

FORECASTING THE FUTURE

Every day there are 80,000 more people on the earth.
In another 50 years the world population will be four billion
—a hungry four billion. And in 100 years?

WE NONE OF US CAN HELP hoping that when anyone undertakes to prophesy the future, the facts will prove him wrong. I share this taste myself, and yet it may appear that I too am starting to prophesy. In fact I am going to try and do something much more modest. Forecasting is the word used for the predictions that the meteorologists make about the probable future weather, and this is the analogy I am going to follow. Through the reports he receives the meteorologist knows better than the rest of us what is happening in other parts of the world, and though he is very conscious that there are a great many things he does not know, with the information and experience that he has, he is in a good position to forecast the *probabilities* of future weather.

The present director of the British Meteorological Office, Sir Graham Sutton, recently wrote an article which describes the situation admirably. In making his forecast the meteorologist is doing the same sort of thing that a player does when he bids his hand at the game of bridge. If he were required to predict what tricks he would take with absolute certainty, he would not get very far; for example, if he had the ace and king of a suit he would only be *absolutely* certain of two tricks if that suit were trumps.

In fact, he does not declare that he will get two tricks, but he makes the estimate that he will probably get say eight or nine tricks. He reckons that this is the probability; he knows that one or two of his strongest cards may possibly fail to win the tricks he expects, but then he knows that this will most likely be compensated by tricks from some of his other cards he was not so confidently counting on. He estimates probabilities, and if he is an experienced player he is usually not far from right in a general way, even though some of his details may be wrong.

That is the sort of prediction that the meteorologist makes about the weather, and it is the sort of prediction

that I am going to try and make about the future prospects of the world.

I want to work out this analogy with meteorology rather further. There are two separate branches of that subject, called respectively weather-forecasting and climatology. In forecasting, the meteorologist uses all the detailed knowledge of conditions in the world at the present moment and applies to them the laws of mechanics and also a good deal of personal experience and personal judgment, and from all this he says what things will be like twenty-four hours hence, and he usually gets it fairly right. He also tries to do forty-eight hours, but has a good deal less confidence about that, because as time goes on the things he does not know get proportionately more and more important.

The subject of climatology is quite different. In this there is no forecasting of what things will be like tomorrow, but instead there are general statements such as that this place will be a desert, that place a tropical jungle, while yet another one has a climate which will support good agriculture most of the time. It is much less detailed but a much more general subject, and it is one that must always be in the back of the mind of the forecaster when he makes his predictions.

I am going to try and make a forecast for the fairly close future, say fifty or a hundred years, but before coming to that I must say something about what I call the climatology of my subject, because that really is a deeper part of it. I will begin this by taking a simplified example. Suppose that somewhere in the ocean there is an island that is completely isolated from contacts with other parts of the world. I am told, in a general way, such things as what its climate is, how hot it is, how much rainfall it has, and what the soil is like. I am also told a little about the inhabitants and their state of culture—say that they know about the use of metals, but have only rather inferior food crops.

by
SIR CHARLES DARWIN

With only this information I could say a great deal about the life of the island; for instance, I could make a very fair estimate of the numbers of its population. To do this I should take as my principle that the normal way that any living species of animal survives is by producing too many offspring, of which only a fraction survive. With many lower animals the excess is often enormous, with a million produced of which only one may survive, but the same rule holds for the higher animals, too; the excess production is much less, but it is still there.

The same rule applies to man. The families on the island will mostly each produce several children and the parents will do all they can to keep their children alive and to bring them up. Now, simply to replace the numbers of the two parents, two children would be enough, but most peasant families surely produce more than two children, so that there is a tendency for the population to increase.

What is it that determines the total population then? The whole island will have come under cultivation, and it will be yielding all the food it can. Through the uncertainties of the weather, in some years there will be good harvests and in some years bad, and the peasants will accumulate a certain amount of reserve food against the bad harvests. But sometimes there will be two or three bad years running, and then they will get short of food, and perhaps two or three times in a century there may be four bad years running, and then there will be real famine. It will be these occasional famines that will determine the average number of people on the island.

This is not the sort of thing we see now anywhere in the world, but, for example, it was what used to control the population of India until about a hundred years ago. All this may seem rather obvious, but it is worth noting that we can say with some confidence that one of the most important features in the life of the island



will be famines at the rate perhaps of three a century, and it is these famines that will mainly determine the number of people on it.

