Science, Technology and Development

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THE purpose of these two papers* is to discuss hypotheses which may help to explain the limited growth of science and technology in the under-developed economies, and to explain also the restricted social function of science in these countries. For the moment the discussion of what to do about this state of affairs—in other words about policies—is given a secondary place. This, not because policy is unimportant or irrelevant, but because policies which are worked out without adequate understanding of the problems they are meant to solve are unlikely to work. The purpose is to diagnose the existing state of affairs.

The discussion of the social and economic functions of science and technology in these papers takes a different form from much of the current literature. It is much less concerned with the measured consequences of scientific research for economic growth within a given economy, than with institutional factors which may account for the development of links between science and production in one economy and for the absence of such links in another.

The present paper reviews some of the theories that have been put forward to explain the links between science and production in the advanced, industrialised countries. The theoretical arguments and the facts of history suggest that advanced industrial capitalism has generated close "organic" relationships between the growth of scientific and technological knowledge and the growth of production, in which science has increasingly become an instrumental factor and perhaps a necessary factor in social and economic development.

In the second paper, on science and the underdeveloped countries, this situation in the advanced economies is contrasted with the under-developed economies.

These papers are really a search for a theoretical framework for understanding the role of science in the under-developed countries, and the impact of world science and technology on them. They are written at a high level of generality and I am only too aware of the problems that arise because of this. On the other hand, generality is unavoidable in the search for theoretical explanation, particularly

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in the early stages. And, it seems to me that the need for a more systematic approach to the question of science and the under-developed countries is so great, the subject area at the present so diffuse and so full of contradictions, that it is worth running the risks that generality carries with it, if only to point up the problems that need research.

In this paper the purpose is to review theories which attempt to explain how the linkage between science, technology and production in the advanced industrialised countries came into being. This theoretical framework will suggest some contrasts between the situation in the advanced countries and that in the under-developed countries. The contrast is the subject of the second paper. This paper will be concerned with the advanced industrialised countries, particularly with the history of their development.

One point needs to be cleared up at the outset. This paper is not concerned with the problem which has recently received a good deal of attention in the economic literature on science and technology, of examining the "returns" to scientific research or "technological development" regarded as investments. Current interests in this kind of problem may reflect a *situation de fait* in which governments and industries in most advanced countries have to allocate resources to science and want to know how much to spend on what. For economists, the starting point for this enquiry is the econometric analysis of the sources of economic growth by Abramovitz, Solow, Denison and others[1] which produced the concept variously described as the Third Factor or the Residual. This paper is not concerned with such analyses precisely because they do not—and probably cannot—provide an explanatory theory of the kind which is needed. More explicitly, most of the work in the economics of science and technology has centred on examining the influence which these factors have had on economic growth in given institutional situations; there has been relatively little examination of the institutional context itself to examine whether and how one kind of economic organisation is better adapted than another to the exploitation of science and technology in production. It is precisely this latter problem, by and large ignored by current studies of science and the economy, which is the main concern here.[2]

The justification for this concern seems the greater because the literature on science and the economy is full of policy proposals which implicitly assume that institutional factors do not affect the issue: the crudest form of the argument is that if education and R and D are good for growth in the industrialised economies,

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[1] See M. Abramowitz, Resources and Output Trends in the US since 1870, *American Economic Review*, Papers and Proceedings, May 1956. R. Solow, Technical Change and the Aggregate Production Function, *Review of Economics and Statistics*, Aug. 1957. E. F. Denison, *The Sources of Economic Growth and the Alterations Before Us*, US Committee for Economic Development, 1962.

[2] This concern with the contingent relationship between technological change (in the broad economic sense) and the institutional condition of the economy is clearly expressed by Balogh and Streeten in their analysis of the Third Factor studies. See T. Balogh and P. Streeten, The Coefficient of Ignorance, *Bulletin of Oxford University Institute of Economics and Statistics*, 1962.

they will be good for growth elsewhere.[3] This is dangerous. Quite apart from the implicit and questionable identification of growth and development,[4] and from the equally questionable assumption that such factors contribute to growth, it rests simply on the assertion that science and education have been good for growth in particular economies; there is no theoretical underpinning to tell us how and why science has been able to have this effect. And until one knows how and why this has happened in, say, the US, there is really no justification for assuming that it will necessarily happen in other places where initial conditions may be totally different.[5] Indeed this kind of assumption can only be made if one is also able to assume that initial conditions do not differ significantly elsewhere. And since measured differences in GNP *per capita* (whatever they may signify) are an aspect of economic reality which presumably cannot be ignored, this amounts to an assumption that all economies are qualitatively similar even if they are quantitatively differentiated. The main argument of the second paper is that this position is untenable. And once the possibility of qualitative differences between economies arising from markedly different forms of economic organisation is admitted, there is no reason at all why science and education expenditure which may contribute to economic growth in the industrialised economies should necessarily do so elsewhere. In fact, under certain conditions an increase of expenditure on education may simply lead to intellectual unemployment—and an increase of expenditure on science to a form of intellectual luxury consumption.[6] Both these phenomena are observable today in the under-developed countries.

These preliminary remarks are intended primarily to clarify the problems which are examined in the remainder of this paper and to some extent to justify their importance. We now turn more explicitly to the theoretical problem of the linkage between science, technology and production in the presently industrialised economies by way of a brief review of the literature.

The discussion is based on some rather abstract, but apposite and (I hope) useful definitions of science and technology. In what follows, "science" and "scientific activity" refer to those activities concerned with understanding natural phenomena; technology refers to knowledge of how to exploit and use

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[3] When the argument is put in this crude form, it may seem improbable that anyone should seriously use it. It is surprising, however, how often it creeps in as a hidden assumption in discussions of what to do about science in the under-developed economies.

[4] The identification of GNP growth and development (in the sense of increasing social welfare) is pretty generally recognised by economists as an analytic convenience with little or no theoretical justification. This has not prevented a heavy—and sometimes exclusive—emphasis on *growth* in development plans. The economists' attitudes to this divide broadly into the argument that we shall not go wrong by far if we assume the growth-welfare identity and the argument that we shall assume. A recent paper in the latter school is Dudley Seers, "Challenges to Development Theories and Strategies". Presidential Address to Society for International Development, 11th World Conference, November 1969.

[5] Balogh and Streeten, *op. cit.*, develop this argument.

[6] This is discussed in C. M. Cooper, Science and Underdevelopment, in *Problems of Science Policy*, Paris, OECD, 1968.

natural phenomena and sometimes to the physical means (e.g., machines) which are used to do so.[7] In these terms, production activities practically by definition, require technological knowledge. There is on the other hand no necessity that increased production should always involve improved technological knowledge; if there is such an association it must be explained by contingent factors. Equally, there is no logical necessity why technological knowledge, or even the advance of technological knowledge, should depend on science; *a priori* the natural environment may be controlled, even if it is not scientifically understood. Again if there is such an association (between science and technology as defined) then it also must be explained by appeal to contingent factors. There are therefore two hypotheses to be examined about the development of the presently industrialised countries. These are:

(i) that a set of factors operated in such a way in the industrialised countries as to make the growth of production dependent upon improved technological knowledge; and

(ii) there were factors at work in these countries which resulted in a close, "organic" relationship such that technological advance came to depend upon scientific advance.

