Karl Marx on the Economic Role of Science
Author(s): Nathan Rosenberg
Source: *Journal of Political Economy*, Vol. 82, No. 4 (Jul. - Aug., 1974), pp. 713-728
Published by: The University of Chicago Press
Stable URL: https://www.jstor.org/stable/1837142
Accessed: 21-02-2019 05:06 UTC

Karl Marx on the Economic Role of Science

Nathan Rosenberg

University of Wisconsin

> It is not the articles made, but how they are made, and by what instruments, that enables us to distinguish different economical epochs. [MARX 1906, p. 200]

This paper examines Marx's treatment of rising resource productivity and technological change under capitalism. Little attention has been given to Marx's view of the role which science plays in these processes. It is obvious that Marx (and Engels) attach the greatest importance to the development of modern science, but the way in which scientific progress meshes with the rest of the Marxian system has not been fully understood. The paper analyzes Marx's treatment of the factors which account for the growth of scientific knowledge as well as capitalist society's changing capacity to incorporate this knowledge into the productive process.

The purpose of this paper is to examine certain aspects of Marx's treatment of rising resource productivity and technological change under capitalism. Many of the most interesting aspects of Marx's treatment of technological change have been ignored, perhaps because of the strong polemical orientation which readers from all shades of the political spectrum seem to bring to their reading of Marx. As a result, much has been written about the impact of the machine upon the worker and his family, the phenomenon of alienation, the relationship between technological change, real wages, employment, etc. At the same time, a great deal of what Marx had to say concerning some 300 years of European capitalist development has received relatively little attention. This applies to his views dealing with the complex interrelations between science, technology, and economic development.

It is a well-known feature of the Marxian analysis of capitalism that Marx views the system as bringing about unprecedented increases in

The author is grateful to Professors Stanley Engerman and Eugene Smolensky for critical comments on an earlier draft.

human productivity and in man's mastery over nature. Marx and Engels told their readers, in *The Communist Manifesto*, that "the bourgeoisie, during its rule of scarce one hundred years, has created more massive and more colossal productive forces than have all preceding generations together. Subjection of Nature's forces to man, machinery, application of chemistry to industry and agriculture, steam-navigation, railways, electric telegraphs, clearing of whole continents for cultivation, canalisation of rivers, whole populations conjured out of the ground—what earlier century had even a presentiment that such productive forces slumbered in the lap of social labour?" (Marx and Engels 1951, 1: 37). No single question, therefore, would seem to be more important to the whole Marxian analysis of capitalist development than the question: Why is capitalism such an immensely productive system by comparison with all earlier forms of economic organization? The question, obviously, has been put before, and certain portions of Marx's answer are in fact abundantly plain. In particular, the social and economic structure of capitalism is one which creates enormous incentives for the generation of technological change. Marx and Engels insist that the bourgeoisie is unique as a ruling class because, unlike all earlier ruling classes whose economic interests were indissolubly linked to the maintenance of the status quo, the very essence of bourgeois rule is technological dynamism.[1] Capitalism generates unique incentives for the introduction of new, cost-reducing technologies.

The question which I am particularly interested in examining is the role which is played, within the Marxian framework, by science and scientific progress in the dynamic growth of capitalism. For surely the growth in resource productivity can never have been *solely* a function of the development of capitalist institutions. It is easy to see the existence of such institutions as a necessary condition but hardly as a sufficient condition for such growth. Surely the technological vitality of an emergent capitalism was closely linked up with the state of scientific knowledge and with industry's capacity to exploit such knowledge.

Marx's (and Engels's) position, briefly stated, is to affirm that science is, indeed, a fundamental factor accounting for the growth in resource productivity and man's enlarged capacity to manipulate his natural environment for the attainment of human purposes. However, the statement requires two immediate and highly significant qualifications, which will constitute our major concern in this paper: (1) science does not, according to Marx, function in history as an independent variable; and (2) science has come to play a critical role as a systematic contributor to increasing productivity only at a very recent (from Marx's perspective)

[1] "The bourgeoisie cannot exist without constantly revolutionising the instruments of production, and thereby the relations of production, and with them the whole relations of society. Conservation of the old modes of production in unaltered form, was, on the contrary, the first condition of existence for all earlier industrial classes" (Marx and Engels 1951, 1:36).

point in history. The ability of science to perform this role had necessarily to await the fulfillment of certain objective conditions. What these conditions were has not been understood adequately.

I

Marx's treatment of scientific progress is consistent with his broader historical materialism. Just as the economic sphere and the requirements of the productive process shape man's political and social institutions, so do they also shape his scientific activity at all stages of history. Science does not grow or develop in response to forces internal to science or the scientific community. It is not an autonomous sphere of human activity. Rather, science needs to be understood as a social activity which is responsive to economic forces. It is man's changing needs as they become articulated in the sphere of production which determine the direction of scientific progress. Indeed, this is generally true of all human problem-solving activity, of which science is a part. As Marx states in the introduction to his *Critique of Political Economy*: "Mankind always takes up only such problems as it can solve; since, looking at the matter more closely, we will always find the problem itself arises only when the material conditions necessary for its solution already exist or are at least in the process of formulation" (Marx 1904, pp. 12–13).

