A NOTE ON SCIENCE AND TECHNOLOGY IN THE INDUSTRIAL REVOLUTION*

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I

It goes without saying that the Industrial Revolution in England has attracted many scholars from diverse disciplines, and has produced rich accumulation of studies.[1] These studies have been grouped into two schools; optimistic school and pessimistic one.[2] They are in opposition with each other especially concerning the estimate of the social consequences of the Industial Revolution, and more fundamentally they have different views on capitalist economy. Yet, new veins continue to be discovered, as new areas are surveyed and new drillings undertaken.

In Japan, the study of the Industrial Revolution in England has been stimulated by the practical interest of the modernization of Japan. Japanese academicians concentrated their interest upon the problems of the transition from feudalism to capitalism, and they treated the Industrial Revolution as a final stage of that transition, since the Industrial Revolution established the capitalist economy.[3] Thus the process of modernization of England has been regarded as a model of Japan.

But, recently a shift of interest can be discernible in Japan. Professor Tsunoyama, for example, insists that the study of economic history should not be ended by the Industrial Revolution, but should be started from the Industrial Revolution. He points out that the problems of modern history, such as industrial revolution, economic crisis, imperialism, have become the central problems of economic history.[4] Furthermore, England, once regarded as a model for modernization of Japan, began to decline in the world economy,[5] and was no longer regarded as a model. However it is not clear from Tsunoyama's view why we must start the study of economic history from the Industrial Revolution.

We accept the idea that the study of economic history should be started from the Industrial Revolution. It is the purpose of this paper to deepen the implication of this new idea.

* We would like to express our gratitude especially to Professor A. E. Musson, whose works provided us with many valuable suggestions.

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[1] For the brief survey of a history of the study of the Industrial Revolution, see, Hartwell, R. M., *The Industrial Revolution in England*, The Historical Association, 1966.

[2] Hobsbaum, E. J., *Labouring Men, Studies in the History of Labour*, London, 1964, p. 64.

[3] Takahashi, K. ed., *Sangyō Kakumei no Kenkyū* (*Studies in the Industrial Revolution*), Tokyo, 1965, p. ii.

[4] Tsunoyama, S., *Keizai Shigaku* (*The Economic History*), Tokyo, 1970, pp. 5-8.

[5] Hobsbaum, E. J., *Industry and Empire*, London, 1968, p. 215. Hobsbaum argues that Britain must be analysed in terms of decline. (*Ibid.*, p. 271.)

We consider the Industrial Revolution as a great discontinuity in history. This is the reason why we accept the opinion that the study of economic history must be started from the Industrial Revolution. The historical discontinuity of the Industrial Revolution can be formulated by the following grounds.

Firstly, the process of industrialization during the Industrial Revolution and onwards produced many goods in quantity and in quality. In other words, the Industrial Revolution was the starting point of the growth of output *per capita*.[6] But at the same time, we must take note of the fact that the Industrial Revolution also produced vast amount of industrial waste. One of the most serious problems of the present day is the pollution of the environment,[7] and the present unprecedented scale of the pollution of the environment has its origin in the Industrial Revolution. This is one of the reasons why we insist the Industrial Revolution as a great discontinuity in history.

Secondly, we consider that the relationship between man and nature was fundamentally changed by the Industrial Revolution. While before the Industrial Revolution man threw himself on the power of nature, from the Industrial Revolution onwards he began to have the power to interfer and control the nature, and man's mastery over nature grew rapidly. This power was achieved mainly by the progress of science and the growing application of science to industrial activities. " Since the recent history of a large part of human society has been so continuously successful, it is quite natural that many people expect technological breakthroughs to go on raising physical ceilings indefinitely."[8]

Thirdly, the Industrial Revolution is the process whereby the large scale of exploitation of the new sources of energy instead of old ones, such as water, plants and animals, was set on foot. This diversion of the sources of energy, the large scale consumption of non-renewable natural resources, supported the development of productive forces and mass production.[9] But the massive use of the new sources of energy was also a new source of the pollution of the environment.

Fourthly, around the Industrial Revolution the world population began to grow faster than ever before, and from the middle of the eighteenth century, the world population grew almost vertically,[10] and the output *per capita* grew faster than ever before. This sustained growth of output and population was not seen before the Industrial Revolution.

Thus the Industrial Revolution must be regarded as a great discontinuity in history. Discontinuity in history has been insisted by W.W. Rostow as " take-off ",[11] and R.M. Hartwell.[12] Let us now examine the arguments of R.M. Hartwell. He argues that " it is necessary to think of the industrial revolution primarily as economic growth through industrialization. The industrial revolution of England was that economic growth which occurred in the century, *c*.1750 - *c*.1850, as a result of industrialization; during the century there was a revolution in the structure and performance of the economy which resulted

[6] Hartwell, R. M., *The Industrial Revolution and Economic Growth*, London, 1971, p. 57.

[7] Meadows, D. H. *et al*, *The Limits to Growth*, New York, 1972, p. 21; Benjamin, B. *et al*, ed., *Resources and Population*, London, 1973, p. 2.

[8] Meadows, D. H. *et al*, *op. cit.*, p. 129.

[9] Cipolla, C. M., *The Economic History of World Population*, Penguin Books, 1970, pp. 51-53.

[10] Stanford, Q. H. ed., *The World's Population, Problems of Growth*, Toronto, 1972, pp. 16-19.

[11] Rostow, W. W., *The Stages of Economic Growth*; Cambridge U. P., 1960.

