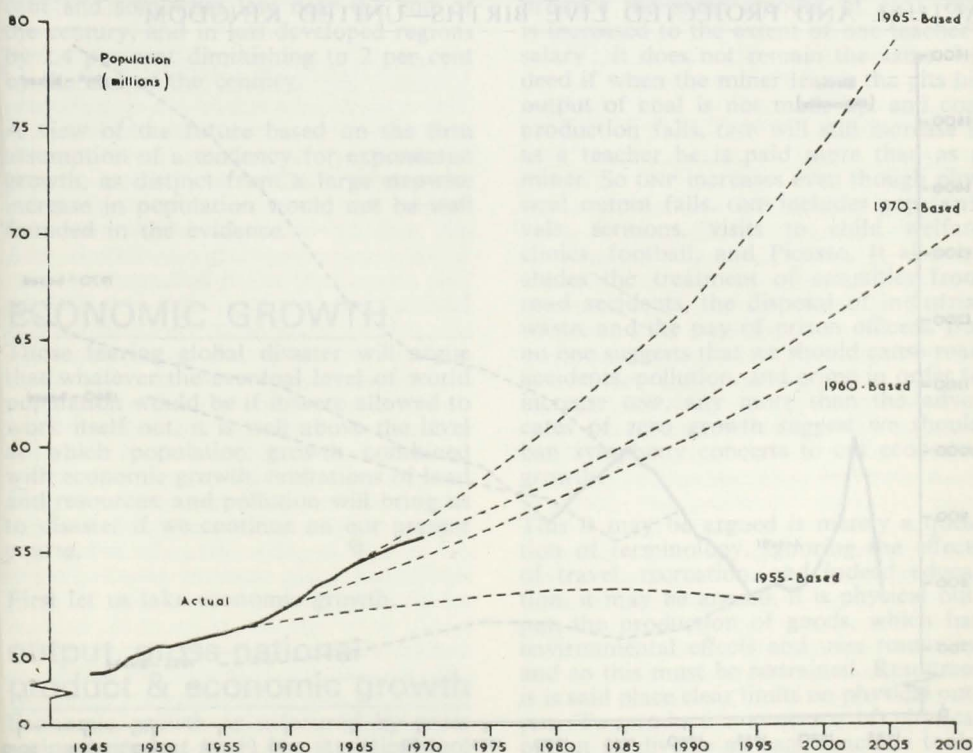
countries because there is so much data available.

The starting population in the base year is known in total for each 1 year age group. The mortality in each of these age groups is known over recent years, and trends are extrapolated into the future. Marriage rates for women in each age group are known in recent years and extrapolated, as is the probability of having a child for different durations of marriage, and different ages of marriage. Adjustments are made for migration to give the final forecasts of population. To show the hazards of even this complex forecasting method the actual and projected population of the UK, based in different years are shown below. The

forecast for the year 2000 has varied from about 53 million in 1955 to 74.6 million in 1965 and is now down to about 66 million. The main cause for these variations is the change in projected birth rates shown overleaf, which in turn reflect changes in actual birth rates. If the expected population increase between 1955 and 2000 can move from 0 per cent to 40 per cent and back to 25 per cent in forecasts made in 1955, 1965 and 1970, in a country with as stable social conditions as the UK then how much greater is the uncertainty in other countries where social conditions are changing rapidly?

For the world population, the main uncertainty is the birth rate in less developed countries. In just five years between 1960

ACTUAL AND PROJECTED TOTAL POPULATION OF THE UNITED KINGDOM



source: *Population projections 1970-2010* HMSO, 1971.

and 1965 the birth rate decreased as shown in the table below.

BIRTH RATE PER 1000 IN LESS DEVELOPED COUNTRIES

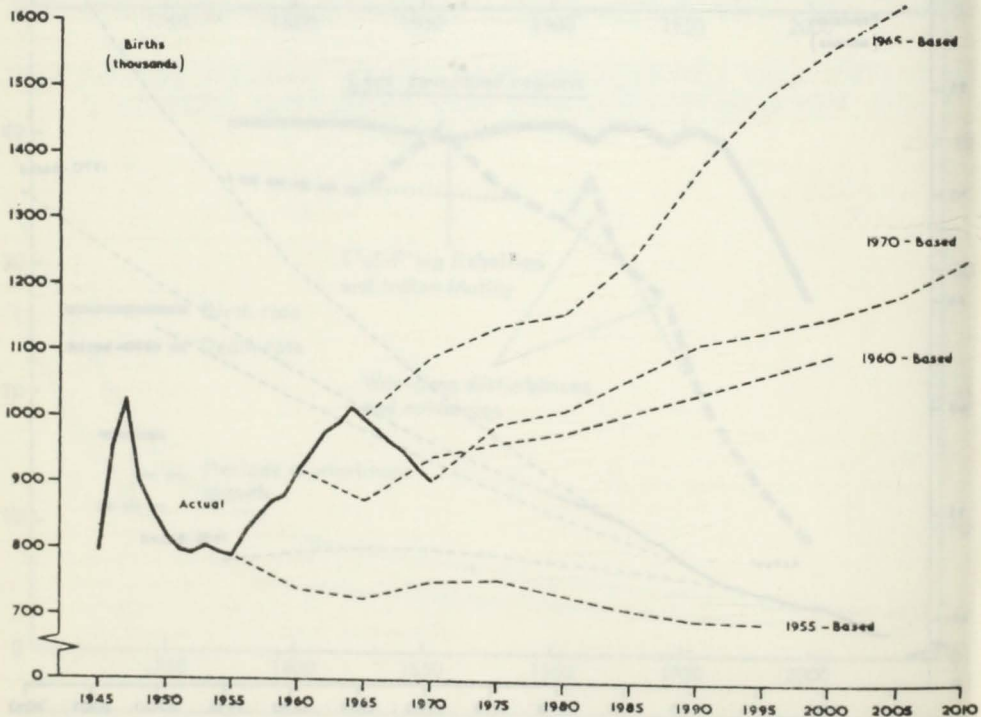
	1960	1965
Brunei	49	42
Albania	43	35
Taiwan	40	33
Singapore	39	31
Hong Kong	36	26
Guyana	43	40
Jamaica	42	39
West Malaysia	41	37
Mauritius	38	35
Guadeloupe	38	34
Ceylon	37	33

These are small countries with on the whole more favourable conditions, and so would be expected to lead India and Pakistan for example. The combined

population of these countries is small in comparison with those in which no appreciable change in the birth rate can yet be seen.