There is no attempt in this paper to examine the first of these hypotheses systematically. To do so would involve a detailed study of the growth of industrial capitalism which, whilst it might be germane, is beyond my competence.[8] The paper concentrates on the second hypothesis—and in doing so, it inevitably takes a lot for granted.

There are two features of the literature, dealing with the kinds of problem which have been outlined, that are remarkable. The first is that there is really very little on the subject. The second is that, at least as far as economic writings are concerned, the most important contributions were made so long ago. One has to rely in the main on two economists of the classical period, Adam Smith and Karl Marx. There have, of course, been more recent contributions—Galbraith[9] discusses the question in *The New Industrial State,* and Bernal[10] also. As we shall

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[7] These definitions are a considerable departure from those which have been used in the past for measuring the volume of scientific activity. See *Proposed Standard Practice for Surveys of Research and Development,* Paris, OECD, 1962. They are, however, apposite to the analytic purposes of this essay and that must be their main justification.

[8] Celso Furtado in *Development and Underdevelopment,* University of California Press, 1964, gives an interesting analysis of this hypothesis. But see also histories of the Industrial Revolution. For example, Paul Mantoux, *The Industrial Revolution in the Eighteenth Century,* London, University Paperbacks, 1966, and amongst more recent studies, John S. Landes: *The Unbound Prometheus,* Cambridge University Press, 1969.

[9] J. K. Galbraith, *The New Industrial State,* London, Pelican Books, 1970.

[10] See J. D. Bernal, *Science in History,* London, Penguin, 1969; also his *Science and Industry in the Nineteenth Century,* London, Routledge & Kegan Paul, 1953. Throughout his analysis Bernal has been concerned to determine how the requirements of the economic system influences the development of science and its "social function".

argue later, Schumpeters' theoretical analysis of "economic development" is not directly relevant to the theoretical problem we have defined. We shall, however, examine Schumpeter's work for the specific reason that it has a good deal to say about the impact of advanced technology on under-developed countries.

Adam Smith[11]

Smith tackled the question of science, technology and production at the beginning of his analysis in his discussion of the division of labour.[12]

Smith regarded the division of labour, which he saw as mainly dependent upon the "width of the market", as fundamental to "the improvement in the productive powers of labour"[13] and hence as one of the fundamental "causes of the wealth, of nations" which he set out to examine. He demonstrated this argument by his analysis of the production of pins. In characteristic fashion, Smith discusses the increase of labour productivity as a consequence of organisational changes in the production system—and not simply as a quantitative phenomenon.

The part of Smith's analysis which is relevant to this discussion, is his account of the advantages which result from the division of labour in manufacture. The first two advantages are: the "increase in the dexterity of the workman" and saving of time "commonly lost in passing from one sort of work to another". The third—which is directly relevant—is "the invention of a great number of machines which facilitate and abridge labour, and enable one man to do the work of many".[14]

There are two points which might be made about Smith's analysis:

First, he argues—and attempts to demonstrate by appeal to observation—"that the invention of all those machines by which labour is so much facilitated and abridged seems to have been originally owing to the division of labour". Thus, . . . "a great part of the machines made use of in these manufactures in which labour is most subdivided, were originally the invention of common workmen, who, being each of them employed in some very simple operation, naturally turn their thoughts towards finding out easier and readier methods of performing it".[15] Smith sees the division of labour within the factory as an important permissive factor in the development of technology.

Secondly, he not only recognises the role of the worker in the development of machines "which abridge labour"; he sees the process of technological advance in more comprehensive terms:

> "All the improvements in machinery, however, have by no means been the inventions of those who had occasion to use the machines. Many improvements

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[11] Adam Smith, *An Enquiry into the Wealth of Nations.* London, Dent's Everyman Library, 1964. Chapter 1.

[12] *Ibid.*

[13] *Ibid.*

[14] *Ibid.*

[15] *Ibid.*

> have been made by the ingenuity of the makers of the machines, *when to make them became the object of a peculiar trade:* and some by that of those who are called philosophers or men of speculation, whose trade it is not to do anything but to observe everything; and who upon that account, are often capable of combining together the powers of the most distant and dissimilar objects".

. . . More than this, Smith recognises the differentiation of philosophers into "classes and tribes" and "this subdivision of employment in philosophy, as well as in every other business, improves dexterity and saves".[16]

Smith's analysis has a direct bearing on the problem of relationships between science and production. Smith draws a close association between a particular aspect of economic organisation (i.e. the division of labour in manufacture) and technological advance; he almost appears to regard the former as a necessary condition for the latter, in so far as technological advance may be identified with the development of machines. At the same time, of course, in so far as the division of labour itself leads to higher labour (and total) productivity, it is a direct cause of technological change in a wider sense. For present purposes, however, it is the first effect of the division of labour which is of interest, i.e. as an organisational system which stimulates the changes in the nature of capital equipment.[17]

But whilst the division of labour in the production enterprise opens the way for the development of increasingly sophisticated machinery, the actual sources of this kind of technological change are varied. Smith identifies three of them: the specialised workman essentially seeking to save his own labour in achieving a given objective, the makers of the machines (when to make them became the objective of a particular trade), and the "philosopher". All three sources are the products of particular forms of economic and social organisation. It is the division of labour in the enterprise itself which opens the way for innovation by the specialist worker; it is the emergence of a specialised machine-making function (an embryo capital goods industry representing, so to say, a broader division of labour within industrial activities as a whole), which opens the way to an innovative group of specialised craftsmen; it is the prior existence of a specialist group of "philosophers" in society (the product of much earlier development in science), which opens the way to the scientific examination of the production techniques. In this wider sense also, Smith's analysis implicitly puts a strong emphasis on the

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[16] *Ibid.*

[17] For the most part, the economic literature has concentrated on the direct impact of the division of labour in the enterprise on labour productivity, and much less on the technological dynamism associated with division of labour and made possible by it. Marshall covered both aspects. In the first place there are the obvious gains to productivity which result directly from division of labour. But, in addition, the division of labour opens the way to development of new production techniques and application of machinery. ". . . when the action has been reduced to routine, it has nearly arrived at the stage where it can be taken over by machinery." And the reduction of operations to uniformity is an outcome of the division of labour in the factory. See Alfred Marshall, *Principles of Economics,* Book IV, Chapter IX, pp. 208–213, London, Macmillan, 1966.

organisation of production activities as a key factor in opening the way to technological advance.

Broadly speaking, the sources of new production techniques which Smith identifies, divide into two main kinds. Some techniques are developed pragmatically, independently of scientific theory, and without the application of formal scientific knowledge. These are the ones which come from the individual workman, and from the makers of machines. Other techniques appear as the product of conscious application of scientific knowledge. We are given no clear indications of the relative importance of these different lines of technical development; nor is there any explanation of how and why scientific knowledge *per se* comes to be applied to production processes. Marx tackled these latter questions in his study.