Now, suppose that the island has settled down into this state, but that its perfect isolation is broken by a ship which is wrecked on its coast and in which there happens to be a cargo of potatoes or some such crop. The new crop will give a much better yield than any of the previous food crops of the island, and it will be gradually adopted by the inhabitants. Every acre of ground will now yield twice as much food as it did previously.

Man is a rather slow breeder, so that the most conspicuous thing first to be noticed is that there is plenty of food for everyone. The bad old days of famines have disappeared and the population starts to increase. The historians of the island will record that it is a Golden Age, with an easy life very different from that of their parents. They will probably have a very human failing; they will forget about the cargo of potatoes, and they will claim how clever the present inhabitants are in overcoming the difficulties of life that used to afflict their ancestors.

This Golden Age will go on for a century or two, while the population increases to double its previous numbers, but at the end of that time the old troubles will begin all over again, because now again the yield of the crops will only be about enough to provide food for the new numbers of the population. There will be

the old trouble over occasional successions of bad harvests which will produce famines again, and this will limit the population in the same old way. Something very like this was what happened in Ireland in the 1840's.

I have developed this imaginary example at some length, because it has a most important application to the present condition of the whole world. The world is just now in a highly abnormal condition, as is shown by the consideration of the increasing numbers of humanity. We are living in a Golden Age, which for man may well be the most wonderful Golden Age of all time. The historians have made fairly reliable estimates of the numbers of world population at different periods of history, and these numbers reveal it rather clearly. At the beginning of the Christian era the population of the world was about 350 million. It fluctuated up and down a bit, and by A.D. 1650 it was still only 470 million. But by 1750 it had risen to 700 million, and now it is 2500 million. That is to say that for 1700 years it was fairly constant, and then in 200 years it has suddenly quadrupled itself.

The increase of world population is still going on at a rate of doubling itself in a century, but it is a most menacing thing to think about. Year in year out the increase is at a rate of about one percent, and this means that every day there are 80,000 more people on the earth. That is the daily difference between the number of babies born and the number of people dying. Even those who are not conscious of this fact are unconsciously used to it, and accept it as natural, but it quite obviously cannot go on forever like this, and the most crucial question for us all is how long it *can* go on.

An abnormal state of affairs

This will be the main thing I shall want to discuss, but to see how abnormal the present condition is, I will imagine for a moment that it was the normal condition and I will look at the consequences that would follow. If the population were going to be able to double itself in each century, it would only be two thousand years before it was a million times what it is now, *and two thousand years is only a short time in the period of human history*. As a matter of simple arithmetic, if the population were a million times what it is now, there would be just about standing room on the land surfaces of the earth, but not room for the people to lie down! This would obviously be a fantastically impossible state of affairs, but it illustrates what an abnormal state the world is in just now with its population increasing at this rate.

It is obvious what has produced this present abnormal state of the world. There have been two chief causes. One of them was the discovery of the New World, much of it barely inhabited, which has provided enormous areas for possible expansion, in particular for the white races. The other is the development of

science, through which it has been possible for man to find ways of producing a great deal more food, and in particular of transporting it from the places where it is produced to the places where it is needed. The Scientific Revolution, which began about three hundred years ago, must rank as one of the two really great episodes in human history; the only thing comparable with it in importance is the Agricultural Revolution. This happened in about 10,000 B.C., when man learned how to become a food grower instead of merely a food collector.

The climatology of humanity

I want to give more consideration to what I have called by analogy the climatology of humanity. As I have shown, the present time is very abnormal, and so present conditions cannot be of much help in this. Are there any deeper principles that can be used? I think there are sufficient of them for us to be able to say a good deal about it. The first point is that the climate—and here I mean the actual climate—of the earth has been fairly constant for something like a thousand million years at least. It is eminently reasonable, then, to expect that we can count on it for say at least one more million years. Here is one constant datum we can use in our estimates.

A second thing is the finite size of the earth, and the fact that its whole surface is now fairly well known. This knowledge, of course, is quite a new thing; even a century ago there were great areas in Africa and South America that were hardly known, and they might have held something quite unexpected. There may, of course, still be many things to be discovered; there might possibly be other gold fields like the South African one, or perhaps great ore-fields of other, more practically valuable metals, but we can now be fairly confident that there is not room on the earth for anything, at present unknown, on a scale that would materially alter the possibilities of our ways of life.

