ROLE OF SCIENCE IN ECONOMIC AND NATIONAL DEVELOPMENT*

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FOUR LEVELS OF ECONOMIC DEVELOPMENT

THE ultimate object of economic development must be to provide for all citizens an increasing supply of food, clothes, housing, drugs, books and other consumer goods, and of services such as education, care of health, cultural amenities, etc. This is the top, or final level of production. In India the first textile mill was established in 1817, nearly one hundred and fifty years ago, and India gradually became the second biggest producer of textiles, next only to America. The production of textiles did not solve India's problems of poverty, under-employment, lack of adequate facilities for education, care of health, etc.

We now realize that the production of any particular kind of consumer goods can be started in two or three years by *importing* machinery for its manufacture; and driving such machinery by *imported* diesel engines or motors, with the help of steam or electricity also produced by *imported* generators. But it is *not* possible to produce many kinds of consumer goods with imported machinery because there is not enough foreign exchange to do this.

The production of textiles or a small number of consumer goods does not itself lead to rapid industrialization and economic development. In India we have now realized tht we must make our own machinery, electric generators, motors, railways, trucks and other capital goods. To establish a minimum base for the production of capital goods including the manufacture of heavy machinery (to set up new steel factories or fertilizer factories) would take at least from 10 to 15 years. This is the second level of production for which planning must start 10 or 15 years in advance.

All consumer goods and all capital goods must be manufactured from domestic or imported raw materials (minerals, agricultural and forest or sea products). This can, however, be done only with the help of engineers, technologists, and technical labour power. To provide a sufficiently large supply of engineers, technologists, etc., it is necessary to establish and increase the number of training colleges and institutions, and to train the teachers for such institutions. This is the

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third level of supply which would take at least 15 or 20 years; that is, planning for this purpose must start 15 or 20 years in advance.

To avoid unnecessary imports, it is essential to make the best use of all domestic resources. How the raw materials and natural resources in each country can be utilized most effectively must be ascertained by applied scientific and technological research. It is, therefore, necessary to promote the advancement of applied research. Applied research, in its turn, must use the basic or fundamental scientific knowledge which is already available. It is, therefore, necessary continually to promote the advancement of basic or fundamental research. This is the fourth level. To establish a minimum base for scientific research would take at least one generation of 25 or 30 years. This is the most slowly maturing sector, and must, therefore, be given the highest priority.

The number of engineers, technologists and technical labour power must be planned to meet the requirements for the production of consumer and capital goods. The number of scientists working on applications of fundamental scientific knowledge may probably be increased in proportion to the number of engineers and technologists. In the case of pure or fundamental research, there is no such limit. Men capable of doing pure or fundamental research are rare in every country. The only wise policy is to provide adequate facilities for pure research for *every* single individual who has the ability to do fundamental research. This must be the aim in every country, large or small, advanced, advancing, or still under-developed. There cannot be any exception.

It is obvious that no single country, however big, can undertake research in all subjects or topics. Moreover, it is unnecessary because science is indivisible. Progress in one subject or in one country would necessarily promote progress in other subjects and in other countries. Each country, large and small, or advanced, advancing, or underdeveloped, must contribute to the advancement of science as a whole by making the best effort to promote scientific research, both applied and fundamental.

We thus have the fourfold logic of economic development. The final or top level of supply is that of consumer goods; the production of any single item can be established in two or three years but not of a large number. The second level is an adequate production of capital goods which would require from 10 to 15 years. The third level is an adequate supply of engineers and technologists; this would take 15 or 20 years. And, the fourth level is establishing sound traditions of scientific research, both applied and pure; this would take a whole generation of 25 or 30 years. This is the scale of priorities which we

adopted in India in 1955 at the time of preparing our Second Five Year Plan which began in April 1956 and ended in March 1961. These considerations make it clear that the production of an adequate supply of scientists and the creation of social conditions in which they can fruitfully operate is crucial to economic growth.