The Marxian Analysis

Marx's analysis goes beyond Smith's in several respects,[18] and is much more explicit about the role of science in production.

First, in the context of his analysis of capitalist production, Marx discusses the factors leading to the institution of a technologically dynamic economy. He insists upon the importance of the accumulation and concentration of capital and examines the historic and institutional factors which made this possible in eighteenth and nineteenth century England. Thus we find a strong emphasis in *Das Kapital* on antecedent factors: the re-organisation of the agricultural sector, the role of the mercantile capital in establishing the conditions for change in industrial organisation, the widening of markets because of the transportation revolution. In brief, whereas Adam Smith relates the possibilities of increasing division of labour mainly to the width of the market, Marx goes beyond and discusses the changes in conditions affecting supply, ownership and concentration of the factors of production, which he regards as having been as necessary to capitalist development.

Secondly, Marx makes a sharp distinction between the division of labour in production and the specialisation of machinery. The distinction, which he relates to changes in the organisation of production, is seminal to Marx's discussion of the relationship between science, technology and production and we shall return to it in detail.

Thirdly, Marx is much more explicit about the differentiation of an engineering profession and a scientific profession, because of the needs of the production system. This again, we shall examine in more detail in what follows. Marx asserts that "(the) separation (of the worker from the requirements for individual skill) is completed in modern industry, which makes science a productive force distinct from labour and presses it into the service of capital".[19]

Much of the remainder of this paper is devoted to Marx's analysis. It concentrates mainly on the distinction which Marx drew between the division of labour and

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[18] Karl Marx, *Das Kapital*, Book One, Part Four, Chapters XIII–XV, pp. 322–508, Moscow Foreign Languages Publishing House, 1961.

[19] *Ibid.*, p. 361.

the specialisation of machinery—and on his comments about the process whereby differentiated classes of scientists and engineers came to be instrumental in production.

In the Marxian analysis, the shift from the "manufacturing system" of production to the "factory system" (characterised by machine production), is a fundamental change in the organisation of production. It opened the way for the massive development of production in nineteenth century Britain ; also—and this is the point we shall examine—it is asserted that this change opened the way for the instrumental use of science.

The manufacturing system—which was characteristic of the latter part of the eighteenth century—was the result of a progression from the simple co-operation of workmen under a single master, to a fully-developed division of labour in the workshop. It represents the "resolution of the handicraft into its successive manual operations". In other words, it is characterised by the "division of labour" which Smith praised.

But where Smith is warm with praise, Marx is more concerned to delineate the limitations of the system. In manufacturing production, he says ". . . each operation (whether complex or simple) has to be done by hand, retains the character of handicraft, and is therefore dependent upon the strength, skill, quickness and sureness of the individual workman in handling his tools. . . . *This narrow technical basis excludes a really scientific analysis of any definite process of industrial production,* since it is still a condition that each detail process gone through by the product must be capable of being done by hand . . .".[20] He later adds that whilst "differentiation of the instruments of production" is characteristic of the system—the development and use of machinery is not.[21] Marx takes a narrow definition of machinery and argues that Smith clouds a number of issues by confounding the differentiated—but basically handicraft—"instruments of labour" with machinery.[22]

But there was a more fundamental limitation in the manufacturing system which Marx sees as one of the reasons for the breakthrough to the factory system of organisation. This was that whilst manufacturing production makes it possible to employ relatively less skilled workers than the handicraft system, it does not open the way to the use of mass unskilled labour. Moreover—because some elements of handicraft skill remained which limited the effective supply of labour, the entrepreneur still depended upon the compliance of the workforce. Machine production was a way out. Andrew Ure remarked, "order is lacking in the manufacture based upon the scholastic dogma of the division of labour . . . Arkwright created order".

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[20] *Ibid.*, p. 338.

[21] *Ibid.*, p. 348.

[22] *Ibid.*, p. 348.—footnote: "A. Smith . . . confounds differentiation of the instruments of labour, in which the detail labourers themselves took an active part, with the invention of machinery; in this latter it is not true workmen in *manufactories,* but learned men, handicraftsmen and even peasants . . . who play an active part."

Marx draws some strong contrasts between machine production and manufacturing production as far as the possibility of an "organic link" between science, technology and production is concerned. The essential feature of machine production in his terminology is that the machine performs with its tools the operations that were formerly done by the workman with similar tools. Once this has been achieved the elements of the machine may become increasingly complex and sophisticated and eventually capable of performing functions that no individual craftsman could perform.

The immediate technical consequence of the introduction of machinery is that the "subjective principle" of the division of labour is swept away.[23] Instead production is now dominated by a process or complex of processes. The grouping and organisation of detail labour skills which is the guiding principle in the manufacturing system, is replaced by the grouping and organisation of machines. The technical determinants of the process are no longer the possibilities offered by the division of labour; they are the possibilities of increasing the specialisation and perfection of the machine with its tools. This latter process—runs the argument—is subject to far less stringent limitations than was the perfection of the "instruments of labour" under the manufacturing system—where the physical and mental capabilities of the craftsman set strict limits to the kind of technical advance that can be envisaged. The process of machine production is subject to scientific analysis and to the application of scientific principles in a way which is impossible in the case of manufacture. Thus Marx says "... the problem of how to execute each detail process is examined objectively, and is solved freely by mechanics, chemistry, etc."[24] A further "subjective limit" is removed when the motive mechanism in production "becomes independent and is emancipated from the limitations of human strength".

The changes in the mode of production in the consumer goods section—largely in textiles—are, however, only part of the story. Marx lays a very strong emphasis on the seminal role played by the mechanisation of machine-making, i.e. of the capital goods sector.

The division of labour itself and particularly "the differentiation of the instruments of production" meant that an elemental capital goods industry came into being at a relatively early stage—even before factory production became predominant. In broad outlines these industries rested upon the skills of a nascent engineering profession: the skills of those "mill-wrights and metal workers of the days of craftsmanship" who Bernal sees as the lineal ancestors of the modern engineer. However rudimentary it may have been, this industry and the craftsmen on which it was based, played a fundamental part in the change to machine production. Hargreaves (with the Spinning Jenny), Arkwright (with the water frame) and the other textile innovators, readily found tool-makers who had the skills needed to produce their new devices and to provide for their large-scale introduction into industry.

23. *Ibid.*, p. 380.
24. *Ibid.*, p. 380.

For all that, the machine-making industry remained essentially for artisans until well into the nineteenth century. The narrow reliance on human skill that this implied, was a constraint on the development of mechanised production throughout the economy—for it set quite strict limits to the kinds of machine which could be envisaged and created. The early history of the development of the steam engine indicates that these constraints might sometimes be overcome, but that the process was a slow and painful one. The handicraft base of the machine-producing industry also sets limits to the area in which scientific knowledge could be applied in production.