The third principle we can use is much the most important. It is human nature. The characteristics of mankind are conveniently, though only roughly, divided into two parts, which have—as I think, rather clumsily—been called nature and nurture. Nurture signifies the environment in which people grow up and live, and it is, of course, what determines most of their day-to-day behavior. It is thus immensely important in making the short-term forecast, but the conditions of life have varied enormously from century to century, and they will surely continue to do so, and therefore nurture gives little reliable help in estimating what the long-term character of human life will be.

The matter is quite different when we consider nature. Here, as we know from the study of many types of animals heredity plays a predominating part, and so for as long as any of us can really care about—say a hundred thousand years at least—we must accept that man will be just like what he is now, with all his

virtues and all his defects. There is simply no prospect at all of any millennium in which pure virtue triumphs, because that is not in the nature of the species *Homo Sapiens*. In so far as heredity determines man's behavior, we can take this as a constant in making our predictions about his destiny.

The most important human characteristics, for my present purpose, are the deepest instincts which human beings have. These are the instincts which are directed towards the perpetuation of the species. One of them is the fear of death, shared by such a vast proportion of humanity that even under the most dreadful catastrophes very few people do actually commit suicide. This instinct serves to help in keeping the individual alive.

Equally important are the instincts serving to reproduce the species. In man and in the higher animals this characteristic falls into two rather separate parts, the sexual instinct and the parental instinct. Among the animals these two instincts suffice to perpetuate the species, and until very recently the same has been true of man. Things have, however, been changed by the developments of methods of birth-control, which have revealed a curious gap in our equipment of instincts.

Most people feel the sexual instinct with a force almost as great as the fear of death, and most people, when they have got children, have a very intense instinct to care for them and bring them up, but a good many people lack the desire to have children in advance; or at any rate, if they have the instinct, it is very much weaker than the other two. The parental instinct seems to be evoked mainly by the presence of the children, and thus it has come about that the sexual instinct can be satisfied without leading to the consequence it ought to have of ensuring the creation of a next generation. This third instinct, coming between the sexual and the parental, may be called the procreative instinct; it is much weaker than the other two, and indeed seems to be absent in a good many people.

Long-range forecast

The really important condition essential for human life was first fully described by Thomas Malthus in 1799, in his celebrated book, *An Essay on Population*. In this he drew attention to the necessity of a balance between the numbers of a population and the food it will require. He pointed out, with numerous examples, that there is a tendency for population to increase in geometrical ratio, whereas the area from which they will derive their food cannot possibly increase in this ratio.

Malthus could not be expected to have foreseen the consequences of the Scientific Revolution, which was going for a time entirely to upset the balance between the two sides of his account. During the 19th century it

was possible to take the view that the disasters foretold by him had not occurred and that, therefore, his principles had been proved wrong.

This comfortable view overlooked the fact that all through that century population was, in fact, increasing geometrically, just as he had said, but for a time this was being balanced by the opening up for agriculture of barely inhabited regions in the New World, from which the newly invented railways and steamboats could convey the food to the places where it was needed.

It was the developments of the Scientific Revolution that for a time upset Malthus's balance, but now once again the balance is coming into effect, because we are now very fully conscious of the finiteness of the earth. There are few more regions that can be opened out for agriculture, and once again we have to face the problem of how our rapidly increasing populations are to be fed.

Population and food production

I have noticed that most people, when for the first time they face the population problem, at once think about the possibilities of producing more food. They first think perhaps of the fields we all notice here and there that are not being properly cultivated. Then they may think of improved breeds of plants that will produce two or three crops a year instead of only one. Then there is the possibility of cultivating the ocean. And there is the *Chlorella*, an alga which might be grown on a sort of moving belt in a factory; it can produce proteins perhaps ten times more efficiently than the garden vegetables do, but unfortunately at a hundred times the cost. Finally with the rapid progress in our knowledge of chemistry, it is not to be excluded that one day the foodstuffs necessary for life will be synthesized in factories from their original elements, carbon, nitrogen, phosphorus and so on.