UN experts in the report referred to already observe: "Aside from the marital and health factors already mentioned, the record of all historical and demographic observations indicates that certain developmental features, singly or in combination, exert a strong influence in the direction of an eventually decisive fertility decline towards the levels now prevailing in the more developed regions. Among these one may mention the decline of mortality, improved health and education, economic transformations, the move from agricultural to other economic activities, urbanization, greater frequency of travel and communications, wider choices for activities on the part of women and so on.

ACTUAL AND PROJECTED LIVE BIRTHS—UNITED KINGDOM



source: *Population projections 1970-2010* HMSO, 1971.

But the speed with which these influences make themselves felt and the resistances they may encounter can vary considerably from one area to another, having regard also to a wide variety of culture patterns, traditions, guiding values, and attachments to symbols expressing them. The implementation of family planning policies, official, semi-official, unofficial, or variously assisted, is a new phenomenon whose possible effect in diverse situations cannot yet be easily assessed but, with time, may also acquire importance."

It is certain that there will be a very large increase in world population up to the year 2000 and beyond. It is uncertain whether and at what level the population will level out in the twenty first century, but the evidence is that the growth will not be exponential. The UN report expects that the growth in developed regions will now rise at average annual rates of 1 per cent and somewhat less near the end of the century, and in less developed regions by 2.4 per cent diminishing to 2 per cent by the end of the century.

A view of the future based on the firm assumption of a tendency for exponential growth, as distinct from a large stepwise increase in population would not be well founded in the evidence.

ECONOMIC GROWTH

Those fearing global disaster will argue that whatever the eventual level of world population would be if it were allowed to work itself out, it is well above the level at which population growth combined with economic growth, limitations of land and resources, and pollution will bring us to disaster if we continue on our present course.

First let us take economic growth.

output, gross national product & economic growth

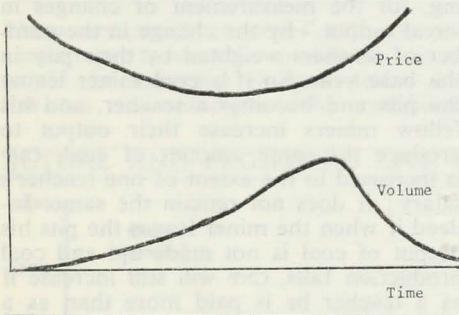
Economic growth as measured by gross national product (GNP) is a statistical tool devised for economic management purposes which has come in for a good deal

of misunderstanding and abuse from those who should know better. The measurement of national income or GNP was first used in war time Britain by Professors James Meade and Richard Stone as a tool for managing the economy according to Keynesian theories of demand management, to maintain full employment without inflation or a deficit in the balance of payments. It is measured in three equivalent ways (Rita Maurice, *National accounts statistics*, HMSO), as the total of incomes, or of expenditures, or of production. Where production itself cannot be measured, as for example from school teachers, production is measured by the pay of teachers, or strictly speaking, for the measurement of changes in "real output," by the change in the number of teachers weighted by their pay in the base year. So if a coal miner leaves the pits and becomes a teacher, and his fellow miners increase their output to produce the same amount of coal, GNP is increased to the extent of one teacher's salary: it does not remain the same. Indeed if when the miner leaves the pits his output of coal is not made up, and coal production falls, GNP will still increase if as a teacher he is paid more than as a miner. So GNP increases even though physical output falls. GNP includes pop festivals, sermons, visits to child welfare clinics, football, and Picasso. It also includes the treatment of casualties from road accidents, the disposal of industrial waste, and the pay of prison officers. But no one suggests that we should cause road accidents, pollution, and crime in order to increase GNP, any more than the advocates of zero growth suggest we should ban symphony concerts to cut economic growth.

This it may be argued is merely a question of terminology. Ignoring the effects of travel, recreation, and indeed education, it may be argued, it is physical output, the production of goods, which has environmental effects and uses resources, and so this must be restrained. Resources is said place clear limits on physical output. To produce a measure of physical output as diverse as cars, machine tools, tooth brushes, and oil it is necessary to measure them in some common unit, and

this is usually money. If some other unit is used to value a product the argument remains the same. Total output is measured as the price per unit times the volume or number of units produced, summed over all the different kinds of product. Consider the volume and the price over the life time of each product which we take to refer to a specific technology (such as stage coaches or nuclear power from gas cooled reactors). They will be typically as shown in the graph below.

VOLUME—PRICE HISTORY OF A TYPICAL PRODUCT



This gives total output various characteristics. For example if the price of a resource which is running out increases rapidly, that resource carries a heavier loading in total output, with the result that the later it is replaced by a new product the larger will be the consequent rise in output, though the actual patterns of activity may end up identical. So the measure of output depends on the particular path taken between the initial and final level and composition of consumption.

Furthermore by the successive substitution of technologies, including possibly the reintroduction of abandoned technologies, real output can go on increasing without limit without the cumulative consumption of any particular resource exceeding limits (see appendix). This is not an economist's conjuring trick. If there was only one product which could be measured physically, like steel by the ton, then certainly steel output cannot go

on increasing indefinitely from limited reserves of iron ore. But people are not interested in buying steel for its own sake. They are interested in what they can do with it, like making a car. And if they find better and cheaper materials for cars, or better means of transport than cars, or better ways of bringing people together than transport, the demand and the price of steel will change.

This change in the composition and relative prices of output is going on all the time. It is not a sinister invention of economists but a recognition of the fact that girls today do not like red flannel petticoats, that now that many well fed people get as much carbohydrate in sugar form as is good for them they do not crave after meat fat as Jack Spratt's wife used to do, that leaning on a farm gate chewing a piece of straw is now, alas, for city dwellers, a rich man's indulgence.

technological change

The crucial question, which it is impossible finally to answer, but which is well worth more investigation than it has received, is whether the interactions of volume and price for particular products, and their effect on the development and demand for competing products, is such that the process of replacement can proceed without obvious limit and without too much dislocation of society. The question is equally relevant in capitalist, socialist and mixed economies. The question can be asked in terms of substitution with electric light regarded as a substitute for candles, coal a substitute for fire wood, and carbon fibres a substitute for steel. It is wrong to suggest that the old technology is always preferable, and indeed it is usually abandoned by free choice before it becomes physically unavailable.