> ". . . Modern industry was crippled in its complete development, so long as its characteristic instrument of production, the machine, owed its existence to personal strength and personal skill and depended upon the muscular development, the keenness of sight (etc.) . . . with which the detail workmen . . . wielded his dwarfish instruments."[25]

Put in these terms, it appears that the mechanisation of machine production was a fundamental step in the development of relationships between science and production. It may perhaps be argued that whilst the introduction of machinery created certain necessary conditions for the application of science to production, the mechanisation of machine-making crowned the process and laid the foundations for science-based industry. Probably the key developments in mechanisation were the mechanised working of metal (based on Maudslay's adaptation of the lathe) and Nasmyth's development of heavy presses and steel hammers in the early 1860's. New techniques in the capital goods industry opened the way to the creation of such machines as the power loom and the carding engine which "could never have been finished by manufacture",[26] by craft skills alone.

Broadly speaking, the mechanisation of machine-making had two main consequences for the development of relations between science and production. First, as we have argued—it created a far wider area for mechanical invention . . . and hence ultimately for the application of scientific principles in production. Second, it appears to underlie the differentiation of an engineering profession. In crude terms mechanised machine-making might be thought of as replacing the metal-working craftsman of the earlier period with a class of semi-skilled and skilled operatives and a class of engineers. It promoted and even required the specialisation of the engineering profession who, so to say, take to themselves the job of interpreting scientific knowledge for the purposes of production. The newly combined activities of engineers and scientists—resting on a sophisticated machine-producing industry—are fully evident for the first time in the development of the dynamo and the electric motor in the latter part of the century.

Thus, whilst Marx was not immediately concerned with the role of science in production, his analysis of the changes in industrial organisation (to use Marshall's

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[25] *Ibid.*, p. 382.
[26] *Ibid.*, p. 385.

term) accompanying the Industrial Revolution, contains explicit reference to the question. More than this, Marx evidently looked upon the instrumental use of science as one amongst a number of fundamental characteristics of the change in the mode of production.

There are a number of problems about Marx's analysis. The first lies in the sharp distinction which Marx draws between a "manufacturing phase", based on division of labour, and the "factory system", based on increasing specialisation of machinery, or rather from the limited point of view of this discussion, in the distinction between a system—the manufacturing system—in which "science" could not conceivably have played a major part, and the factory system in which it could and did. There are really two difficulties here. One is that as a matter of historical fact, the distinction between the manufactory and factory phases is hard to draw. Paul Mantoux remarked upon this in his study of the Industrial Revolution.[27] The problem is that:

(*a*) the transition was inevitably gradual in the industries where it was taking place. Essentially, the division of labour in the manufacturing system progressively laid a basis for mechanisation. Marshall observed that "... when the action has ... been reduced to routine it has nearly arrived at the stage at which it can be taken over by machinery."[28] And, evidently this did not happen everywhere at the same time in a given industrial branch. Everything depended upon the extent to which the "action" had reached the point of "routine" and also upon the ingenuity and motivation of machine inventors. Moreover the motivation of machine inventors often depended upon whether the parts of the industrial process which remained unmechanized were—for that reason—a real constraint upon the overall development of production. The system could tolerate unmechanised phases in a given process, provided that they did not restrict production—or threaten to make the mechanised phases unprofitable. When the threat was real, the search for new inventions became intense.[29] This means that even within a given branch of production, the introduction of mechanised production was a spotty affair—and Marx's distinction is hard to draw in particular cases.

(*b*) even where the transition occurred, the "older modes of production" continued to exist side by side with the new. Marx himself recognised this,[30] and John S. Landes has recently analysed the problem again.[31]

For all this, there is no real dissension that the Industrial Revolution was indeed

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[27] See Paul Mantoux, *op. cit.*

[28] A. Marshall, *loc. cit.*

[29] A point we return to in discussing the influence of intersectoral demand conditions on the innovation and the use of science in production. See particularly John S. Landes, *op. cit.*

[30] Marx, *op. cit.*, p. 383.

[31] John S. Landes, *op. cit.*

characterised by a change in industrial organisation and the mode of production. Nor is there any serious question that mechanisation was the dominant force in the transition. Marx's categories are useful from this point of view. They are questionable only in the short term sense that they do not give us much help in examining the uneven and ill-defined transition from one situation to another.[32] Marx himself did not always recognise this[33]. He accused Smith for confusing the "instruments of labour" of the manufacturing period with "machinery". But this confusion—if, indeed it was a confusion—was inevitable in the circumstances in which Smith made his analysis—in short, in the actual circumstances of transition.

The other difficulty arises directly from the fact that it is often hard to sustain a sharp temporal distinction between the modes of production that preceded the Industrial Revolution and that which characterised it. This in fact often makes the Marxian assertion, that mechanisation was necessary to the instrumental use of science, hard to verify empirically. For example, we have Smith's assertion—presumably based on observation—that "philosophers", as well as workmen and machine-makers, were a source of new techniques under the system of "division of labour"—i.e. prior to mechanisation in the Marxian sense. Were these "philosophers" simply furthering the "division of labour" and rendering it more efficient—or were they proposing new techniques for an industry which by virtue of prior mechanisation had freed itself from the "subjective limitations" of the "detail labourer"? And in the former case, must we reject Marx's assertion about mechanisation as a necessary condition for the application of science to production? This kind of problem is exceptionally difficult to resolve even by the most meticulous historical examination. The difficulty arises because the mechanisation of production was spotty—and also, because in the marginal case the distinction between "the instrument of labour" and "machinery" may be very hard to draw. Often the transition was progressive[34]—and, it would be hard to say precisely when the necessary conditions for the application of science to production in the Marxian sense were achieved in any given case.

A second problem arises essentially from the logical nature of the argument. Marx was not actually concerned with explaining the conditions for the application of science to production. The argument in *Das Kapital* is an attempt to explain the change in the mode of production which underlay the Industrial Revolution. One aspect—admittedly an important one—is that the change in the mode of production involved certain conditions i.e. mechanisation, which were necessary for the instrumental use of science. The argument is that mechanisation was a necessary condition, not a sufficient one. This again, leads to some difficulties from the point of view of empirical verification, particularly if we accept the arguments of Bernal and others, that science did not actually become

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[32] Paul Mantoux, *op. cit.*

[33] Marx, *op. cit.*, footnote to p. 348.

[34] This is indeed the implication of Marshall's discussion in *Principles*, Book IV, Chapter IX.

instrumental in technological change until quite late in the nineteenth century[35]—i.e., a long time after mechanisation. Now Bernal's argument, which is based on research, does not oppose Marx—but it does point up the difficulties of justifying the Marxian argument by empirical research. For if one accepts Bernal's assertion, then in order to sustain the Marxian argument, it is necessary to show that the science-based development of the chemical and electrical industries[36] in the later nineteenth century would have been impossible, or at least greatly retarded, if mechanisation had not been previously established.