THE EMERGENCE OF MODERN SCIENCE

We have to go deeper to appreciate the full significance of science in the modern age. Four hundred years ago the generally accepted view was that the earth was at the centre of the world and the heavenly bodies were revolving round the earth; the position of human beings was unique and supreme; and the highest sanction of truth was divine revelation and abstract logical reasoning in the mind of man. This has been replaced by the idea of an objective world of physical reality of which all knowledge must be based on empirical observations and experimentation. Progress was at first slow in the 16th century. I shall recall only a few selected names to indicate the gradual transformation of ideas : in astronomy, Nicolaus Copernicus (1473-1543) whose book on "Orbits of Revolution of Heavenly Bodies", published in 1543, supported the view that the planets including the earth itself were revolving in orbits round the sun; Tycho Brahe (1546-1601) who supplied astronomical observations of unprecedented accuracy to make the next steps possible; Johann Kepler (1571-1630) who formulated the descriptive laws of planetary motion in "Cosmographic Mystery" (1597) and "The Harmonies of the World" (1619); Galileo Galilei (1564-1642) who made conscious propaganda in favour of the new philosophy of the universe in his "Dialogues on the Two Chief Systems of the World" (1632) and "Mathematical Discourses and Demonstrations concerning Two New Sciences" (1638); in anatomy, Andreas Vesalius (1514-64) whose book on "Observations on the Human Body" was published in 1543; in physics, William Gilbert (1544-1603) who in his book on "The Magnet", published in 1600, gave an account of observations based on "trustworthy experiments"; in physiology, William Harvey (1578-1657) who gave an account also based on observations of the circulation of the blood in his treatise "On Motion of the Heart" (1628); in mathematics, John Napier (1550-1617) whose discovery of logarithm supplied a convenient tool for computation; Rene Descartes (1596-1650), a philosopher, who contributed the powerful concepts of co-ordinates for geometrical representation, of mathematical functions, and of change in the motion of matter as a fundamental factor of the physical world; and also, Francis Bacon (1561-1626), a philosopher also born in the 16th century, who firmly stated that the only true method in science was to proceed from particular sense observations to wider generalizations (*Novum Organum*,

Book I, xix), and clearly recognized that "the true and lawful goal of the sciences is...that human life be endowed with new discoveries and power."[1]

The concept of an objective world of physical reality gradually took firm shape in the 17th century in the hands of a large number of gifted astronomers, mathematicians and scientists. To indicate the trend, I may recall a few names from among those who were born in the first half of the century: Pierre Fermat (1601-65), Christian Huygens (1629-95), Blaise Pascal (1623-62), Robert Boyle (1627-91), John Ray (1627-1705), Robert Hook (1635-1703), Isaac Newton (1642-1727), and Gottfried Wilhelm Leibniz (1646-1716). The rate of advancement of science increased progressively in the 18th and the 19th centuries, and during the last few decades has opened new frontiers with almost unimaginable possibilities.

THE INDUSTRIAL REVOLUTION AND THE RISE OF CAPITALIST POWERS

I must also refer, again very briefly, to the beginning of the industrial revolution in the 18th century, first in spinning and weaving, next in iron and steel and then in electricity in the 19th century, which stimulated the growth of the bourgeoisie and the capitalist class with their aspirations towards social and political power. The spread of the scientific outlook also prepared the ground for the age of reason and the French Revolution towards the end of the 18th century; this led to the growth of nationalism, in its modern sense, in Europe in the 19th century.

The industrial revolution increasingly replaced human and animal power with steam or electricity to drive machinery for the production of both consumer and capital goods. This development of engineering techniques led to a close linkage between science and technology in the 19th century. Since then industrial development is being sometimes stimulated by a new scientific discovery, or scientific discovery is being stimulated by industrial needs.

Very soon, there was a revolutionary rise in the level of living in the advanced countries of West Europe and North America. For the last five or six thousand years of human history the average per capita share of the social product had remained more or less constant or had fluctuated within narrow limits all over the world. The industrial revolution changed all this. Over the last century and a half, new trends of rapid economic growth appeared in the Western countries.

1. Quoted by A.R. Hall in *The Scientific Revolution, 1500-1800*, London, Longmans, 1954, p. 165.

To look back half a century, scientific research and its application to industry lifted the living standard of the West to a level far above those of the rest of the world. Moreover, because of the advance of science, technology and industry, the military power of the West became invincible; and because of such military supremacy, the capitalist West had driven the rest of the world either into direct colonial rule or into conditions of economic and political subjugation.

THE OCTOBER REVOLUTION AND THE RISE OF SOCIALIST POWERS

Then in 1917 came the October Revolution in Russia. Since then, again through the promotion of scientific research and the application of science and technology to industry, the U.S.S.R. and other socialist countries are making rapid economic progress; are improving continually and rapidly their level of living and have also broken the monopoly of scientific and technical knowledge of the Western countries. The indisputable military supremacy of the Western capitalist countries has also vanished.

This is a most significant fact of the present time. The increasing parity, between the Western capitalist countries and the socialist countries, in science, technology, industry and military power, has extremely important consequences. First of all, because of the invention of atomic and nuclear weapons of unprecedented destructive power, it has become absolutely necessary to avoid a nuclear war which would be suicidal to both sides and to the whole world. That is, there must be co-existence of both the Western capitalist and the socialist powers.

Secondly, it must be also recognized that during this period of co-existence, the most dangerous areas for possible conflicts between the two blocs (usually called "East" and "West") are the less advanced countries of Asia, Africa and Latin America. Even if there is disarmament, war may start with primitive weapons in the less advanced countries, and may lead to the manufactures of atomic and nuclear weapons and thus add to the risk of a general nuclear war. Consequently the very existence of the less advanced countries is a continuing threat to peace. A rapid transformation of the less advanced countries into modern industrial and viable economies is therefore an essential condition for enduring the permanent peace.

Rapid industrialization of all the countries of the world is thus indispensable for co-existence and for permanent peace. This is the great task in front of us which must be achieved with the promotion of science and technology all over the world, and with special urgency in

the less advanced countries. It is, therefore, necessary to examine still more closely the role of science in world development.