[12] Hartwell, R. M., *The Industrial Revolution and Economic Growth*.

in sustained economic growth."[13] As for the place of the industrial revolution in history, Hartwell insists that the industrial revolution is a great discontinuity in history, which divides " between a world of slow economic growth, in which population, output and real incomes were rising slowly (or not at all), and a world of much faster economic growth, in which population has increased at an almost frightening rate, and in which there have been sustained increases in output and in *per capita* real incomes."[14] He argues that the industrial revolution is the greatest discontinuity in history, greatest in terms of changes in institutions and organization, or in terms of output.[15] For the meaningful study and research of this discontinuity in history, Hartwell insists that it is necessary to analyze the economic growth as a multi-variables interdependent social process, and rejects the sectoral studies.[16] Thus his analysis of the process of the industrial revolution is extended from the heavy variables such as capital, population, technology and organization,[17] to the service sectors,[18] and education and law.[19] He insists that the industrial revolution of England is an example of balanced growth.[20]

We consider this Hartwell's arguments to be stimulating and challenging ones, but we have a few comments on his work. His arguments are summed up in two points; the industrial revolution was the growth of output *per capita*, and it achieved the improvements of the standards of living and the way of life. We do not deny that these two historical phenomena brought forth a profound change in society in general. But they do not deserve of being placed as the mark of a great discontinuity in history. It is ture that Hartwell's arguments are constructed by a broader view not confined to economic factors but extended to unmeasurable and non-economic factors. Nevertheless, as we have already formulized in the above the meanings of a discontinuity in history, the fundamental element of this discontinuity is the change of the relationship between man and nature, and this change was brought about by the rise of modern science and the growing application of science into industrial activities. [Further, the rapid development of various industries would have probably led to the pollution of the environment. Thus we consider the Industrial Revolution as a great discontinuity in history.

II

We have pointed out in the previous section four characteristics of the Industrial Revolution. Against these settings, it is clear that science and technology play the central role. Thus we must consider the problems of science and technology in the Industrial Revolution. In approaching the problems of science and technology in the Industrial Revolution, the following statements expressed by J.D. Bernal are quite important: " It is ture that in the recent past scientists and people at large got on very nicely in the com-

13 *Ibid.*, p. 46.
14 *Ibid.*, p. 42.
15 *Ibid.*, p. 50.
16 *Ibid.*, p. 53.
17 *Ibid.*, pp. 262-310.
18 *Ibid.*, pp. 201-225.
19 *Ibid.*, pp. 226-261.
20 *Ibid.*, p. 187.

fortable belief that the application of science led automatically to a steady improvement in human welfare." "It was only the immense and progressive changes in science and manufacture that came about with the Industrial Revolution that were to make this idea of progress an assured and lasting truth. It is certainly not so now, in these grim and anxious days, when the power that science can give is seen to be more immediately capable of wiping out civilization and even life itself from the planet than of assuring an uninterrupted progress in the arts of peace."[21] Bernal says that men live in fear of destruction by the atom bomb or biological weapons; in hope of living better lives through the application of science in agriculture and medicine.[22] We must supplement these phenomena by the pollution of the environment by industrial activities. This paper is a first step to approach these difficult problems concerning science and technology.

The problems of science and technology in the Industrial Revolution to be surveyed are as follows: (1) how science and technology developed, (2) how science and technology were applied to the industrial activities, (3) what changes were achieved by the application of science and technology to industries and trade, (4) to what extent the relationship between man and nature changed. These problems are naturally containing many difficult questions and to our regret to answer these questions completely is beyond our capacity. So we attempt to approach these problems with the survey of the works of eminent scholars from our viewpoint.

To approach the problems of science and technology in the Industrial Revolution, the work of A.E. Musson and E. Robinson is indispensable.[23] Musson and Robinson sought to answer two main questions: What were the connections between the Scientific and the Industrial Revolutions? And how was the technological knowledge developed and diffused?[24] The traditional view argues that there is an important difference between the work of knowledged "scientists" of the eighteenth century and the operations of industrialists. J.D. Bernal, for example, argues that "it may appear somewhat arbitrary to divide, at the beginning of the eighteenth century, an Industrial Revolution from Scientific Revolution of the seventeenth. There is naturally no question of the unbroken continuity between them ..... Nevertheless, it seems that the distinction is more than one of convenience. There is a noticeable difference between the two periods. The breakthrough in the former was essentially in understanding, in the second in practice."[25] Thus he says that "the Industrial Revolution was not mainly, and certainly not in its first phases, a product of scientific advance."[26]

To this argument, Musson and Robinson point out four aspects of science and technology during the Industrial Revolution and confirm the collaboration of science and technology. Firstly, the eminent scientists such as Priestley and Cavendish would certainly not have thought of Watt, Wedgwood, Boulton and other industrialists as 'non-scientists'. All of them were, in their own views, partners and collaborators in the task of extending

[21] Bernal, J. D., *Science in History*, London, Third edn., 1965, p. 3.
[22] *Ibid.*, p. 1.
[23] Musson, A. E. and E. Robinson, *Science and Technology in the Industrial Revolution*, Manchester U. P., 1969.
[24] *Ibid.*, p. vii.
[25] Bernal, J. D., *op. cit.*, p. 355.
[26] *Ibid.*, p. 352.