Now this kind of argument—about what would have happened if certain antecedent changes had not occurred—is extraordinarily hard to establish. A major difficulty in this particular case is to disentangle the effects of growing demand for chemical intermediates and for sources of power in stimulating the development of these industries—and perhaps making them possible—from the supply side effects (i.e. changes in the mode of production) which Marx asserts were the preconditions for the application of science to production. Of course, the growth of demand was no doubt in itself made possible by income growth as a result of mechanisation, but this is beside the point which Marx wishes to make. On the other hand, without making artificial distinctions between the effects of demand and supply (the blades of the scissors in the capital mythology), the Marxian argument would probably look a good deal stronger if one focussed upon the progress of mechanisation in the capital goods sector, in the nineteenth century, rather than on the much earlier inception of mechanisation in consumer goods production. It is, in fact, probable that developments of the chemical and electrical industries would have been severely hampered if it had not been for more or less immediately antecedent technological changes in the capital goods sector. From this point of view Marx's argument about the fundamental importance of changes in the mode of production in accounting for the growth of an instrumental role for science, may retain its strength. The point is that here a new use of science in production (as in the chemical and engineering industries) can be related to a change in organisation of production which preceded it by a short time period (e.g. the progressive mechanisation of machine-making), the argument that first change was necessary to the second, is much easier to defend, than when the period separating the two changes is very long.

Marx did not concern himself with this kind of problem. It is clear that he regards his assertion as fully justified by the evidence he gives in *Das Kapital*. As far as he is concerned this is no problem of empirical justification for the concept that mechanisation preceded and was necessary to the instrumental use of science in production—simply because—he might argue—it is practically self-evident that science became "instrumental" as soon as mechanisation was achieved. At the limit, the statement may almost be tautological, in the sense that one might

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[35] J. D. Bernal, *Science in History*, London, Penguin 1969.

[36] Bernal asserts that it was in these industries that the organic link between science and production was first established.

meaningfully define mechanisation as the introduction of scientific methods or science in production.

It is quite plain, however, that Marx did not intend a definitional relationship of this kind, if only because it is most improbable that he would have spent as much space and effort as he did on the question if he had considered it to be self-evident in the tautological sense. More to the point, he repeatedly does bring evidence to bear on the question—and in this sense regards it as a question susceptible to empirical verification or disproof.

This leaves us with a problem, for we are faced with apparently contradictory assertions:

(i) Marx's implicit assertion that, at the time of *Das Kapital* there was empirical evidence that science had become instrumental in production, mechanisation having made this possible; and

(ii) the assertion of Bernal and other modern writers that, whilst the evolving technologies of the nineteenth century were objects of interest and study for the scientists of the day, science itself did not have a major impact on production processes until the end of the century—i.e. long after *Das Kapital* had been written.

The claim is that each assertion is substantiated by empirical evidence. Assuming that in some sense this is the case (i.e. that there is empirical evidence for each assertion), the only way out of the impasse is to argue that the concept of "science" has a different meaning in each of these statements, i.e. that there is a semantic confusion.

There does, in fact, seem to be a semantic confusion, which—I believe—is worth examining, not simply in the interests of precision about words, but also because the examination may help to clarify some important aspects of the argument.

There is little doubt what Bernal means when he writes about science. Bernal is mainly interested in the body of knowledge and understanding tied up—so to say—in the formal natural science disciplines which had become differentiated by the latter part of the nineteenth century—and also in the research process of adding to this body of knowledge. This is, in a non-derogatory sense, a formal view of what "science" is.

Marx's view of science in *Das Kapital* almost certainly embraces the Bernal concept (at least to the extent that disciplinary boundaries could be drawn at the time he wrote), but more besides. This is clear when Marx argues that not only did mechanisation create necessary conditions for the application of science to production, but also that the competitive requirements of production thereafter brought into being "the Modern Science of Technology".[37] This point seems to

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[37] Marx, *op. cit.*, p. 461.

me essential to a real understanding of what Marx meant by "science" in relation to production. Marx was basically concentrating on a newly formed interface between science and technology: his terminology is designed to cover a new kind of economically orientated activity involving the search for new inventions, and the rational scientific examination of production processes made possible by the factory system. In this process, individual inventors, mill-wrights, erstwhile instrument makers, and nascent engineers draw upon the existing body of scientific understanding (of the formal Bernal kind) and use it for innovation in production in a way which was not possible before. Progressively these functions became differentiated and specialised particularly when the mechanisation of machine-production develops. At the same time, however, in such a process—particularly in its earlier stages, it may be extremely difficult to determine which particular bits and pieces of scientific knowledge contribute to a given invention or factory improvement, or indeed to know whether a particular inventor was "scientific" in his approach, rather than purely pragmatic. But this need not upset the argument.

Seen in this light, Bernal's concept of the instrumental use of science in production represents something like the culmination of the process that Marx describes. The crucial element in Bernal's analysis is the identification of particular pieces of scientific research which lead relatively clearly to particular industrial innovations. There is little doubt that Bernal is correct when he says that this highly differentiated use of science did not come about until late in the nineteenth century—but, as we have seen, this does not gainsay Marx's argument. In fact, it adds something to the argument, since it shows how after a time, the invention function itself becomes specialised and progressively tied up with the conduct of organised scientific research (which is characteristic of the forms which it takes in the modern economy). All of this, of course, leaves the way open for practically endless and generally unproductive debates about definitions. It may, for example, be argued that what Marx regards as the use of science in production, has less to do with science as we (and Bernal) understand the term and is more about "development" work or minor innovations or "technology" or whatever. Indeed this seems to me true if we take the currently conventional meaning of these terms. But, there remains a legitimate and analytically useful sense in which Marx describes the growth of the instrumental use of science in production, and a strong presumption in favour of his assertions that the introduction of machinery opened up the horizons for the instrumental use of science in this sense. From this point of view, and also from the point of view of its strength as an *a priori* argument, Marx's analysis of science and production appears to be by and large undisturbed by the arguments raised against it, and broadly speaking is unique of its kind.

A final point needs to be made about this analysis. It is that Marx himself placed relatively little emphasis on the way in which sheer quantitative increases in output, made possible by mechanised production in one branch, generated a need for innovations in other branches, and sometimes hastened the application of science to production in an indirect way. Marx recognises the phenomenon quite clearly. After all, the potentials opened up by machine production in textiles itself created the groundwork for mechanised production of textile machines—and mechanisation in the capital goods sector is a pillar of Marx's argument. More generally, he specifically argues that advances in one branch call forth advances in others—and illustrates with the case of relations between spinning and weaving.[38] On the other hand, he does not fully recognise (and by no stretch of the imagination could he have recognised) how pervasively important intersectoral demands were to become. More recent studies have concentrated on this aspect. Intersectoral demand arising from the massive growth of textile products seems to have been a major factor in the development of science-based (in Bernal's sense) production of chemicals. They may account for the way this industry took the lead in the differentiated use of scientific research for production. The importance of intersectoral effects has been examined both by Bernal[39] and recently by Landes.[40]

Thus at the end of this analysis we are left with a reasonably coherent thesis about the contingent institutional factors that created a situation where science came to have a major instrumental function in technological change in the industrialised economies.

This, it will be recalled, is the problem we set out to examine. The bare bones of this thesis may be summarised as follows:

(i) The switch from a manufacturing system based on the division of craft labour to mechanised production created certain conditions which were necessary for the instrumental use of science in production. In the wide sense in which Marx uses the term "science" this instrumental function became apparent very early, in that the inventors and minor innovators drew upon existent scientific knowledge (in a patchy way at first) and began to examine the process of production in a scientific, rather than purely pragmatic manner.