But let us consider those cases where the old technology is preferred but will cease to be available in due course because of the exhaustion of a mineral reserve or for some other reason. If a substitute is already available then in theory as the price of the old product rises and its supply

falls, the investment in producing the new product will rise, increasing the supply, and reducing the price. Whether gross national product will rise or fall because of the substitution process will depend on the particular course taken by the prices and volumes of production of the old and new products. Usually it rises. If however a substitute is very much needed but the development work required to produce a substitute cannot be completed in less than a certain time, more foresight is needed. Theoretically, if a very high price for the substitute can be expected if it is in short supply when the old product ceases to be available, then however long the development period, and however high the discount rate, the development will be profitably undertaken in time if events can be foreseen. However, the risks of misjudgement are greater, in that the development of substitutes may be left too late, or if undertaken too early the substitutes may be uneconomic.

Each of the main sources of energy—wood, coal, oil, natural gas, liquified petroleum gases, water and nuclear power, each of the main bulk materials—timber, steel, cement, plastics, aluminium and copper, each of the other main metals—manganese, chromium, nickel, molybdenum, tungsten, cobalt, lead, zinc, tin, gold and silver, their reserves, extraction rates, costs and end uses in the past, present, short and long term future are the subject of ever more sophisticated enquiries by those trading in them, and by public and private research bodies of many kinds. It is desirable that the number, diversity and influence of these research activities should increase. It is by no means the case that the consumption of all materials increase exponentially. The consumption of tin for example has not grown fast because of decreasing availability of the ore and the development of substitutes. The growth of aluminium production on the other hand accelerated after the war, and is expected to resume rapid growth after the current recession. On the energy side nuclear fission and still more, fusion, offers virtually unlimited sources of energy.

The application of materials with exotic

properties like superconducting alloys, silicon carbide and carbon fibres, of processes like ion implantation and chemical machining, of the computer aided optimisation of design to use unfamiliar properties of new materials, and many laboratory curiosities could have orders of magnitude effects on material efficiencies.

Having said all this, it can still be asked, are not the remaining mineral deposits running out rapidly? Reserves look small enough at current rates of usage, but in many cases usage is increasing rapidly. If consumption continues to grow at present rates the reserves will be exhausted much quicker. Professor Meadows quotes reserve lives for mercury of 13 years, nickel 53 years, aluminium 31 years, and iron 93 years, for example. (The figures tend to vary a good deal: in a paper a few months earlier than his book Meadows gave the reserve life of nickel as 30 years, aluminium as 34 years and iron as 73 years). Such estimates are rather like trying to estimate the demand for a new synthetic fibre by scanning the pages of Littlewood's mail order catalogue. The mail order catalogue is useful for showing what you can buy now. It is a poor guide to what you will be able to buy 10, 20 or 50 years from now.

Certainly ores above any level of richness are limited, whether we know the limits or not. Attempts can be and are made to estimate the likely level of undiscovered reserves. Models can be built like that of Professor Meadows to illustrate the dynamic relationships between unproven reserves, discovery rates, proven reserves, usage rate, price, and cost of exploration for particular minerals. Over the total life cycle usage rises and then falls as reserves are exhausted. But to use the word "crisis" about the exhaustion of reserves of one particular mineral is to beg the question. It will of course have local effects in the region, and in the industries and applications concerned. But whether there is a "global crisis" will depend on what other adaptive processes are going on in the economy. It is necessary to look at the effects of the accumulation of stock in use on new demand, of

re-cycling, and above all of substitution. Man cannot live indefinitely like a nomad exploiting one iron reserve and when it is exhausted moving on to the next. But if we think not in terms of geographical migration but of technological migration, moving on from one technology to the next, we have scarcely begun to conceive the possibilities. There is no justification for facile optimism about technological development. But there is still less room for defeatism, built on the selective compounding of degenerative influences.

There is, however, a problem about the exploration and preparation for longer term developments. It is not sufficient to rely on oil and mining companies motivated by discounted profit maximisation, nor on Departments of Commerce motivated by current pressure groups and short term economics, nor on Departments of Health motivated by discounted social cost benefit studies. Discounting tends to obliterate all considerations more than ten or at most twenty years into the future.

discounting the future

We are not concerned here with the technicalities of money interest rates, liquidity preference, and the management of money supply. We are concerned rather with the simple device for weighting present against future costs and benefits, offered by counting costs and benefits or profits in year 1 as x per cent less than in year 0, and in year 2 x per cent less than in year 1, and so on. The discount or interest rate x is calculable on any stream of costs and benefits, and in the discussion below is taken as net of the rate of inflation: that is the money cash flow is first deflated to constant price terms, and the discount rate then calculated. Furthermore the discussion is framed in terms of the marginal discount rate, that is the discount rate on the least profitable of the projects undertaken at the margin.

Discounted profit or social cost benefit maximisation will work—and has worked—as an objective so long as long term requirements are met by pursuing short

term objectives. Thus the long term need to educate the next generation in primary schools is met because there is a short term demand from parents for a good education for their children now. It has already been observed, in discussing technological development with a long lead time, that such development will still be undertaken profitably if a sufficiently high price for the resulting benefits can be expected in the future. The higher the discount rate the higher the eventual price must be; and the higher the future price (relative to other future prices) the greater the degree of dislocation, rate of adaption and switching of resources will be needed and may be in process at that future time. A high discount rate encourages giving much the greater weight to the needs of the moment, leaving things to the last possible moment, and living from hand to mouth.

Conversely if at the present time there is a high degree of dislocation, if assets are poorly distributed in relation to current needs, if therefore a rapid rate of adaptation and switching of resources is needed, if society and the economy are far from (dynamic) equilibrium, then the marginal discount rate will be high. For example, if we have already invested in cars but not in the motorways to drive them on, the discounted return on building a motorway system will be higher than if we had to buy the cars as well. We get the benefit of using the cars at the price of the motorways alone. A high discount rate puts a premium on short term measures. So disorder now is associated with a high discount rate which in turn leads to disorder in the future.

A low discount rate indicates a low call for further investment against future needs, leaving resources free for consumption now in a reasonably balanced society. Given the many problems in society it is unlikely that the marginal discount rate can be expected to fall to low levels. So the problem is how to prevent high discount rates, and a high level of disorder in society from perpetuating themselves. It must be emphasised that this is not a problem of securing growth: if discount rates are high there will be a

higher level of investment, but it will be directed at short term rather than long term needs.

In social policy this problem can be redressed by accepting lower discount rates on long term social investment, such as housing, schools and hospitals.

research and development

A similar need arises in research and development. Profit motivated companies, whether privately owned or publicly owned, will tend to judge their research and development expenditure at the same discount rate as their physical investment. They may accept a lower discount rate on R & D (or be happy to assume a lower rate since it is very difficult to identify the return on R & D). They would give much the same reasons as we have given for society as a whole, stated in the form that the company wishes to protect its long term future. However, the R & D will generally be conducted within the same broad assumptions about technology, cost of factors of production, and markets as the rest of the business, and rightly so. The other activities need the support of R & D, and to be effective R & D needs a purpose.