All these things are possible, and I do not doubt that some of them will be done, but to accomplish them is no help, because of the central point made by Malthus, that there has to be a balance between food production and population numbers. Until population numbers are controlled, it will always continue to be true that, *no matter what food is produced there will be too many mouths asking for it*. New discoveries in the way of food production may make it possible for many more people to keep alive, but what is the advantage of having twenty billion hungry people instead of only three billion?

In the light of these considerations it seems to me that the food problem can be left to look after itself and that all attention must be given to the other side of the balance. Can anything be done about it? Frankly,

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though perhaps for a short term something might be done, in the long run I doubt it. My reason is this. Nature's control of animal populations is a simple, brutal one. In order to survive, every animal produces too many for the next generation, and the excess is killed off in one way or another. It is a method of control of tremendous efficiency, and during most of his history it has also applied to man. To replace a mechanism of this tremendous efficiency it is no use thinking of anything small; the alternative we must offer, if we want to beat nature, must also be tremendous.

The difficulty is even greater than it appears at first sight, because there would be an instability about any alternative scheme deliberately adopted. Thus, suppose some really good solution was found, and was adopted by half the world. For a generation or two this half would prosper. Its numbers would stay constant and the people would not be hungry, but all the time the numbers in the other half of the world would be increasing, so that in the end they would swamp the first half. That is the terrible menace of the matter; there is a strong survival value in being one of those who refuse to limit population.

The most easily imagined solution would be the establishment of some *world-wide* creed prohibiting large families, but when we reflect how many rival religious creeds there already are, all largely subsisting on account of their mutual differences, there seems little hope for any universal creed which would permanently limit population in this way.

It is very much to be hoped that a great deal of thought will be given to this matter on the chance that someone may hit on a solution, but I must repeat that nature's method of limiting population is so brutally tremendous that it can never be replaced by any such triviality as the extension of methods of birth control. It calls for something much more tremendous if there is to be any prospect of success.

Short-range forecast

I have said all I want to say about what by analogy I called climatology, and I will turn to weather forecasting; that is to say, I will attempt to forecast what will happen in the near future of say 50 or 100 years. I would remind you of the description of forecasting that I gave at the start, that it is like declaring a hand at bridge, where one makes a general estimate on incomplete data and one only expects to be right in general and not in detail. The weather forecaster can only do his work by receiving a great deal of information coming from all over the earth, and I need similar information for my forecasting. I have derived this from a fairly wide variety of sources. One of the most useful sources was a book entitled *The Challenge of Man's Future*, by

Prof. Harrison Brown of Caltech. As a geochemist his study of the prospects of shortages in the future supply of various minerals led him on to study other shortages facing the world. A second book, *The Future of Energy*, by P. C. Putnam, deals very usefully with a narrower subject, the rate of exhaustion of our present fuel supplies and the various possible alternatives to them. Another very valuable source of information came from attendance at the UNO Conference on Population which was held in Rome in 1954. I may also refer to a book, *World Population and Resources*, recently composed in England by the organization known as P.E.P.

Cautious estimates

As I have already shown, we have been living during the past hundred and fifty years or so in a period of history of quite unique prosperity. Expert demographers estimate that our present two and a half billion population will have become four billion by A.D. 2000 and six billion by A.D. 2050. These estimated increases will be fairly equally distributed among the different races and among the social classes in each. For example, one of the most rapidly increasing groups at present consists of the moderately well-to-do Americans, who are increasing at a rate faster than the peoples of India or Japan. I may say that these estimates should be regarded as cautious ones.

The first thing we may think of which might reduce the numbers is war, but most war is not nearly murderous enough to have any effect. Thus we should count as a really bad war one in which five million people were killed, but this would only set back the population increase for less than three months, and that hardly seems to matter. I doubt if even an atomic war would have any serious influence on the estimate, unless it led to such appalling destruction of both the contestants that the economy of the whole world was so entirely ruined that barbarism and starvation would ensue. There is perhaps some hope that man will be wise enough not to embark on such a war, but anyhow I shall refuse to consider it in my forecast.