the frontiers of 'natural philosophy'.[27] Secondly, science and empiricism are often regarded as opposites. But modern science is a combination of theory and experiment, and Musson and Robinson say, "if by empiricism we mean procedure by trial and error, then the progress of science has been empirical, and there is no distinction between science and empiricism: practical experiment has been directed by theory, while theory has been shaped by experiment."[28]

Thirdly, " the fact that many erroneous theories prevailed two or three centuries ago, and that laboratory equipment and procedures were rudimentary by modern standards, does not justify rejection of eighteenth century natural philosophy as being 'unscientific'."[29] Fourthly, " many scientists and technologists have been interested in both knowing and doing: scientific knowledge has improved technology, while technological researches have led to advances in science."[30]

In this way Musson and Robinson confirm the importance of the collaboration between science and technology during the Industrial Revolution. This collaboration was not, according to Musson and Robinson, confined to the period of the Industrial Revolution. " The men of sixteenth and seventeenth centuries were well aware of the fruitful collaboration between scholars and artisans."[31] Ample examples of the collaboration between scientists and industrialists are showed in various parts of their book. Their findings necessitate considerable modification of the traditional view of the Industrial Revolution as being almost entirely a product of uneducated empiricism, and they advance the suggestion that developments in science and in technology during the eighteenth century were not unrelated and that the Industrial Revolution was also an intellectual movement.[32] At the same time, they have also stressed the existence of plentiful evidences of the continued importance of practical craftmanship.[33]

III

It is necessary to survey briefly the scientific revolution of the seventeenth century, because the debate of our concern is not confined to the period of the Industrial Revolution. In this section we consider the meaning of the birth of modern science and seek the connection between the Scientific Revolution and the Industrial Revolution.

It goes without saying that science began soon after the birth of civilization. Even in the Middle Ages there had been important developments in the application of water, wind and animals as sources of power.[34] Yet, as A.R. Hall insists, " rational science, by whose methods alone the phenomena of nature may be rightly understood, and by whose

[27] Musson, A. E. and E. Robinson, *op. cit.*, p. 3.
[28] *Ibid.*, pp. 3-4.
[29] *Ibid.*, pp. 4-5.
[30] *Ibid.*, p. 5.
[31] *Ibid.*, p. 11.
[32] *Ibid.*, p. vii.
[33] *Ibid.*, pp. 7-9.
[34] Lilley, S., *Men, Machines and History*, London, 1965, pp. 46-50.

application alone they may be controlled, is the creation of the seventeenth and eighteenth centuries."[35]

Tracing the development of the new science from its birth and early growth to intellectual maturity, J.D. Bernal argues that the change in ideas in science was " far greater than that in politics and religion. It amounted to a *Scientific Revolution*, which the whole edifice of intellectual assumptions inherited from the Greeks and canonized by Islamic and Christian theologians alike was overthrown and a radically new system put in its place."[36] Bernal insists that " a new quantitative, atomic, infinitely extended, and secular world-picture took the place of the old, qualitative, continuous, limited, and religious world-picture."[37] This substitution of world-picture was " only a symptom of a new orientation towards knowledge."[38] It was changed from being a means of reconciliation of man with the world as it is, was, and ever will be, to one of controlling Nature through the knowledge of its eternal laws. The process of this substitution spreads over a long time, and the consequences are really revolutionary.

In order to understand the actual process of the creation of the new science, Bernal says that, " it is convenient to divide the whole period of the Scienctific Revolution into three which may for convenience be called: Those of the Renaissance, 1440-1540; of the Wars of Religion, 1540-1650; and of the Restoration, 1650-90."[39] The first phase of the developments in science challenged the whole world-picture which the Middle Ages had adopted from classical times.[40] The opening phase of the Scientific Revolution was one of description and criticism rather than constructive thought.[41] The second period includes the first great triumphs of the new observational, experimental approach.[42] " The third and definitive phase in the establishment of modern science was reached in the latter half of the seventeenth century."[43] In this phase the *virtuosi* of the mid-seventeenth century were men of independent means instead of depending for their livings on the favour of princes.[44] These men were competent and interested enough to carry out scientific research on their own; but as they became numerous they tended to gravitate naturally together for discussion and interchange of knowledge. Third phase was also the period of the formation of the first well-established scientific societies.[45] The foundation of the early scientific societies made science into an institution,[46] and acquired their cumulative nature

[35] Hall, A. R., *The Scientific Revolution, 1500-1800, The Formation of the Modern Scientific Attitude*, London, 1954, p. xii.
[36] Bernal, J. D., *op. cit.*, p. 253. "The influence of the Renaissance, of rationalism and the 'scientific spirit' appears to have opened up vast possibilities of Man's controlling and exploiting his environment 'by reason and experiment'." (Musson, A. E. ed., *Science, Technology and Economic Growth in the Eighteenth Century*, London, 1972, p. 57.)
[37] Bernal, J. D., *op. cit.*, p. 253.
[38] *Ibid.*, p. 254.
[39] *Ibid.*, p. 255.
[40] *Ibid.*, p. 256.
[41] *Ibid.*, p. 200, p. 264.
[42] *Ibid.*, p. 281.
[43] *Ibid.*, p. 310.
[44] *Ibid.*, p. 313.
[45] *Ibid.*
[46] *Ibid.*, p. 318.

which marked off science from the other human institutions, such as those of religion and art.[47]

The accent of the period was one of *extensive* inquiry covering the whole field of Nature, and *constructive* theory in those parts where mathematical methods could be applied.[48]