Long term R & D however is not provided for. What will happen when the cost and supply of particular materials and processes have shifted drastically? If the R & D is left until then, and it takes a long time, the dislocation will be that much the greater. The R & D should be undertaken in sufficient time to be ready when required. However not only does it need a lower discount rate. It would have to be justified in terms of a very different cost structure with a very different technology and "state of the art" than that of today or even ten years' time. Society itself will have changed greatly, not only in the material culture and level of education, but also in social values and patterns of relationships and behaviour. And this future against which it is necessary to justify long term R & D is largely unknown and unknowable today when we have to initiate the research.

A practical response to this dilemma will be suggested later.

POLLUTION

While the problem of resources lies in the future, the problem of pollution is here today. There is much that we can do, and should do, and some good things have been done. In the UK the Clean Air Act has abolished London smog, and changed the atmosphere in many towns. The River Thames is cleaner than it has been for very many years, and the number of species of fish to be found in the river has increased greatly. Plans are in hand to clean up the other rivers of England. Effluent and smoke control orders in industry are enforcing the installation of much equipment to clean up harmful effluents. Dust control in coal mines has greatly reduced the incidence of silicosis among miners. The pattern of effluents in tidal estuaries and at sea are traced accurately by infra-red line scan photographs which can detect variations in temperature of 0.001 centigrade. The scientific and technical calibre of pollution prevention work has increased.

Serious hazards from pollution still do arise. There is currently an official enquiry in progress into a new lead/zinc smelter at Avonmouth which has caused lead poisoning of workers, and has been closed down for extensive modifications. Drums of dangerous chemicals from a wreck at sea were washed up on the South Coast of England. But whereas it used to be difficult to get action taken on pollution issues it is now easier and quicker. Indeed there are cases where health and safety measures per unit of risk where pollution is involved are far more lavishly provided than they are for the normal population going about their daily lives. This is no reason for easing up the pressure for increased anti-pollution measures, but it is good reason for making sure equal pressures are maintained for the improvement of basic health and welfare services, and for avoiding a backlash against the anti-pollution lobby.

Progress is particularly needed in the effect

of the motor car. Lead free petrol, conditions for the total combustion of fuel, and anti-lock braking are examples of restraints that should now be introduced by law, and are likely to be.

The following general principles have been much canvassed and should continue to be until they are implemented.

1. The polluter should bear the costs of preventing pollution. In other words "external" costs should be made "internal."
2. The enforcement of standards is required by law, and should be supported by a scientifically well qualified and equipped inspectorate.
3. Standards should be international (Lord Kennet, "The Stockholm conference on the human environment," *International affairs*, January 1972).

The problem of course varies from country to country. But globally is the problem of pollution out of control, or likely to go out of control? Will continued economic growth take it out of control? The indications are that the resources required to prevent increasing pollution and then reduce it well below present levels are quite modest. Professor Meadows for example quotes \$500 million per year investment in the United States in 1973 for waste water treatment alone, suggesting this is a large sum, but it is only 0.05 per cent of GNP in the United States.

Just as it was argued above that the exhaustion of particular mineral reserves need not halt or seriously embarrass the continuation of economic growth, so too pollution can be kept within limits we choose while the world economy continues to grow. Indeed other things being equal the tighter the control of pollution the more economic growth we shall need. Economic growth, or the growth of GNP, does not entail a proportionate increase in physical output of any one product or group of products or processes, and increased physical output need not entail increased pollution.

3. the argument

We are confronted with enormous developments in world population and the world economy, and in our environment as a whole. It is right that we should try to understand what is happening, and use whatever methods are available to us in doing so, particularly if we believe there may be actions we should take.

study of strategy

The Club of Rome, of which I am a rather inactive member, commissioned Professor Meadows at MIT to extend Professor Forrester's application of his modelling methods to world problems. Professor Meadows' preliminary conclusions (*The dynamics of global equilibrium*) and my comments are as follows:

1. *Meadows: Exponential growth in population and material output is the dominant force in socio-economic change in most contemporary societies.*

Comment: The growth in population is not exponential, either in a mathematical or statistical sense of a roughly constant percentage increase each year, or in the causal sense that the increase in population is broadly driven by a force proportional to its size. The more likely path of population growth in present conditions is a very large stepwise increase, taking world population from the present 3 billion to perhaps 7 billion by the year 2000, and perhaps doubling again in the next century, but not driven on indefinitely by its own momentum.

Material output is a vague term. The physical output of any one product or technology has not and is not likely to increase exponentially. The typical path will be as shown for the volume in the figure shown earlier. Any physical aggregation of products again is unlikely to increase exponentially.

The growth that there is in population and outputs of many kinds is not the dominant force today. A greater consideration than population in socio-economic change is the raising of standards, in both developed and underdeveloped countries. The vol-

ume of material output is not the dominant expression of these rising standards in developed countries. In underdeveloped countries growth in the volume of outputs is more the result than the cause of change.

2. *Meadows: Current growth rates of population and material output cannot be sustained indefinitely. Probably growth would over reach important physical limits if continued for another 50-100 years.*

Comment: Growth rates are unlikely to continue. But the idea of physical limits is misleading, since it ignores the process of social, economic and technological adaptation that goes on all the time, with the constant obsolescence and innovation of successive technologies.

3. *Meadows: Growth may come to an end either through an orderly accommodation to its limits (a transition to equilibrium) or through overshooting its limits and collapsing.*

Comment: The idea of equilibrium is misleading, as conclusion 7 below suggests, and the alternatives are not the only ones. Population will continue to adapt to circumstances.

4. *Meadows: Because of the delays in many feedback loops which govern growth in material output and population, the most probable result of current global growth trends is overshoot and collapse.*

Comment: This is a conclusion about Professor Meadows' model in the first place, but it is a common feature of many dynamic systems. A characteristic feature of such systems, which is likely to be true of the world (whether or not it is true of Professor Meadows' model) is that given delays in response, as the pressures towards a particular level (the "gain" in a feedback system) are increased, the system is driven first into overshoot and damped oscillation about the desired level, and then into unstable or increasing oscillations about the desired level. In politico-social terms this would mean an alternation of ever more extreme reactions and counter reactions doing great

damage to society. "Stop go" in Britain is a painful example of instability caused not by external or structural factors, but probably by stabilisation policy itself. It is not an example to be followed.