Some people may feel that methods of birth control might upset the whole forecast. This is a most important matter, which must be considered. The proponents say a contraceptive may be discovered which would put in our hands the possibility of completely controlling population numbers. It is very possible that such a discovery may be made, and I hope it will, but I do not think it seriously affects the forecast. This is because of the time-scale in human affairs. Even if we already possessed the full knowledge of what I may call the "contraceptive pill," a good deal of time would be taken in building factories to make it on a scale large enough to provide pills for the whole world population and the world-wide distribution would take some arranging; but

there are other more serious troubles which would also have to be overcome.

It is hardly likely that the physiologists could be absolutely confident that such a drastic medicine would have no collateral effect at all, and to verify this, many years of experiment on a smaller scale would be necessary. For example, it would take two or three decades to verify that when the habitual users of the pill did decide to have children, those children would grow up into normal adults. It would be necessary to verify that there were no unforeseen collateral effects, such as a premature aging of the habitual user, or perhaps a special liability to some disease—I may quote as a parallel the liability of people exposed to X-rays to develop cancer a good many years later.

Furthermore there would need to be an enormous educational campaign, and the number of educators would have to be so vast that it would take all of a generation to train them, and therefore two generations for them to produce their results.

On all these counts I think it is safe to say that no large-scale effects could possibly be seen under two generations or so, and therefore the contraceptive pill—which in fact we have not got yet—would have little influence in affecting the forecast for fifty years, though it might for a hundred. But things are unlikely to be even as favorable as this; there are religious doctrines that might prohibit the use of the pill and there is a tremendous stock of unreasoning emotion in such intimate matters that would make a lot of unforeseeable difficulties.

A population of four billion

In the light of these considerations I see no escape from the estimate that by A.D. 2000 the world population will be four billion.

It is time to turn to the other side of the Malthusian account. Malthus only thought of actual food production as the balancing item, but since his day there are a lot of other things to be included which he could not have foreseen—such things as the supply of energy and the metals which are essential for the city life which alone can carry large populations.

First, the agriculturists at the 1954 Rome Conference on Population claimed that a doubling of food production can probably be achieved, but to do so everything has got to be exactly right. There must be no creation of dust bowls by the exhaustion of poor soils, and the stores of artificial fertilizers must not be distributed freely, but must be controlled so that they are only used in the places where they will give the most advantage. I am not competent to discuss this matter, but I do wonder how far this strict control will be possible.

In connection with agriculture I may refer to a thing of the recent past which is at least suggestive. Between

1947 and 1953 the world's agriculture made the most tremendous strides; in these seven years it increased by 8 percent, a truly wonderful performance, which we owe largely to the brilliant work of the scientific agriculturists. *But*—during those seven years the world's population increased not by 8 percent, but by 11 percent, so that the world was hungrier at the end than at the beginning. So, as I have said, I forecast there will be four billion people in fifty years from now, but I forecast that they will be hungrier than the two and a half billion we have now.

Now, to turn to other matters, Malthus needed only to think about agriculture, but we have to consider the provision of a lot of other things, because since his day the enormously increased numbers can only exist by living in large cities, and these demand all sorts of equipment like good roads, railways, water supply, electricity and so on. If some of these things could not be supplied it would be quite impossible to maintain the large numbers we have. So we must add to the right-hand side of Malthus's balance sheet things like energy and metals, and consider whether the supply of these will be adequate to keep us going for the next fifty years.

The prospects for energy

As to energy, as far as we can see the prospects are not too bad. There are only three sources which can provide power in quantities sufficient to be important. They are the "fossil fuels" coal and oil, nuclear energy, and the direct use of sunlight. Notice that water-power is not in the list; this is because the total quantity yielded, if all the rivers of the whole earth were fully exploited, would be only 12 percent or so of even the present energy developed.

At present, of course, practically all the power comes from coal and oil, and it is being used up at an ever-increasing rate. It is not possible to estimate the reserves with any great accuracy because it would be necessary to take some standard of the ease with which the coal can be won; for example, would it ever be worth while to mine a seam only a foot thick? But an estimate very definitely on the optimistic side predicts that the coal will be all gone in 500 years. Since it took some 500 million years to make the coal, it may be said—speaking only very loosely, of course—that we are living on our capital at the rate of a million to one. Is it surprising that we can create wonderful prosperity for a short time? Oil is won much more easily than coal, and it is expected it may at most last for a century.