It is true that until the end of the eighteenth century science drew far more from industry than it could give back. Yet, the greatest achievement of the scientific revolution is the substitution of old world-picture for new secular one, and the idea that the knowledge was only a beginning and there was no limit to possible advance along the same line.[49]

Needless to say Francis Bacon's idea is fundamentally important to these debates. The essence of the idea of Francis Bacon is that " knowledge ought to bear fruit in works, that science ought to be applicable to industry, that men ought to organize themselves as a sacred duty to improve and transform the conditions of life."[50] " Bacon's ambition was to reconstitute man's knowledge of Nature in order to apply it to the relief of man's estate."[51]

" The true and lawful goal of sciences ", Bacon writes, " is none other than this: that human life be endowed with new discoveries and powers."[52] " It will not be amiss to distinguish the three kinds and as it were grades of ambition in mankind. The first is of those who desire to extend their own power in their native country; which kind is vulgar and degenerate. The second is of those who labour to extend the power of their country and its dominion among men. This certainly has more dignity, though not less covetousness. But if a man endeavour to establish and extend the power and dominion of the human race itself over the universe, his ambition (if ambition it can be called) is without doubt both a more wholesome thing and a more noble than the other two. Now the empire of man over things depends wholly on the arts and sciences."[53] Bacon wanted to restore to man dominion over nature, to enable him to control and alter improve on nature.[54] But the whole tradition of learning of his day did not help, and Bacon made a sharp break with it. And in the Preface to the *Novum Organum*, Bacon writes, " I would address one general admonition to all; that they consider what are the true ends of knowledge, and that they seek it not either for pleasure of the mind, or for contention or for superiority to others, or for profit, or fame, or power, of any of these inferior things; but for the benefit and use of life; and that they perfect and govern it in charity."[55] He pleads above all else for the

[47] *Ibid.*, pp. 18-19.
[48] *Ibid.*, p. 324. Despite the variety of fields of study, science in the seventeenth century had an underlying unity which had a threefold basis; that of persons, of ideas, and of applications. In the first place, the scientist of the seventeenth century was himself able to cover and to produce orginal work over all the field of then known science. In the second place, there was an underlying unity produced by a guiding idea and method of work that was essentially mathematical and based on mathematics. The third and most characteristic unifying principle of the new science was its concern with the major technical problems of the day. (*Ibid.*, pp. 344-345.)
[49] *Ibid.*, p. 346.
[50] Farrington, B., *Francis Bacon, Philosopher of Industrial Science*, London, 1951, p. 3.
[51] *Ibid.*, p. 5.
[52] Robertson, J. M. ed., *The Philosophical Works of Francis Bacon, Reprinted from the Texts and Translations with the Notes and Prefaces of Ellis and Spedding*, London, 1905, p. 280.
[53] *Ibid.*, p. 300.
[54] Farrington, B., *op. cit.*, p. 94.
[55] Robertson, J. M. ed., *op. cit.*, p. 247.

work to be undertaken in the spirit of charity.[56] Thus Bacon was not proposing simply a revolution in knowledge but a revolution in the conditions of life.[57] Bacon says that the difference between civilized men and savages was almost that between gods and men. " This difference comes not from soil, not from climate, not from race, but from the arts."[58]

Bacon's influence can be perceived everywhere among men of science in the seventeenth and eighteenth centuries, constantly encouraging them to comprehend workshop practices.[59] At the same time we must turn our attention to the fact that Bacon insists the necessity of humility. "This Instauration of mine", he writes, "seeks for the sciences not arrogantly in the little cells of human wit, but with reverence in the greater world."[60] " Man is but the servant and interpreter of nature: what he does and what he knows is only what he has observed of nature's order in fact or in thought; beyond this he knows nothing and can do nothing."[61] The virtues of charity and humility were, in Francis Bacon's idea, the fundamental elements of knowledge and the conditions for the improvement of human life. It is very doubtful whether the modern science continued to promote these virtues, and it seems likely that the idea of progress has been charged with the arrogance towards nature. This may be nothing else but the degradation of science. The reason and the process of this degeneration of science could be sought in the context of social and economic backgrounds. But this is another theme beyond our paper.

We must consider that the changes in knowledge which are summed up as the scientific revolution transformed the Western civilization.[62] At the start the modern science no doubt intended to collaborate with industry. From the beginning of the sixteenth century, Usher argues that in the field of mechanics there were conscious application of known scinetific principles, scientific research leading to the formulation of new principles, and brilliant imaginative achievement.[63] But the real collaboration between science and industry began with the Industrial Revolution.[64] This may be illustrated, for example, by a rapid development of method of refining and working iron, which opened up new uses of iron and steel and soon led to the building of industrial machinery of iron.[65]

IV

The problems of science and technology have been treated by diverse disciplines with different interests. Recently the researches into the relationship between science, technology

[56] Farrington, B., *op. cit.*, p. 88.
[57] *Ibid.*, p. 113.
[58] Robertson, J. M. ed., *op. cit.*, p. 300.
[59] Musson, A. E. and E. Robinson, *op. cit.*, p. 16. There is another estimate of Francis Bacon. A. R. Hall insists, for example, "while Bacon's works gave a useful impetus to the growing interest in science, especially in England, his attempt to define the intellectual processes involved in the understanding of nature was limited and only partially helpful. Empiricism alone is an insufficient instrument in science." (Hall, A. R., *op. cit.*, p. 167.)
[60] Robertson, J. N. ed., *op. cit.*, p. 247.
[61] *Ibid.*, p. 253.
[62] Clark, G. N., *Science and Social Welfare in the Age of Newton*, Oxford, 1949, p. 60.
[63] Usher, A. P., *A History of Mechanical Inventions*, Harvard U. P., revised edn., 1954, p. 304.
[64] Musson, A. E., ed., *op. cit.*, p. 58.
[65] Usher, A. P., *op. cit.*, p. 358.