5. *Meadows: Technological solutions designed to release some pressure caused by growth (starvation, escalating resource costs and so on) can serve only to postpone the collapse if they are not accompanied by changes which decrease the social, economic and political factors causing growth.*

Comment: The main factor which has caused the growth of population is the reduction of mortality before child bearing age. Professor Meadows cannot mean we should increase it again. By all means let us reduce fertility, by electric light, encouraging birth control and other means. But the experts tell us a major influence reducing fertility seems to be economic growth, and as has been shown it is not at all clear we should try to reduce that. The positive "technological solutions" like the "green revolution" include many of the processes by which technology is adapted, and cannot be separated out as mere delaying influences. Also a "technological solution" which would merely postpone collapse, given exponential growth, could avert disaster altogether if as has been suggested the growth of population is not exponential but stepwise.

6. *Meadows: It seems possible to identify alternative states of material equilibrium on a global scale in which population and material output are essentially constant and in balance with the finite resources of our environment. These states could be defined in ways which would satisfy man's most fundamental needs, permit cultural progress and sustain his society indefinitely.*

Comment: A policy of zero growth would cause strife within and between nations. It is based on a misconception of what economic growth is. Economic growth is not limited by any specific material resources. To speak of zero growth of material output is still misleading, and

even with zero growth of the output of manufactures it would not be possible to maintain the same technology indefinitely. There is no escaping the necessity of change.

7. *Meadows: There is no unique, optimal long term population level. Rather there is an entire set of trade offs among personal freedom material and social standard of living, and the population level. Given the finite and diminishing stock of resources on this globe, we are inevitably faced with the necessity of recognising that a larger population implies a lower material standard of living over the long term.*

Comment: If there is no unique optimum level, then it can vary from time to time, so what is the purpose of seeking an equilibrium if at different times we find different levels result from social pressures? A larger population need not imply a lower material standard of living over the long term. As at times in the past, and in parts of the world today, the available resources could in some circumstances be better used by a larger than a smaller population. And in standard of living in the full sense, mankind could be richer with a larger population, once we can crack the problem of poverty, though it is not a sensible objective now.

8. *Meadows: Since the delays involved in negotiating an orderly transition to any state of equilibrium are very long, 50 to 100 years or more, it is essential that society begins through study and action to remove the implicit promotion of population and material growth. Each year of delay decreases the long-term options of society and the probability of carrying out an orderly transition to equilibrium.*

Comment: The sense of urgency is understandable. But anyone tempted to argue we cannot do any harm by going along might pause to wonder whether it is quite the right policy to halt "material growth," especially other, and poorer men's "material growth."

It may be asked how can Professor

Meadows have been mistaken in his conclusions? Has he not used all the available evidence in a computer model and checked its consistency? Has he not shown that his conclusions stand even if there is wide uncertainty in the magnitude and timing of specific effects? The difficulty lies in the methods devised by Professor Forrester, which he used in building the model. A technical criticism is given in the appendix. The methods are a means of articulating the intuitive judgments of the model builder, conditioned by his subjective preferences for the future.

The ideas and conclusions that Professor Meadows puts forward are shared by many other sincere and well meaning people, but his work gives no greater authority to his views than theirs.

blueprint for survival

The Ecologist journal drew encouragement from the work of the Club of Rome and issued a "Blueprint for survival" (January 1972), calling for a Movement for Survival, "a national movement to act at a national level, and if need be to assume political status and contest the next general election." The manifesto was supported by 33 eminent scientists, mostly in the life sciences. On top of the now familiar predictions of the disruption of ecosystems, the failure of food supplies, the exhaustion of resources, and the collapse of society within the lifetimes of our children, the manifesto called for the halving of Britain's population over the next 100 years to a level where Britain can grow her own food. Organic fertilisers should replace inorganic fertilisers. There should be taxes on raw materials and subsidies for re-cycling processes. Social accounting should include ecological costs. Habitation, social and economic life, and government organisation should be decentralised into neighbourhoods of 500 people, grouped in communities of 5000, in regions of 500,000, with as much as possible of daily life contained within localities. The keynotes of industry should be durability and craftsmanship, with work being for the community rather than profit. The manifesto knits the whole

programme together in a critical path network.

It all sounds rather pleasantly pastoral. Elements of the manifesto like the clearance of derelict land and subsidies for public transport are already in party programmes, and others will find their way in. The prognostications of the manifesto may be no better founded than were those of Marx, but that does not stop us looking at the political programme as such.

It is not so much the details of the programme as the emotional force behind the concern for the environment that we should consider, whether it is organised in the movement for survival or in other ways.

4. the politics of the environment

Concern for the environment in Britain is beginning to develop some of the feeling of the early days of the Campaign for Nuclear Disarmament. There is first the reality of the problems, and the uneasy conscience of established leaders about issues on which it is impossible to have a complete solution. There is the threat to the survival of mankind itself. It is a good story for the mass media. There are single minded enthusiasts. Westminster Central Hall is easily filled with an excited audience to listen to Paul Ehrlich the American ecologist give his message. Non-returnable bottles are piled up round the Schewepes head office in London. It cannot be long before the first march and rally in Trafalgar Square. It will include lead poisoned workers from Avonmouth, Peter Scott, ex-Conservative candidate and director of the Wild Fowl Trust, trade union leaders uneasy as to whether they should really be calling for a halt to economic growth, old age pensioners who want to do their bit for survival before they die, a contingent of Fellows of the Royal Society, dedicated school teachers thumbing through their teachers' guide to abortion practices throughout the world, many concerned young men and women, and Vanessa Redgrave.

The environment is already a subject that crops up at local Labour Party meetings, and naturally at Preservation Societies in Conservative rural England. But there is a long way between this and the capture of the mass vote at the conferences of the political parties. It seems rather unlikely that major manual trade unions would go the length of satisfying environmentalists by seeking to halt economic growth, and halve the population over the next hundred years. If the cause were to spread, it is more likely that it would be by capturing the support of some professional groups, perhaps the British Medical Association, and then spread through nurses and teachers to the white collar trade unions for whom halting economic growth conveniently became a matter of restoring wage differentials.

The real tragedy would be if it ended as the Campaign for Nuclear Disarmament did, with prominent supporters quietly

joining a new Labour government and swallowing the policies they had campaigned against, with none of the fundamental issues resolved. The only legacy left would be the souring of relationships, the disillusionment of another generation, the weakening of the Labour Party, and the distraction of politics from effective policies for a decade.

The effective way to handle issues on population, pollution, resources and the environment is to think through the issues, sort out the wheat from the chaff in the debate, and then put forward clear Labour Party policies for dealing with real and soluble problems. I have tried to go through the issues, and now suggest the policies.