The prospects for nuclear energy are good, but the construction of nuclear power stations will inevitably take a good many years. It has been estimated that at the end of 30 or 40 years something like a quarter of the power developed in Britain will come from uranium

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instead of coal. Even at the present rates of consumption of power this would still mean a very large demand for coal, and as the demand in fact is growing year by year, there seems little prospect of the coal situation improving. Indeed, I would not be surprised if there was going to be a rather awkward period for us in about 50 years, when the expense of winning the remaining coal has increased a good deal, while there are still not enough nuclear power stations.

These difficulties apply specially in Great Britain. In America the situation is much easier in respect to coal. It is being consumed at an almost fantastic rate here, but there would seem to be enough easily mineable coal to last you a century. I have called the rate fantastic, and this can be justified by the following consideration. In the history of the world man has burnt up a very considerable amount of coal in all, but half of this total has been burnt in the United States since 1920.

Favorable prospects

As far as we can judge in these rather early days there is not likely to be any shortage of uranium for many centuries, and there is also always the possibility that the fusion of deuterium into helium may be made to occur slowly instead of, as now, only in the form of a super-bomb. The prospects for the supply of energy are therefore rather favorable, but it must be noticed that it may make very considerable changes in our ways of life. Nuclear power units are likely to have to be very large, and this may mean that there will have to be far fewer small units such as motor-cars. This suggests that in the nuclear age the population will be concentrated in the great cities even more than it is now.

The energy arriving at the earth day by day in the form of sunlight is quite enormous, and if it could be turned into mechanical power it would supply many times over the needs of mankind. A square yard facing the sun receives energy at a rate of about a horse power, but this implies that a great area would be required in order to make any reasonable power station. It may well be that improving techniques will solve this problem, but there is certainly a long way to go. Indeed it is rather humiliating to know that at the present time the most efficient way of collecting solar energy is to plant a row of trees, let them grow, cut them down and burn them.

If the provision of energy is not necessarily going to be a great difficulty, the same cannot be said of many other raw materials, in particular many of the metals, though even the supply of such a common thing as fresh water is going to be a formidable problem. Of course, strictly speaking, the metals, unlike coal, are indestructible; once won they can be used again and again, but in fact there is always some wastage due to wear or to actual loss, and this wastage must be allowed

for. There has been the same enormous increase in the extraction of metals as of coal; in fact, of all the metal mined from the earth, half has been dug up in the last 30 years.

The possession of metals in great quantity seems to be essential for industrial development. It would appear likely that there simply is not enough of many of them, such as lead or tin or copper, to permit the underdeveloped countries to become industrialized on a scale at all equivalent to that of the highly developed ones. It is true that substitutes can often be found, but usually they will be inferior; for example, an electric transformer could be made with aluminum wires to replace the copper, but it would be less efficient. The underdeveloped countries which are trying to improve their industrial power are already handicapped in two respects. They lack capital, and they lack engineering experience, and to these difficulties must be added a third, the expected world shortage of constructional materials. So I forecast that at the end of this century industrialization will not have spread very greatly over the less developed parts of the world.

My general conclusion then is that in fifty years the population of the world will be four billion. They will be a rather hungry four billion, busily engaged in straining the resources of the earth to yield enough food, but they will not have succeeded very much in their present ambitions about becoming more industrialized.

I regard the forecast for a century with a great deal more doubt. The demographers forecast six billion for the year 2050, but my own guess is that the world will not have succeeded in yielding enough food for this, and that by then the world will have begun to go back into what I earlier called its normal state, the state in which natural selection operates by producing rather too many people, so that the excess simply cannot survive.

A gloomy picture

I fear this is a gloomy picture, and I ought to say that there are many people who forecast quite the opposite. They are the technological enthusiasts. They claim that whenever a shortage has declared itself the technologists have produced a substitute and that things will go on forever like that. To me they do not seem to appreciate the overwhelming importance and difficulty concerning the population numbers, and that is why I must disagree with them. If they are right and I am wrong the world can look forward longer than I expect to a continuance of the present era of prosperity.

I hope that they will prove right, and that I shall be proved wrong, but I must repeat my opinion that the central problem is that of world-population. I do not see any happy solution of this, but I earnestly hope that if many people face the difficulties, someone may possibly be inspired to find an acceptable solution.