(ii) These invention and innovation functions became progressively differentiated and more specialised; more explicit and defined relations slowly developed between them and the pre-existent scientific disciplines. The growth of the chemical and electrical industries are the first cases where "modern" relations between science and production appear. There, differentiation has gone to the point where—at least *ex post*—it is often possible to show relationships between specific pieces of scientific research work in the natural science disciplines, and specific industrial innovations.

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[38] Marx, *op. cit.*, p. 383.

[39] J. D. Bernal, *loc. cit.*

[40] Landes, *op. cit.*

(iii) A crucial factor in the whole process was the mechanisation of machine production. This enormously broadened the field for machine innovations *per se*, because it made it possible to carry out processes which were inconceivable by handicraft methods. It also created new possibilities for innovation in machine manufacture (e.g. interchangeable parts). By extention of argument (i) above, those developments greatly widened the field for the instrumental use of science in all phases of production. It may well be shown that the development of science-based electrical and chemical industries would have been impossible without it. Also, development in the capital goods sector apparently underlay the growth of a differentiated engineering profession which later became an essential link between science and production.

(iv) Quantitative growth of intersectoral demands (and supplies) between an innovative branch and other branches, often created a basis for a further wave of innovations—and further application of science—outside of the branch which innovated in the first phase.

We shall leave the argument at this point[41]—to make it up later in relation to the under-developed economies. Before that, however, we shall pause to take a look at the rather particular implications of Schumpeter's study on economic development as far as science and production are concerned.

Schumpeter and Science and Technology in Production

Schumpeter was concerned with the role of innovation in a wide sense, as it affected competitive relationships within industrialised capitalist economies. He was *not* therefore, examining the kind of problem which Smith and Marx analysed. They were concerned, at least implicitly, with institutional and organisational pre-conditions which, so to say, open the way for the instrumental use of science to create new techniques and products. Schumpeter's theory of the entrepreneur takes these pre-conditions for granted. In this sense, it is a theory about the dynamics of a given type of economic system. In so far as Schumpeter has anything to tell about science and production, (and I believe he has), it is at a different level of analysis to what Smith and Marx had to say. It is, however, an important digression, for the reason that economists have recently developed hypotheses of the Schumpeter type to account for the role of technology in

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[41] Before doing so it is worth pointing out that this line of argument suggests solutions to some of the historical problems which Bernal posed. For example, Bernal remarks that a number of technical advances of the nineteenth century were in fact based upon scientific understanding which had already existed in the preceding century—and that in general there were very long time-lags in the use of scientific knowledge. Part of the reason at least might lie in the fact that the basic technical transformation of production upon which this application depended only took place in the early mid-nineteenth century.

the international economy. And these hypotheses (to which we shall return in the second paper) are particularly useful in analysing the problems of technology transfer to the under-developed countries.

Most discussions of equilibrium between enterprises under perfect competition define the equilibrium conditions (equality between price, marginal costs and average costs) by showing that if the firm were producing at some other point where prices exceeded marginal costs, there would be an incentive for new producers to enter the given line of production. Schumpeter's main argument is that in reality there is an incentive for an established firm (or a new entrant) to innovate specifically so as to operate at a point where price actually does exceed marginal costs. If in fact, the firm is able to do so, it will evidently create a situation where there is an incentive for other firms to copy the methods it used to achieve this position—and the increased returns to the "innovating" firm will diminish as there are new entrants to production. Prices fall and (possibly) factor prices rise. Nevertheless, the innovating firm will earn profits over and above the so-called "normal" returns to capital defined in terms of competitive equilibrium, because the appearance of new entrants, commodity price reductions and factor price increases take time. Schumpeter defines these profits as entrepreneurial profit.[42] They accrue to the entrepreneurs who "carry out new combinations"[43] of production factors, either to produce a given output at lower costs than established producers, or to produce a new output. In Schumpeter's analysis, the "new combinations" are very widely defined; thus ". . . the introduction of machinery is a special case of all changes in the productive process in the widest sense, the aim of which is to produce a unit of product with less expense and thus to create a discrepancy between the existing price and their new costs."[44] The entrepreneurial profit and "the entrepreneurial function as such, perish in the vortex of the competition which streams after them". But in most cases—unless the "new combinations" are very minor modifications of the old—there will be a period of time during which the profits are earned. It is the time dimension in the adjustment to the new equilibrium which makes entrepreneurial profits possible, and which creates the incentives which Schumpeter places at the centre of his "theory of development". Particularly in the case of a "new combination" which results in a new type of output, prices and the entrepreneurial profit are determined by the principles of monopoly.[45]

Schumpeter regards entrepreneurship as a factor—and this leads him to a (tautological) distinction between factor requirements in the innovative phase and thereafter. "If we conceive of (entrepreneurship) . . . as a kind of productive factor, then we can say that in the mere repetition of the familiarised new combin-

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[42] J. Schumpeter, *Theory of Economic Development*, New York, O.U.P., 1961. Chapter 4: Entrepreneurial Profit.

[43] *Loc. cit.*

[44] *Loc. cit.*

[45] *Loc. cit.*

ations one of the factors of production which were necessary to carrying them out initially, disappears."[46]

We may stop at this point, leaving out Schumpeter's more detailed analysis of the nature of the entrepreneurial profit—and also his incorporation of the "innovation" argument into a theory of business cycles.

Schumpeter's theory suggests that even where the assumptions of perfect competition are met, it is improbable that the actual conditions of perfect competitive equilibrium will occur at any given point in time. Even under these conditions there will be inherent tendencies for the enterprises to seek temporary monopoly positions. Furthermore, there will evidently be a considerable gain for any enterprise, if it can sustain its competitive advantage over a long period, or alternatively, if it can replace one competitive advantage by some other—as the first is gradually eroded by new entrants.

Now, any "new combination" in the Schumpeter sense, particularly insofar as it involves the production of some given output with lower unit factor inputs, must also be regarded as a technological advance in the economic sense. In terms of neo-classical analysis, "new combinations" represent a "shift in the production function".[47] Also, in terms of our somewhat less precise definition, "new combinations" may be taken to lead to an improved capacity to control the natural environment.

Such shifts in the production function—or advances in environmental exploitation—may well be achieved in a variety of ways, as Schumpeter himself indicated. They may, for example, result from improvements in plant lay-out, or from adjustments of process flows, or whatever. Clearly, also, they may result from the discovery of new techniques of manufacture, or from new products which fulfil the functions of older ones at lower cost. Such more narrowly defined technical advances might arise from purely pragmatic search for new technologies—or conceivably, they may come from the conscious instrumental use of scientific research by the enterprise. From this point of view, Schumpeter's theory of capitalist dynamics carries some strong suggestions about the competitive role of science in production.