POLICIES FOR THE FUTURE

These policy proposals are put forward as policies for the Labour Party in the UK, but in a European context. Similar policies may well be appropriate in other European countries. The policies which are practicable and appropriate will be different in the USA, USSR, Japan and the developing countries, since it is necessary to take into account the political, social and economic background in each country.

population

Birth control facilities should be available free on the National Health Service. Clear direct instructions on birth control methods should be given in schools, in the context of lessons on human relations. The Roman Catholic position can be understood and respected. If the issues are put honestly and tactfully it is unlikely that there would be opposition from the hierarchy in Britain and any pressures from Catholics within the Labour Party can be sympathetically withstood. They would not vote for free birth control, but the Conservatives would be unlikely to vote against. It would not be sufficient to offer birth control facilities on the National Health Service with a charge, because it is where a charge would be a

deterrent that birth control would be most needed. This policy naturally assumes progressively reduced Health Service charges for other services.

There should not be any suggestion of setting population targets because other policies should enable us to provide well for whatever population we have. But there should be every encouragement to people to bring into the world only those children they wish to have. In fact it seems likely that the average size of the completed family in the UK and other European countries has already dropped below the replacement rate which would keep the population stable in the long run. But it is right to recognise the problem of population generally, and let public opinion and personal preference and belief express itself.

pollution

1. The long established Alkali Inspectorate now responsible for some aspects of pollution should be reconstituted as the Pollution Control Service, responsible for inspection and enforcement of legislation, and for monitoring and avoidance of hazards to the health and safety of people, and to the environment. It should have a high calibre scientific staff, and should be responsible for government laboratories concerned with pollution. The Nuclear Inspectorate would deal similarly with nuclear hazards.

2. Every industrial establishment should have a joint management-trade union Health and Safety Committee which should deal also with environmental effects. The local authority would be entitled also to appoint a member of the committee in view of effects on the local community. The committee would be entitled to call at any time for an investigation of any matter by the Pollution Control Service the report of which would be published.

3. Legislation should lay down a time table for standards of control on engine exhaust fumes, for lead free petrol, and also for tighter noise control.

4. Support should be given to international regulations on industrial effluents, but any delay in international agreements should not delay legislation in the UK.

5. Local authorities should receive increased subsidies for installing complete rubbish processing plants, for the recovery of worthwhile scrap and the reduction of the remainder to a form in which it can be used immediately for filling or building. Such plants would be subject to control and inspection on their own effluents.

6. The construction of sewage treatment plants should be accelerated with an early end to the discharge of untreated sewage off shore and into rivers. Measures to eliminate river pollution should be accelerated.

7. Legislation should be introduced to control the use of packaging materials and containers with a view to ensuring the most economic use of resources, avoiding squalor, and taking into account the cost of disposal. The framing and administration of regulations would be the responsibility of the Pollution Control Service.

8. Much of the effect of pollution depends on the pattern of life and structure of the environment. For example an urban environment with much commuting causes more pollution and disturbance from traffic than an urban environment with minimal commuting. Pollution should be considered along with other environmental effects in urban structure plans, and the development of the urban environment generally.

9. The general principle should be accepted that the polluter pays the costs of pollution, including any effect on the environment. That is "external costs" should be made "internal."

resources

1. A Resources Research and Development Commission should be constituted to carry out the long term research and development on the supply, processing and re-cycling of those fuel and mineral

resources which may be needed in the future beyond ten to fifty years when the availability and relative costs of present processes will have changed greatly from present levels.

The initial task of the Commission, which will take some years, will be to study factors which will determine material needs, and formulate research programmes which may be needed to meet them. These will be research programmes which would not profitably be undertaken by nationalised or private industry because of the limitations of discounted cost benefits discussed above, but which nevertheless because of the length of the research needed should be initiated now. They will necessarily be high risk programmes, but they should be as rationally based as possible.

Since the subject matter of the research would necessarily lie well outside the technology of existing industries, it would not generally be appropriate for these industries to conduct the research, but where they are best qualified to do so they should on contract to the Commission. It will sometimes happen that the research eventually intended for one industry will more nearly match the current technology of another. Arrangements should be made for any direct industrial applications that arise, but generally speaking the research will establish practicalities which will need more predictable and specific development by industry when needs arise.

Encouragement should be given to other countries to set up research programmes with similar objectives, because a diversity of effort and point of view is needed to secure sufficient successes in a necessarily speculative field. The separate national efforts should be in touch with each other, and duplication avoided by agreement, but any suggestion of central control should be avoided as it would reduce the diversity in planning and analysis which is essential. In particular the effort should not be left to the US and USSR, nor to a single programme undertaken in the EEC.

Provided the quality of the research is

high and the attempt sustained to make it as relevant to future needs as possible, the volume of the research should build up over ten years to not less than £20 million per annum in the UK and should not drop below this level. It would be a possible continuing mission for the Atomic Energy Research Establishment at Harwell, which has been in need of some fresh and important mission it can tackle well.

While research of this kind is likely to be expensive needing large concentrations of effort to produce entirely new technologies, the study needed to raise good questions about the future is relatively inexpensive, and a variety of institutions such as the Science Policy Research Unit at Sussex University should be established and encouraged, each with its own experience of the present and approach to the future.

2. A full and detailed picture should be built up of national and world wide reserves, stocks, flows and prices of strategic materials. Since this can only cover distant future supply if short term variations and their causes are first taken into account, a fairly detailed up to date inventory is needed. This will provide the basis for more satisfactory studies of resource utilisation and its economics, which will in due course provide the evidence for any policies that may be needed on utilisation. This work is well defined though technically difficult and it is necessarily for common use between countries, so it would be appropriate to do this at EEC if not UN level. UK statisticians and Professor Stone in particular have taken a leading part in the development of the UN standard system of national accounts and they would also be able to make a useful contribution on resources.

developing countries

It should be accepted and made a basis of planning that the population of developing countries will double from 2,500 million to 5,000 million by the end of the century and may double again in the next century before levelling out. The

cause is reduced mortality and this can only be welcomed by civilised men. While every assistance should be given with spreading birth control, population is not the major problem in developing countries: it is poverty. Population increase has a long term effect in developing countries in reducing income per head, but likewise economic growth has a long term effect in reducing the birth rate. So the priority must be economic growth, with the reduction of the birth rate a part of this objective.