and economic growth were pursued. A.E. Musson edited a book entitled *Science, Technology and Economic Growth in the Eighteenth Century*, which is an important work to this theme. This book is composed of eight articles previously published in journals or in books, and the editor's Introduction. Editor's Introduction written by A.E. Musson is not merely an introduction for the students interested in science, technology and economic growth during the Industrial Revolution, but also a very clear-cut independent article. In this Introduction Musson traces the evolution of economic and sociological theories in regard to the problems presented by scientific and technological process, and against this theoretical background he views recent historical studies on these aspects of the Industrial Revolution. Musson's fundamental recognition to approach the problems of science and technology during the Industrial Revolution is stated as follows: "The scientific and technological achievements of the past two centuries are overwhelmingly obvious in their transformation of economic and social life."[66]

These achievements have not always been treated in the same direction. To the immense forces of change——revolutionalizing industrial organization and production, expanding trade and transport, requiring vast amounts of capital, and altering the whole structure of labour force and society in general——there exists a wide variety of approaches, and most modern economists have regarded them as 'exogenous' or external to the economic system. Economic historians, however, have always given great prominence to industrial-technological development, for "economic history has retained a much greater realism, a much broader approach, and on account of the multiplicity and complexity of the factors involved, has tended to be strongly empirical, utilizing only a loose framework of theoretical ideas."[67] But recently, the resurgence of interest in business studies and technological growth among economists raises the possibility of closer collaboration with economic historians, who now recognizing more clearly the uses of theoretical and statistical tools in historical analysis.[68] Musson surveys the history of economic theories, especially how economic theories treated science and technology in their framework. Musson declares that most modern economists left the scientific and technological achievements entirely out of account. But he says that the neglect of scientific and technological development by economists became pronounced only in the late nineteenth century. Mercantilists in the seventeenth and eighteenth centuries stressed the importance of invention and technological improvements. Classical economists showed a broad concern with industrial-technological and social as well as 'economic' factors.[69] But neo-classical economists of the late nineteenth and early twentieth centuries turned their attention from 'dynamic' to 'static' analysis, and discarded the empirical socio-historical approach and adopted more rigorously theoretical and mathematical techniques. Thus developed the theory of margin and general equilibrium.[70]

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[66] Musson, A. E. ed., *op. cit.*, p. 1.
[67] *Ibid.*, pp. 1-2.
[68] *Ibid.*, p. 2.
[69] *Ibid.*, pp. 2-4.
[70] *Ibid.*, pp. 4-5. This concentration on static analysis of limited problems was, according to Musson, "probably a reflection of the contemporary optimism and faith in progress, resulting from a century of continued and unprecedented economic expansion." (*Ibid.*, pp. 5-6.) Of course, there were even in the neo-classical period, economists who wrote broadly on the development of industry and trade, studied industrial fluctuation. There were also some outspoken contemporary critics of narrow unreality of neo-classical theory. (*Ibid.*, pp. 6-7.)

Neo-classical micro-static theory held sway until after the First World War. The shock of war caused economists to look afresh at the problems of economic growth and fluctuations, and revived economists' interest in the factors responsible for long-term economic development and growth.[71]

Schumpeter was one of the first to emphasize these long-term aspect, particularly the factors producing economic fluctuations, in which entrepreneurial ' innovations ' played a dominant role. He emphasized particularly the importance of major technological innovations, which accounted to a large extent for discontinuous economic growth. Schumpeter, however, tended to neglect the scientific-technological aspects, stressing the entrepreneurial side of innovations rather than technical inventions.[72] " In many ways, however, Schumpeter's writings were outside the field of dominant economic theory."[73]

New ideas did develop within established economic schools during the inter-war period, Keynesian macro-economic analysis. But this new theory was still static: it excluded long-term ' dynamic ' factors affecting economic growth, such as capital accumulation, science and technology, population, etc. Post-Keynesian theory created ' dynamic ' models, with the aim of achieving ' dynamic equilibrium '. But scientific-technological and other largely unknown or non-quantifiable variables were still treated as ' given ', as ' non-economic ' or ' exogenous '. In short-term analysis such assumptions may be justifiable and useful, but in the long-term they are untenable. Changes in science and technology certainly cannot be disregarded, since they are crucial to investment decisions and continued growth.[74] Musson emphasizes that " mere figures of capital accumulation may be quite misleading, since all capital is not homogeneous——quality is important as well as quantity——and statistics may not truly indicate a country's economic-technological progress."[75] An associated weakness of these macro-economic models is their aggregative and abstract character: they take no account of the varied realities at the level of particular industries and firms. There is little apparent contact with scientific-technological-industrial reality.[76]

Some have constructed more complex dynamic models, including ' disaggregated ' or multi-sectoral models of Leontief type. These have included technological progress along with land, capital, and labour among the factors of production determining economic growth, but in a highly abstract manner, with many unrealistic assumptions. Other ' development ' economists have combined general concepts with a broader more empirical approach. They have shown considerable sympathy towards inter-disciplinary studies, since many psychological, sociological, political, historical, scientific, and technological, as well as economic factors are involved in the growth process. This new development reflects the growing realization among economists that science and technology cannot any longer realistically be treated as ' exogenous '.[77]