It is interesting to consider—if only in *a priori* terms—the potential role of science and technology as compared with other sources of "new combinations". There is at least a possibility that monopoly positions which result from new technical developments, based perhaps on the discovery of new products or processes in the research laboratories serving the enterprise, will be more permanent than those based upon, say, new plant lay-outs, or improved after-sales services—simply because they may be inherently harder to emulate. (They may also be patentable—whereas other kinds of "new combinations" are not—and this in itself could give the enterprise greater protection from competition). In

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[46] *Loc. cit.*

[47] D. Spencer and A. Woroniak, *The Transfer of Technology to Developing Countries,* New York, Praeger, 1967.

this sense, provided that the organisation of production is susceptible to application of science in the Smithian and Marxian sense, the competitive demand for science may become more considerable. There would be all the more reason for an emphasis on an organised research activity, if such an activity not only generated relatively durable kinds of competitive advantage, but also opened up the possibility of a *succession* of technical discoveries, thus sustaining the competitive advantage of the enterprise.

The "real world" situation may be more complex than Schumpeter's original analysis suggests. There are at least three modifications which *prima facie* are needed to bring the theoretical construct into closer relation with current reality.

In the first place, whilst Schumpeter's model could be construed as throwing the possibility of a perfect competition equilibrium out of the window, he nevertheless retains most of the assumptions of the perfect competitive situation. He reveals the possibility that even if conditions for perfect competition exist, the situation at any point in time is not likely to be one where production is carried out according to rules which are far from those which the equilibrium conditions of perfect competition would suggest. This is complex enough. But the real situation is likely to be even more complex. Generally speaking, outside of the agricultural sector (and often even in it), the basic ground rules of perfect competition seldom apply. In other words, the underlying—and probably unattainable—equilibrium position which the production system tends towards, is not that of perfect competition, but rather the condition of imperfect competition or possibly of oligopoly. And, at least in the case of oligopoly, we remain very uncertain as to whether an equilibrium position can be defined at all. In short, even if one retains the often questioned assumption of profit-maximising enterprise the conventional framework of micro-economics is quite insufficient to allow or to make any prediction about what the situation will be at any given point in time, i.e., about economic reality.

A second problem is that the instrumental use of science in production may itself impose conditions, which, whilst they do not necessitate inherent imperfections in competitive relationships, at least put a premium on large companies, and so create a tendency in the direction of such imperfections. This argument is usually based on one or both of the following assertions:

(i) there are critical minimum levels in research and development activity and if these levels are not surpassed, the R and D will not yield commercially usable results. The concept of commercially useful results is important to this argument; the main cost burden in making use of scientific discoveries in production is generally supposed to be in the so-called "development-activity", i.e. in the pilot plant stage and in the initiation of production. In this context, it is not necessarily the research activities *per se* which demand a minimum absolute resource allocation (though this is also argued) but particularly the "development work". In certain industrial branches the critical minimum effort may be very large indeed and may give strong competitive advantage to large firms.[48] Evidently bigness *per se* is not necessarily or always associated with imperfection in competitive relations—but a premium on big firms may be expected to create a tendency in that direction.[49]

(ii) more generally, it is argued that there are economies of scale in R and D activities. This argument evidently leads to similar conclusions to the first. The main difference between (i) and (ii) is simply that (i) carries the implications of a discontinuity in the function relating resource allocation to R and D and the results obtained from it, whereas (ii) leaves open the possibility that some commercially viable results might be obtained at a low absolute level of resource allocation, but that maximum returns per unit input to the R and D activity will only be got when there is a large effort in absolute terms. In short, in case (ii), the fundamental relation between R and D inputs and commercial returns is presumed to be continuous.

There is practically no empirical evidence which allows us to distinguish which of these assertions is the right one, though there is a certain amount of evidence that scale factors operate in one way or another—in the R and D activity in certain sectors. And at least in these sectors, scale requirements appear to be sufficiently exacting to give considerable competitive gains to large companies. It has indeed been argued that scale factors in R and D activity put a premium on bigness, not only because the resource inputs required are large, but also because the R and D costs of the new products that eventually emerge must be amortised over very large markets.[50] Thus, the use of science by the enterprise reinforces imperfections in competitive relations in the industry. Moreover, if the "critical minimum size" argument is right—it is clear that the necessity for absolutely large scientific inputs may also be a barrier to new entrants.

Both these modifications of Schumpeter's model have important implications. Schumpeter conceived of entrepreneurial profits as an essentially short-term advantage, which given the underlying tendency to perfect competitive relationships, would be rapidly eroded "in the vortex of competition". If the underlying tendency is not towards perfect competition, but oligopoly or at least monopolistic equilibrium in the Joan Robinson and Chamberlin[51] sense, it is quite possible that the entrepreneurial profit could be sustained over long periods of time. Temporary monopoly positions may not be quite as temporary as Schumpeter's argument would suggest. And it can be argued that the use of science by the enterprise, as a way of generating "new combinations", itself

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[48] Christopher Freeman, "Research and Development in Electronic Capital Goods," *National Institute Economic Review*, No. 34, Nov. 1965.

[49] *Op. cit.*

[50] *Ibid.*, and see also "International Economic Exchanges", *Analytical Report on Technological Gaps*, Book IV of OECD, Paris, 1970.

[51] Joan Robinson, *The Economics of Imperfect Competition*, London, Macmillan, 1961.

creates relatively long-lived innovative advantages and also strengthens the tendencies away from perfect competition in other ways.

A third modification to Schumpeter's model suggests itself. In the original formulation, one is left with the impression that the distinguishing feature of the innovating enterprise is simply the presence of the entrepreneur, who applies his ingenuity and ability to use an existing range of factor inputs in a different way. This—as we have seen—leads Schumpeter to the tautological statement that the phase of entrepreneurial profits is differentiated from the equilibrium condition by the presence of a third factor—the entrepreneur. In fact, however, the innovative activity of an enterprise appears to require far more in the way of inputs than entrepreneurial ingenuity *per se*. It may—as we have seen—involve also an R and D activity—and the specialised managerial and operative skills required to carry into production the new techniques coming out of the laboratories. An identifiable entrepreneurial function of the Schumpeter kind remains: someone must perceive the opportunities opened up by the research activity and conceive of the "new combinations" needed to exploit them in the first place. But the point is that—at least in modern industry—the innovative activity generally requires a number of highly specialised inputs in its own right.[52] The costs of these inputs must be met out of the revenues of the enterprise, before it is possible to identify the monopolistic returns, i.e. the "entrepreneurial profits", generated by an innovation. And, of course, the enterprise will only maintain a permanent corps of research workers if it is expected that they will give rise to a reasonably steady output of innovations with reasonable opportunities for "entrepreneurial profit" over a long-term. Once the advantages accruing to one innovation are eroded by compeition it must be replaced by another. The innovative activity has, in this sense, become institutionalised within the enterprise.[53]

Schumpeter's analysis lies at the basis of a good deal of the current discussion about the role of science and technology in the competitive system. The concept of the search for temporary monopolistic advantages through "new combinations" (often involving new techniques of production or new products) has been used in recent attempts to explain trade patterns; in particular it is the underlying idea in the "product cycle theory" of trade in industrial goods, which is associated with the names of Posner, Hirsch,[55] Hufbauer,[56] Raymond Vernon[57] and others.