Aid, trade, and reciprocal development are the means by which developed countries can help. Aid in money and technical assistance should be given greater momentum. In particular in the context of this subject, research and development policy aimed at the long term future should take into account the position and needs of developing countries which will be a very major factor in the environment of developed countries in the long term. The developing countries will want to trade with developed countries, and any attempt at self sufficiency on the part of developed countries would restrict the growth of the developing countries. Reciprocal development goes the step further of matching the growth of developed countries to that of developing countries. Labour intensive industries are closed down because imports are cheaper, and new occupations in the service sector and other industries should be opened up for the displaced worker. If the development is to go smoothly and be socially and politically acceptable, improved methods of economic management are needed in the developed countries, along with appropriate employment, training and industrial policies.

economic growth

The growth of GNP is not in itself a sufficient objective for economic policy. Bearing in mind that GNP includes personal services of all kinds, that GNP bears no necessary relationship with the consumption of any specific material or group of materials, nor with any particular effect on the environment, the continued growth

of GNP however is needed to meet the many human needs in all nations, including provision for a rapidly expanding population for the next 50 to 100 years. In practical human and political terms it is much easier to redress serious inequalities, and to provide for new needs within nations and between nations if men feel their own conditions of life are improving, and this is roundly though inadequately expressed in terms of a higher GNP per head, particularly when under the proposals on pollution external environmental costs are charged internally. However the objectives of economic policy should be stated in terms of the priority to be given to consumer expenditure, specific items of public expenditure, full employment, and the avoidance of inflation rather than in terms of maximising GNP.

In order to minimise the imbalance and disturbance in society during a period of major social and industrial change, an effort should be made to carry the management of the national economy to a higher level of sophistication, so that disturbances are not gratuitously introduced. This will certainly require the fuller development and applications of models and the flow of information, so that specific economic policy changes can be directly related to the priorities decided (see Jeremy Bray, *Proposed structure for a simple control model of the UK economy*, 1971). However the best that can be hoped for, and that would in itself be a considerable improvement, is that the process of economic management would not aggravate the internal adjustments that still have to be made within the economy.

Micro-economic policies in the creation of new jobs, industrial training and retraining, urban renewal and other public expenditure programmes should be shaped bearing in mind the needs of local communities as a whole. In the course of rapid social and industrial change, one community will lose employment, another need a new public transport system, a third will have to catch up in higher education, a fourth will have to spend heavily to clear up industrial squalor, and in every case the local community will have its own stresses

and its own values. Public administration should be as sensitive as possible to local considerations and this can only mean the close involvement of the local community in shaping their own environment, and giving them the means by which they can do so effectively. Local authorities should have a large role in making economic growth human (see Jeremy Bray, *Decision in government*, Gollancz 1970).

policy as a whole

Policies on population, pollution, resources, developing countries, and economic growth cannot be pursued in isolation from social, economic and foreign policy as a whole. In his latest work on the environment (*The closing circle*, 1972), Barry Commoner concludes, "In our progress-minded society, anyone who presumes to explain a serious problem is expected to offer to solve it as well. But none of us—singly or sitting in committee—can possibly blueprint a specific "plan" for resolving the environmental crisis. To pretend otherwise is only to evade the real meaning of the environmental crisis: that the world is being carried to the brink of ecological disaster not by a single fault, which some clever scheme can correct, but by the phalanx of powerful economic, political, and social forces that constitute the march of history. Anyone who proposes to cure the environmental crisis undertakes thereby to change the course of history. But this is a competence reserved to history itself, for sweeping social change can be designed only in the workshop of rational, informed, collective social action. That we must act is now clear. The question which we face is how."

Getting action, the process of organising a consensus on a complex of interlocking issues is the stuff of politics. So effective action on the environment cannot be non-political or divorced from politics. There are great problems we do not fully understand, great issues we shall have to face, and we shall have to rally the vision and efforts of mankind as a whole. But it will be the whole man we must address in his family, his home, his livelihood, with all his different interests and his will

to shape his own future. The human race does not move except through the movement of individual human beings. So involvement in the democratic process, for all its faults, is not only the necessary means of action, but also by far the most effective.

appendix

the arithmetic of growth and substitution

The arithmetic of growth should not bemuse the reader. There are conditions where zero growth is inescapable, though they are scarcely those contemplated by its advocates. Consider the extreme case where in year τ goods are produced at zero cost, but in necessarily finite physical quantity. GNP can grow no further because of increases in physical production R , because R has zero weight in GNP. The value of personal services S can grow no further either because the GNP deflator is equal to the wage deflator. With year τ weighting GNP has only grown by $(S(\tau)/S(0) - 1) \times 100$ per cent,

THE VOLUME (v_i) AND THE PRICE (p_i) OVER THE LIFETIME OF A PRODUCT (i)

total output at time (t) is:

$$\sum_i p_i(t) v_i(t)$$

the rate of increase of output at current prices is:

$$\frac{\sum_i p_i \frac{dv_i}{dt} + v_i \frac{dp_i}{dt}}{\sum_i p_i v_i} \times 100\% \text{ p.a.}$$

the rate of increase of average price is:

$$\frac{\sum_i p_i v_i \frac{dp_i}{p_i}}{\sum_i p_i v_i} \times 100\% \text{ p.a.}$$

so the rate of increase of output at constant prices is:

$$\frac{\sum_i p_i \frac{dv_i}{dt}}{\sum_i p_i v_i} \times 100\% \text{ p.a.}$$

representing the increase in personal services available after the needs of physical production have been met. However, with year 0 weighting GNP may have increased far more, in fact indefinitely, if the path of successive physical substitution of technologies has followed an appropriate course.

model building methods

Computer models of complex engineering, or socio-economic systems are useful for trying out the effect of policies before applying them to the real system itself. Thus housing policy in a town can be simulated by a model of the numbers and type of houses and the size and ages of families occupying them. There are three stages in using models: the construction or estimation of the model, forecasting with the model, and policy optimisation or control. The forecasting is usually straightforward and all the difficulties lie in the estimation and control stages. Estimation theory and control theory are now highly developed, though difficult mathematical subjects with a growing number and range of applications, and a vast literature on both theory and application.

The methods used by Forrester and Meadows to which they give the rather general name "systems dynamics" however are simple. In considering a system, whether it is a company, urban decay, drug addiction, or population, the model builder reflects on the problem, and may talk to experts and read the literature. He then picks out perhaps six to a dozen key variables and postulates simple arithmetic relations giving the causal mechanism by which each variable is determined in the view of the model builder. These relations which Professor Meadows himself rightly describes as hypotheses are then programmed on a computer and set to run.

The computer may be set to run from some date in the past, and the forecasts compared with what has happened, where data is available or qualitative judgments can be made. Adjustments may be made

to the relationships to improve the fit to past data. Unfortunately the ability to predict over past data used in estimating or adjusting the model is a notoriously inadequate test of predicting ability over the future. Better practice is described below.