Simon Kuznets had stressed strongly the vital role of science and technology in economic growth. Kuznets distinguished between (a) a scientific discovery, an addition to

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[71] *Ibid.*, pp. 8-9.
[72] Schumpeter, J. A., *The Theory of Economic Development*, Harvard U. P., 1934, pp. 74-94.
[73] Musson, A. E. ed., *op. cit.*, p. 9.
[74] *Ibid.*, p. 10.
[75] *Ibid.*, p. 11.
[76] *Ibid.*, pp. 11-12.
[77] *Ibid.*, pp. 12-13.

knowledge, (b) an invention, a tested combination of already existing knowledge to a useful end, (c) an innovation, an initial and significant application of an invention, (d) an improvement, a minor application, and finally (e) the spread of an innovation, usually accompanied by improvements. Between these phases there is also a feed-back effect. Kuznets pointed out that, at the point where innovations transform new technical knowledge and inventions into productive use, three factors are important: (a) capital investment; (b) entrepreneurial talents; and (c) the market.[78] Economic growth is thus a product of economic and social as well as scientific and technological factors.

More recently, Kuznets has emphasized even more strongly the importance of science and technology. The most important capital of an industrially advanced nation, he considers, is not its physical capital, but its human capital, its scientific and technological knowledge, resulting from improved education and training.[79] These views have been supported in recent years by an increasing number of other economists.

Fellner, for instance, has emphasized the importance of a continued flow of technological and organizational improvements as the main factor behind long-run growth.[80] Bruton pointed out that modern dynamic models have proved largely unrealistic, because of their artificial assumptions, particularly their exclusion of so-called ' exogenous ' factors, which are inextricably part of the economic system.[81] He stressed the strategic importance of innovations to the growth process, and said, " any theory of economic growth must contain an explanation of their behavior. Contemporary economics does not offer a 'theory of innovations '."[82]

These criticisms of the inadequacies of growth theory have given rise, during the last decade or so, to a swelling flood of reseach and publications of the links between science, technology, and modern industrial development.[83] Salter likewise emphasizes that " behind productivity lie all the dynamic forces of economic life: technical progress, accumulation, enterprise, and the institutional pattern of society."[84] Salter's opinion is that among the causes of increased production and productivity, primary emphasis must be placed on technical progress and economies of scale.[85]

Nelson, Peck and Kalachek have similarly emphasized ' the leading role ' of scientific-

[78] Kuznets, S., *Six Lectures on Economic Growth*, Illinois, 1959, pp. 30-32.

[79] Kuznets, S., *Modern Economic Growth, Rate, Structure, and Spread*, Yale U. P., 1966, pp. 80-85, pp. 286-294.

[80] Fellner, W., *Trends and Cycles in Economic Activities*, New York, 1956, p. 53, p. 118, p. 128, p. 138.

[81] Bruton, H. J., "Contemporary Theorizing on Economic Growth", in Hoselitz, B. F. *et al*, *Theories of Economic Growth*, Illinois, 1960, p. 261. "In introducing structural changes into the discussion, considerable departure from a 'Keynesian-type' world had been achieved." (*Ibid.*, p. 267.)

[82] *Ibid.*, p. 287.

[83] Musson, A. E. ed., *op. cit.*, p. 17. Professor Jewkes and his collaborators have demonstrated that from the Industrial Revolution onwards there has been an increasing close relationship between science and technology in the making of inventions. They suggested that there were close links between industrialists and scientists even in the eighteenth century; there were many agencies for the development and diffusion of scientific and technical knowledge. They emphasized particularly the importance of individuals in the making of inventions. They also emphasized that the underlying motives were by no means entirely economic, but also psychological and social. (*Ibid.*, pp. 18-19.)

[84] Salter, W. E. G., *Productivity and Technical Change*, Cambridge U. P., 1960, p. 1.

[85] *Ibid.*, pp. 133-134, pp. 140-142, pp. 145-146.

technological progress in economic growth,[86] and the vital contribution of education and training in producing entrepreneurs, managers, and workers with scientific and technical competence and flexibility.[87] But they emphasize that it alone is not sufficient and that inventions are stimulated by economic factors.[88] While they emphasize 'demand-pull' effect, they also counterbalance it with the statement that "capability is important as well as demand."[89]

In recent years efforts to manipulate scientific and technological developments by statistical tools has been strained. But there still seems little possibility of directly measuring scientific-technological developments with anything like mathematical accuracy. Despite intensive econometric efforts, it still remains true that "there is no way to measure the rate of technological change directly."[90]

Econometricians have, according to Musson, succeeded to some extent these problems of measuring technological change directly, by subtracting measurable elements and leaving 'residuals'.[91] Abramovitz was one of the first to discern that much the greater part of the increase in net product *per capita* was associated with something other than inputs of physical capital and labour. Other economists have reached a similar conclusion, that technological progress has been far more important than capital accumulation in causing economic growth.