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[52] This should not necessarily be construed as an adverse criticism of the Schumpeter model *per se*. It may simply reflect a progressive change in industrial organisation for innovation since Schumpeter formulated his theories. Essentially one is dealing with the increasing differentiation of the function of innovation and innovation in relation to production.

[53] Research and development activity may become a matter of survival to the enterprise in the long-term, as well as a source of entrepreneurial profit in the Schumpeterian sense. See C, Freeman: "Science and Economy at the National Level", in *Problems of Science Policy*, Paris, OECD. 1967, p. 55.

[55] S. Hirsch: *Location of Industry and International Competitiveness*, Oxford U.P., 1967.

[56] G. Hufbauer: *Synthetic Materials and the Theory of International Trade*. Cambridge, Harvard University Press, 1966.

[57] Raymond Vernon, D. Mehta and W. Gruber: "The R and D factor in International Trade and International Investment of United States Industry", *Journal of Political Economy*, Fall, 1966.

Vernon has also used the temporary monopoly concept in his analysis of the behaviour of multinational firms. More recently Constantine V. Vaitsos, in an excellent paper, has extended and modified "product cycle" arguments for the case of technology transfer to under-developed countries.[58]

Concluding Remarks

This paper has examined two kinds of theoretical analysis, which approach the question of the role of science in production from very different points of view. We have included both kinds of analyses because both are relevant to the discussion of the role of science and technology in the under-developed countries.

The first kind of theory is about the institutional factors which account for the growth of "organic links" between science, technology and production in the industrialised countries; this has been the main point of discussion in the paper.

The discussion started from the argument that:

(i) it is not strictly necessary in terms of the definitions we have used that increased production should depend on improved technology; and

(ii) it is conceivable that technological improvements might come about without the application of science.

From this we argued that if—as matter of fact—the growth of production does depend on technological advance, and if technological advance is significantly dependent on science and scientific research, then we must look for contingent, historical factors to explain these relationships. The paper more or less takes for granted the existence of such contingent factors as far as the first set of relationships is concerned, i.e. the relations between the growth of production in the industrialised capitalist countries, and the advance of technology. We then concentrated upon the second set of relationships—i.e. the observed relationship between technological advance and science.

The review and analysis of Smith, Marx and others, led us to the conclusion that the instrumental role of science in generating technological change has depended upon organisational changes in the production system of the industrialised countries. Specifically it depended upon mechanisation in consumer goods and particularly capital-goods industries and also on the differentiation of engineering and inventive skills which the modes of production required. Once these skills had appeared, they provided the basis for new rounds of technological advance—and at each round a more precise and specialised use of science became possible, until the point was reached where it is possible (sometimes at least) to trace precise relationships between scientific research activities *per se* and specific technological advances.

[58] C. V. Vaitsos: *Transfer of Resources and Preservation of Monopoly Rents,* mimeographed draft, Dubrovnik Conference of Harvard University Development Advisory Service, April 1970.

No doubt, the prior existence of considerable culture of empirical science was very important in this process. In general, this cultural inheritance may well have had profound influence on the way people (particularly artisans) thought about technology and the problems of production. In short, the consciousness of rational scientific explanation (however limited it might have been) probably played an important part in the process. Also, and more particularly, the cultural inheritance meant that there was a substantial and accessible body of knowledge about natural phenomena on which to draw.

No doubt also, once the links between science and production had been established, the requirements of the economy (and eventually of the state) came to influence the orientation and growth of science itself.[59] What had once been a culturally motivated activity became increasingly instrumental in society. At least in part the subsequent and rapid growth in the natural sciences can be viewed in this light.

Evidently a good deal of the argument is hypothetical in character. Smith, Marx, Bernal, Mantoux and others provided an empirical basis for the discussion but the case is hardly proven. At the same time, the main theses have, I think, fairly high probability—they go a good way to explaining Furtado's assertion that whilst "a desire to understand and explain the physical and metaphysical world has been common to all cultures . . . it was only in the industrial economy . . . that this fundamental impulse of the human mind became incorporated into the pricing element of the economic system".[60]

The Schumpeterian theory—as we have argued—tackles a different kind of problem. It is less concerned with the relationships between the use of science and the organisation of production, than with the role of innovation in general (and, by extension, science and technology in particular), in the competitive process. In a sense, Schumpeter's analysis presumes the prior existence of the necessary organisational conditions for the application of science to production, and looks at what happens afterwards. To an extent, Schumpeterian arguments are revealing some of the conditions which led to a relationship between technological advance and the growth of production in the industrialised countries. But we are not conerned with them from that point of view. The main immediate interest in the Schumpeter argument is that—by extention—it leads to a view of science in the competitive system as a source of entrepreneurial (or monopolistic) profit. As Schumpeter shows, the possibility of such profit not only exists where the conditions for perfect competition are met, but are likely to characterise competitive relations even under these conditions. In reality, of course, the ground conditions are not those of perfect competition, but rather of imperfect or oligopolistic competition. This will enhance the incentive to use science and technology as a source of monopoly—and may extend the period during which

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[59] The impact of economic and state requirements of science is discussed in a recent paper prepared for the United Nations, by the Sussex group; to be published by United Nations.

[60] Celso Furtado: *Development and Under-Development,* University of California Press, 1964.

monopolistic gain can be got from science-based innovation. We also speculated that in a Schumpeterian framework, the advantage of a science-based innovation from the point of view of the private enterprise, may well be that it is harder to emulate (as well as being more readily amenable to patent protection), so that it may lead to more permanent protection from competition than other sources of innovation. Scientific research and development work has therefore tended to become institutionalised within the enterprise, and has become a permanent source of costs which must be amortised, before the purely entrepreneurial profits (in Schumpeter's sense) can be counted. In some sectors at least, the absolute expenditures on R and D that are required if the scientific effort is to be productive appear to be very substantial—this puts a premium on large firms which can control markets of sufficient size to amortise the R and D "overhead" expenditure. In these cases the use of science in production may itself lead to, or at least reinforce, an oligopolistic situation.

As we have said, both these kinds of theory are relevant to the discussion of the role of science in under-developed economies. However, they are relevant in very different ways. The Smith-Marx argument emphasises the importance of institutional and organisational conditions in accounting for the development of the link between science and production. As far as the under-developed economies are concerned, it leads to the hypothesis, that one can only expect science and technology to play a similar role in the under-developed economies, if these conditions of organisation (or some equally favourable ones) exist. From the fact that initial conditions in the under-developed economies are very different and unfavourable to the use of science in production, we shall attempt to explain the restricted social function of science in these countries and its comparatively limited growth.

The relevance of the Schumpeter line of reasoning is somewhat different. In the circumstances of a weak internal development of science in the under-developed economies, nearly all growth of production (particularly in industry) has come to depend on technology from the advanced countries. To the extent that these technologies are (*a*) in private ownership and (*b*) are a source of monopolistic advantage to the companies that possess them, this may have a marked influence on the terms on which under-developed countries get access to technology, and on the impact which the transferred technologies have on development.

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