Forrester and Meadows frequently make the point that wide variation of parameter values often make little difference to system behaviour. This of course depends on the structure of the equation and where the parameter is. In a simple linear system a pole has only to shift from just inside to just outside the unit circle to make the system unstable. It is often impossible to distinguish between two perfectly plausible long term hypotheses by the examination of short runs of data with a high noise level. For example in examining whether in the UK the growth of "productive potential" depends on the level of unemployment—a crucial problem affecting the argument whether the economy should be operated with or without a significant margin of unemployment—I found the data insufficient to prove or disprove the hypothesis, though I myself believe, the growth of "productive potential" is faster with low unemployment (Jeremy Bray "Dynamic equations for economic forecasting," *Journal of the Royal Statistical Society*, 1971). The difficulties are particularly acute with second and higher order systems, where there are effects with both short and long time constants possibly of opposite sign. The difficulties are not eased by the choice of variables, multiple independent and dependent variables, and non-linear systems.

It can be argued that all these difficulties, which can and should be overcome in time, justify the short cut methods of Forrester and Meadows. But the methods can be used to prove anything. In Professor Meadows' world model (*The limits to growth*, figure 26), by putting a strong direct negative feedback from "total population" to "desired birth rate," a positive feed back from "mortality" in each age group to "desired birth rate," and a stronger and consistently negative feedback from "industrial output per

capita" to "desired birth rate", all of them credible, Professor Meadows could alarm us with the prospect of an immediate population crash rather than a population explosion. And a little playing around with non-linearities and further loops could make the model "fit" past data impressively well. It would of course be quite dishonest, but if the appeal is to be made, as it should, to data, then with the data available, particularly on population, much better methods than Forrester's and Meadows' can and should be used. The principle conclusion would be that it is just not possible to make good long term (more than 30 year) population models.

The argument then shifts to the role of the models in decision processes. Meadows puts forward a simplistic view of the decision process in society, comparing his model with the "very simple mental models" in the minds of decision makers at every level. However, the decision process, embracing certainly the ideas of individuals, is essentially the interaction of Cabinet Committee discussion, government statements, parliamentary debates, press comments, trade union executive committee discussion, boardroom decisions, popular reaction, elections, research and many other processes proceeding simultaneously on hundreds of different interacting issues. And this vast "computer model" which is the process of decision in human society is constantly interacting with the actual live course of events in real time. The adaptive capability of this enormously sophisticated "computer model" of which Professor Meadows is a part, has enjoyed unparalleled success, despite all the tragedies and triumphs of human history. It is this with which Professor Meadows' "world model" should be compared if comparison must be made. No one programmes this "computer model" (or perhaps they do!) but it is wholly legitimate to analyse its operation as an information and decision system.

I believe there is an important role for man-made computer models as "intelligence amplifiers" in many parts of the human decision system, and maybe there

is a place for global models. But there is a difference between saying that a particular global model may be better in some respects than some men's prejudices, perhaps some important men's prejudices, and saying that the whole human decision process will work better if the dictates of this model are followed. Indeed the model could be "better" than any individual's preconceptions yet be disastrous if applied in the whole human decision process. As it is I think his model, by its methodology is rather too near Professor Meadows' preconceptions for comfort.

The most extensive, painful, but instructive experience of model building in socio-economic systems is in econometrics. Good practice here is to fit relationships to data up to year N , and use them to predict for years $N+1$, $N+2$. . . then update the relationships using data up to year $N+1$, and predict for years $N+2$, $N+3$. . . compare the actual values with the forecast values, and the actual errors of the forecasts with the statistically estimated errors. If the statistical distribution of the actual errors does not correspond to that of the estimated errors, then there is something wrong with the model.

In the control or policy optimisation phase likewise, at any point in time, given an optimisation criterion, an optimal set of policy changes can be computed. This will depend not only on the forecast with maximum likelihood, but also on the expected error of the forecast, and on the uncertainty of the constants in the model. In the following year or other time interval the whole process has to be repeated because the system has not behaved quite as expected.

Even this laborious process of checking cannot guarantee a sound model, but it certainly eliminates a lot of nonsense on the way, and also shows whether or not evidence exists in the data for a particular cause effect relation or optimal policy (see Jeremy Bray, "Dynamic equations for economic forecasting," *Journal of the Royal Statistical Society*, 1971 and *Proposed structure for a simple control model of the UK economy*, 1971 and also papers

by Aström, Bohlin, Box, Jenkins, Westcott, Mayne, Caines, and others). It can also uncomfortably upset the prejudices of the model builders.

Forrester and Meadows have replied to these criticisms as follows:

1. *The data is not available for the application of econometric methods to the global problems they are concerned with. In those sectors where data is available, such as agriculture and population, Meadows has used the regression results of others.*

Comment: Why not at least test these parts of the model rigorously?

2. *Estimation and control theory is more highly developed for linear and linearisable systems, and their equations are non-linear.*

Comment: Much of the estimation and validation process can be applied to their equations or improved versions of them.

3. *How can empirical estimation methods be used when we are only part way through the first transient response?*

Comment: No problem in theory, but the significance of estimates depends on the structure of the equation and the noise.

4. *The world model is imperfect but it only needs to be better than those which would otherwise be used. What do you think of the mental models now being used for running our nations and the world? Produce a better model or your criticisms are frivolous.*

Comment: This is rather like showing a man with a heart condition a synthetic heart to be implanted in him, and when he complains about its obvious leaks and failure rate, telling him he must take it or make a better one. He may feel safer with the one he has got. I gave my own proposals in the section *Policies for the future*.

There is no harm in the methods of Forrester and Meadows provided they are recognised for what they are—a

means of articulating the intuitive judgments of the model builder, conditioned by his subjective preferences for the future.

fabian society the author

The Fabian Society exists to further socialist education and research. It is affiliated to the Labour Party, both nationally and locally, and embraces all shades of Socialist opinion within its ranks—left, right and centre.

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Enquiries about membership should be sent to the General Secretary, Fabian Society, 11 Dartmouth Street, London, SW1H 9BN; telephone 01-930 3077.

Jeremy Bray was MP for Middlesbrough West 1962-70 and Parliamentary Secretary in the Ministry of Power and the Ministry of Technology. He wrote *The new economy* (Fabian Tract 362) and *Decision in government* (Gollancz 1969). He was Chairman of the Fabian Society in 1971. He is one of three British members of the Club of Rome, and co-director of a research programme in London University on the application of control theory and systems analysis to economic management and is also Deputy Chairman of Christian Aid. Since losing his seat in the 1970 election he has been Personnel Director of Mullard.

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