These views have led to growing emphasis on the importance of 'human capital' and 'investment in human beings', on the 'stock of knowledge'. There is no doubt of the considerable importance of technological progress, including intangible factors such as educational improvement and growth of scientific and technological knowledge, in the process of economic development.[92]

Another approach towards quantitative measurement of technical progress and assessment of its causes has been made by Schmookler, using patent statistics as an index of inventions.[93] He points out that inventions are products of supply and demand: on the supply side they result from accumulated technical knowledge, while on the demand side they are produced for utilitarian purposes, to satisfy consumer wants. He therefore seeks to answer the question whether they are "mainly knowledge-induced or demand-induced".[94] After examination of the patent statistics he comes down heavily on the

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86 "In advanced nations economic growth is best understood with technological advance playing the leading role, and capital formation and education providing the necessary support." (Nelson, R. R. and M. J. Peck and E. D. Kalachek, *Technology, Economic Growth and Public Policy*, Washington, 1967, p. 18.)

87 *Ibid.*, pp. 10-13, p. 107.

88 *Ibid.*, p. 28.

89 *Ibid.*, p. 34.

90 Musson, A. E. ed., *op. cit.*, pp. 21-22.

91 *Ibid.*, p. 23.

92 *Ibid.*, pp. 23-24. Schmookler insists that "the accumulation of *intellectual* capital—reflected in the production of better products and the use of better methods—has been much more important than the accumulation of physical capital in explaining the rise of output per worker in advanced countries when the period studied covers several decades." (Schmookler, J., *Invention and Economic Growth*, Harvard U.P., 1966, pp. 4-5.)

93 Schmookler, J., *op. cit.*, p. 23.

94 *Ibid.*, p. 12.

demand side.[95] He concludes that economic growth determines the rate of invention and technical progress, rather than *vice versa*, and that economic growth is determined by socio-economic forces, such as the state of the economy, population growth and structure, changes in per capita income, etc.[96]

Musson, however, points out some weakness of Schmookler's analysis in both his evidence and arguments, and declares that his conclusions cannot be regarded as decisive. Patents do not cover all inventions, nor all patented inventions of equal importance. Schmookler has to postulate ' latent demand ' as the determining influence, but he does not explain how this latent demand becomes operative, and how inventors are made aware of it. In the case of new basic invention, or new product, an inventor cannot be influenced by present output or sales of that product, though he may discern future market possibilities. Musson declares that Schmookler is very brief and vague in his examination of the socio-economic forces affecting demand, and how individual inventors are affected by them. Musson also criticizes the supply side of Schmookler's argument; Schmookler is very vague and inadequate in the evidence on the motives of particular inventors, especially those of major importance in the industries concerned. Schmookler excludes the motives of scientists. Schmookler suggests that the explanation might be largely in terms of market demand, to which scientific and engineering progress is probably responsible, but this is obviously debatable.[97]

It has been pointed out that an invention tends to come before society needs it or is willing to buy it. A market has often to be created for new products. Similar views have been put forward by Schon, who emphasizes that invention, innovation, and marketing are full of uncertainties and risk.[98] The process of technical development takes unexpected " twists and turns ".[99] There exist even the forces that resist technological innovation.[100] The notion that invention is a direct response to clearly discerned ' needs ' is a ' myth ', except where small improvements are concerned. In the case of a major new invention or product, the ' need ' for it does not pre-exist, and a market has to be developed.[101] Marketing pressure do not, in any case, automatically bring forth technological solutions.

The prevalent tendency among economic and social historians is to place emphasis upon the demand side, upon market forces at home and abroad. Most of these stress that growing demand was the main driving force behind technological change. But there is evidence that leading innovators created the markets for their new products. Invention and innovation often preceded exploitation of market possibilities. And without the technological advances, which made possible greatly increased production at lower costs,

[95] *Ibid.*, p. 66. Schmookler insists that "(1) invention is largely an economic activities which, like other economic activities, is pursued for gain; (2) expected gain varied with expected sale of goods embodying the invention; and (3) expected sales of improved goods are largely determined by present capital goods sales." (*Ibid.*, p. 206.) And "the fundamental conclusion that demand determines the allocation of inventive effort among alternative uses probably applies to consumer goods." (*Ibid.*, p. 212.)

[96] *Ibid.*, pp. 180-181.

[97] Musson, A. E., *op. cit.*, pp. 26-27.

[98] Schon, *D. A.*, *Technology and Change*, New York, 1967, pp. 24-25, p. 30.

[99] *Ibid.*, p. 12.

[100] *Ibid.*, p. 56.

[101] *Ibid.*, p. 72, p. 109.

market could possibly have expanded as they did. There are two blades to the scissors of supply and demand.[102]

Musson states that research into inventions reveals the complexities of the processes and motivations involved. Although economic and social factors were undoubtedly of immense importance in motivating scientific and technological changes, many of the leading scientists and scientifically-minded industrialists were motivated also to a considerable extent by innate curiosity. There is plentiful evidence to support the view that entrepreneurs were motivated not simply by a hedonistic desire for profits, but also by a will to achieve, to acquire power and renown, to found a 'dynasty', and other psycho-sociological drives.[103] Musson insists that "if one studies at first-hand the detailed contemporary evidence, then a theory of inevitability appears ludicurous: it completely ignores the realities of individual achievement, the imaginative insight, sustained effort, and mixture of motives involved."[104]

Musson declares that both in theoretical analysis and in statistical investigation, economists are a long way from the precise understanding of the process of economic growth, particularly with regard to technological development. But now the broadening of scope and inclusion of long-term variables has brought growth theory into closer relationship with economic history. On the particular aspects of growth, Musson states, there is now an obvious possibility of mutual stimulus and collaboration.[105]

V

The possibility of an interdisciplinary approach is also opened up by the increasing interest of sociologists in the problems of economic growth and scientific-technological development. Talcott Parsons first drew attention to the shortcomings of economic theory in its neglect of sociological and psychological factors. He has stressed the importance of 'non-economic' factors such as social structure, institutions, cultural patterns, values, wants, and motivations. Economic development is thus closely related to social changes. The importance of socio-cultural factors in economic growth has been increasingly emphasized in recent years by other sociologists.[106]

Hoselitz has stressed the need for a general theory of growth, which should include social, cultural, and political, as well as 'purely economic' factors.[107] Similarly, Hagen states that income in a society may rise because of capital formation. But "if capital formation consists solely of the construction of instruments already known and does not embody new ideas", Hagen declares that "rise in income will gradually come to a halt."