THE DEEPER SIGNIFICANCE OF SCIENCE IN WORLD DEVELOPMENT

In every sphere of organized activity in human society, authority has always been associated, and must always be associated with a system of hierarchical levels. This was true in primitive societies, matriarchal, patriarchal or tribal, and for successive levels of feudal lords. This has always been true in all organized churches and religions (animist, Hindu, Buddhist, Confucian, Jewish, Christian, Islam, etc.); in all military, police, or administrative systems, in enterprises, business and commerce; and in law. A law court of appeal may reverse the decision of a lower court; but the decision of the court of appeal may itself be changed by a still higher court. The decision of the highest court to which a case is referred must be accepted, not because such a decision is necessarily right, but because it is the decision of a superior authority.[2] This authority principle is indispensable and must be accepted.

This very authority principle must, however, be absolutely and completely rejected in the field of science. Modern science is based on the firm conviction that nature has a uniformity which can be discovered by the human mind.[3] Modern science is based on a patient accumulation of observations of facts, of processes, and their interrelations or interactions. There is a continuing revision of the theory or conceptual framework in which all known facts have to

2. It is possible, indeed, that this decision itself would have been reversed if there had been a still higher court to which the case could be referred. If a decision of a higher court of appeal is considered to be like the turning up of "heads" in tossing an unbiassed coin when the decision upholds the verdict of the lower court, and is considered to be like the turning up of "tails" when the verdict of the lower court is reversed, then the successive decisions of the higher court would look like the results of the tossing of a coin. This would be the real guarantee that the system of law is functioning properly.

3. The phrase "uniformity of nature" must be, of course, interpreted to include chance events and random processes. Although games of chance were known and were widely prevalent in ancient times in China, India and other countries, it is important to note that the concept of probability did not arise until the 16th and the 17th centuries, that is, not until the emergence of modern science. This is easy to understand. Before the emergence of the modern scientific view of an objective world of physical reality, all chance events would have to be necessarily ascribed to the whims of gods, demons, or supernatural forces. After the emergence of the scientific view of an objective world of physical reality, it became necessary, both logically and psychologically, for the human mind to accommodate the occurrence of chance events as an integral part of the uniformity of nature. This could be accomplished only on the basis of the theory of probability, or rather, as I should prefer to put it, only through a statistical view of the world. It seems to me, therefore, that the concept of probability or the statistical view of the world did arise at the same time as the emergence of modern science only because it could not possibly have arisen earlier.

find a proper place. A single new observation or fact may require and lead to a more comprehensive theory. The older accumulated knowledge, however, continues to remain valid. The later discoveries must somehow be integrated and reconciled with earlier knowledge. Einstein's theory of relativity did not prove that Newton was wrong, but went much further beyond the realm of knowledge known at the time of Newton; the same is true of all advances in science.

The accumulation of scientific knowledge is thus increasing *all* the time through the efforts of *all* scientific workers *all* over the world. A new fact may be observed, or a new theory may be formulated by any worker, however young, and in any country of the world, however small. Authority derived from higher status is completely irrelevant to science. Scientific activity is therefore essentially democratic in nature. Also, any intervention of authority, based on anything outside science, must be completely destructive of scientific progress. There can be no exception.

The scientific revolution brought about during the last four centuries introduced a new concept of "scientific" or "objective" validity which has its foundation in nature itself and which cannot be upset by any authority based on status or by supernatural powers. This indeed is the foundation of the modern age.

THE NEED OF PROMOTION OF SCIENCE OVER THE WHOLE WORLD

It is, therefore, essential in every country, large and small, or advanced, advancing, or under-developed, to establish and strengthen increasingly the outlook of science, a way of thinking which would become more and more powerful as it becomes more widely adopted. This scientific outlook cannot be established by force. It must depend on acceptance through proper understanding. A scientifically trained group may evolve a wise policy but such policy can be accepted and implemented only when it is properly appreciated by persons capable of similar understanding. The important point is that men should be persuaded to adopt and implement a wise programme of action, on the basis of rational argument supported by relevant factual evidence, and should not be swayed by false argument or emotional bias, or be guided by purely formal dogma or conventional rules of procedure. The future development of each country, and of the whole world, will, therefore, depend on the growth of the scientific outlook. It is essential to have a sufficient number of men with the scientific outlook to think upon the problems of national development. It is, therefore, necessary continually to encourage and promote the advancement of science in every country, large or small.

Because science is indivisible, and also because science must be established in every country, it is also necessary, continually, to promote scientific collaboration between all countries of the world, large and small, and advanced or developing.

Scientists cannot possibly take the place of administrators or political leaders. It is neither necessary nor desirable that they should do so. What is necessary is that scientists should have initiative and freedom of action in the field of science.

How to attract and hold a sufficient number of able persons to science is thus the crucial problem of national and world development. This can be achieved only through a proper and adequate social appreciation of science and scientists.

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