102 Musson, A. E. ed., *op. cit.*, pp. 40-42.
103 *Ibid.*, pp. 47-48. A. E. Musson and E. Robinson insist that "although economic and social factors were undoubtedly of immense importance in motivating scientific and technological changes..... many of the leading scientists and scientifically-minded industrialists were motivated also to a considerable extent by innate curiosity, by desire to discover more about how industrial process worked, by an urge to make improvements, and to be esteemed by their fellows, not merely for the money they made, but for their contributions to scientific and technological advance." (Musson, A. E. and E. Robinson, *op. cit.*, p. 8.)
104 Musson, A. E. ed., *op. cit.*, p. 49.
105 *Ibid.*, p. 29.
106 *Ibid.*, pp. 30-32.
107 Hoselitz, B. F., *Sociological Aspects of Economic Growth*, Illinois, 1960, p. 24, p. 29.

" Continuing rise in income, that is, continuing economic growth, is obtained only by continuing improvement in techniques or products."[108] Hagen stresses the complexity of the process of social change,[109] and suggests to use the method known as system analysis.[110] He states that " since the economic state of a society is closely related to its political state, and the forces that bring change in the one also bring some sort of change in the other, a model that explains economic growth must take into account noneconomic as well as economic aspects of human behavior."[111] " Economic growth ", Hagen writes, " always requires innovation."[112] " The innovations required are not only techno-economic changes but also social ones."[113] Thus Hagen stresses the importance of the complex sociological and psychological motives of innovating entrepreneurs, the agents of technological progress.[114] Hetzler states that "development is, above all else, an acquisition of machines and a knowledge of how to employ them."[115] From Hetzler's viewpoint, " social change, technological advancement, and mechanization are, in a broad sense, synonymous. Societies may change over long periods of time on the basis of shifts in techniques alone."[116] And he discerns the sources of technological growth " in the nature of technology itself."[117] Most sociologists, however, tend to maintain a social-determinist point of view.[118]

Other sociologists, while adopting similar social-determinist views of historical development, have placed much greater emphasis on the role of science. Merton, for example, has stressed the determining importance of social forces in scientific discovery and applied science.[119] Merton's ideas have been strongly challenged by some historians of science, who maintain the distinction between ' pure ' and ' applied ' sciences, and who consider that the development of scientific ideas has been little influenced by either social or industrial changes. Marxist historians, such as Bernal, stress the close interconnexions between scientific, industrial, and social developments, in both the early modern and modern periods.[120]

After the survey of economic and sociological theories, Musson confirms the increasing awareness of the importance of science and technology in economic growth. Musson reveals that there certainly does not exist anything like an agreed theory, integrating science

[108] Hagen, E. E., *On the Theory of Social Change*, Illinois, 1962, p. 12.
[109] *Ibid*, p. 3. "The transition to economic growth is accompanied by major political and social change." (*Ibid.*, p. 35.)
[110] *Ibid.*, p. 4.
[111] *Ibid.*, p. 25.
[112] *Ibid.*, p. 30.
[113] *Ibid.*, p. 35.
[114] *Ibid.*, p. 93, p. 95, p. 104. "Although the size of markets and of the flow of saving available influence the pace of growth when innovators arise, change in these economic variables does not seem important as a force causing economic growth to begin." (*Ibid.*, p. 239.)
[115] Hetzler, S. A., *Technological Growth and Social Change*, London, 1969, p. 113.
[116] *Ibid.*, p. 184.
[117] "It well may be that technological growth occurs as a series of changes in the ways in which men interact with machines with which they work." (*Ibid.*, p. 161.) "Technology is a socio-technological entelechy containing the seeds of its own growth, which can, fortunately, be implanted independently of the more superficial and economic stock factor with which it is commonly associated." (*Ibid.*, p. 293.)
[118] Musson, A. E. ed., *op. cit.*, p. 32.
[119] Merton says that "it seems justifiable to assert that range of problems investigated by seventeenth century English scientists was appreciably influenced by the socio-economic structure of the period." (Merton, R. K., *Social Theory and Social Structure*, Illinois, 1949, p. 363.)
[120] Musson, A. E. ed., *op. cit.*, p. 37.

and technology into the older theories of economic growth.[121] He stresses the importance of a 'disaggregated', qualitative approach towards science and technology.[122]

So far we have reviewed the treatment of the problems of science and technology in diverse disciplines, especially in economics and sociology. As Musson declares the necessity of the collabolation of economic theory, economic history and sociology is now evident for the students interested in the problems of science and technology. We consider that the collaboration must be pursued with new interest in the present serious effects of science and technology upon human life and human society, especially with interest in environmental pollution.

[121] *Ibid.*, p. 38.
[122] *Ibid.*, p. 68.