Marx views specific scientific disciplines as developing in response to problems arising in the sphere of production. The materialistic conception of history and society involves the rejection of the notion that man's intellectual pursuits can be accorded a status independent of material concerns. It emphasizes the necessity of systematically relating the realm of thinking and ideas to man's material concerns. Thus, the scientific enterprise itself needs to be examined in that perspective. "Feuerbach speaks in particular of the perception of natural science; he mentions secrets which are disclosed only to the eye of the physicist and chemist: but where would natural science be without industry and commerce? Even this 'pure' natural science is provided with an aim, as with its material, only through trade and industry, through the sensuous activity of men" (Marx and Engels 1947, p. 36). Egyptian astronomy had developed out of the compelling need to predict the rise and fall of the Nile, upon which Egyptian agriculture was so vitally dependent (Marx 1906, p. 564, n. 1). The increasing (if still "sporadic") resort to machinery in the seventeenth century was, says Marx, "of the greatest importance, because it supplied the great mathematicians of that time with a practical basis and stimulant to the creation of the science of mechanics."[2] The difficulties encountered with

[2] Marx 1906, pp. 382–83. Engels states: "Like all other sciences, mathematics arose out of the *needs* of men; from the measurement of land and of the content of vessels; from the computation of time and mechanics" (Engels 1939, p. 46; emphasis Engels's. Cf. Marx 1906, p. 564).

gearing as waterpower was being harnessed to larger millstones was "one of the circumstances that led to a more accurate investigation of the laws of friction."[3]

These themes are repeated by Engels, who asserts that "from the very beginning the origin and development of the sciences has been determined by production."[4] In accounting for the rise of science during the Renaissance, his first explanation again drew upon the requirements of industry.

> If, after the dark night of the Middle Ages was over, the sciences suddenly arose anew with undreamt-of force, developing at a miraculous rate, once again we owe this miracle to production. In the first place, following the crusades, industry developed enormously and brought to light a quantity of new mechanical (weaving, clock-making, milling), chemical (dyeing, metallurgy, alcohol), and physical (spectacles) facts, and this not only gave enormous material for observation, but also itself provided quite other means for experimenting than previously existed, and allowed the construction of *new* instruments; it can be said that really systematic experimental science now became possible for the first time.[5]

Moreover, in a letter written in 1895, Engels stated: "If, as you say, technique largely depends on the state of science, science depends far more still on the *state* and the *requirements* of technique. If society has a technical need, that helps science forward more than ten universities. The whole of hydrostatics (Torricelli, etc.) was called forth by the necessity for regulating the mountain streams of Italy in the sixteenth and seventeenth centuries. We have only known about electricity since its technical applicability was discovered" (Marx and Engels 1951, 2: 457, Letter from Engels to H. Starkenburg, January 25, 1895; emphasis Engels's).

[3] Marx 1906, p. 411. He adds: "In the same way the irregularity caused by the motive power in mills that were put in motion by pushing and pulling a lever, led to the theory, and the application, of the flywheel, which afterwards plays so important a part in Modern Industry. In this way, during the manufacturing period, were developed the first scientific and technical elements of Modern Mechanical Industry."

[4] Engels 1954, p. 247. Earlier in the paragraph, he had stated: "The successive development of the separate branches of natural science should be studied. First of all, astronomy, which, if only on account of the seasons, was absolutely indispensable for pastoral and agricultural peoples. Astronomy can only develop with the aid of mathematics. Hence this also had to be tackled. Further, at a certain stage of agriculture and in certain regions (raising of water for irrigation in Egypt), and especially with the origin of towns, big building structures and the development of handicrafts, mechanics also arose. This was soon needed also for navigation and war. Moreover, it requires the aid of mathematics and so promoted the latter's development."

[5] Ibid., p. 248. The editor of Engels's unfinished manuscript points out that Engels had written in the margin of the manuscript opposite this paragraph: "Hitherto, what has been boasted of is what production owes to science, but science owes infinitely more to production."

This statement is probably the most explicit and direct assertion in the writings of Marx and Engels that factors affecting the demand for science are overwhelmingly more important than factors affecting its supply. Scientific knowledge is acquired when a social need for that knowledge has been established. Science is, however, not an initiating force in the dynamics of social change. Developments in this sphere are a response to forces originating elsewhere. Thus, Marx and Engels appear to be presenting a purely demand-determined explanation of the social role of science. Scientific enterprise supplies that which industry demands, and therefore the changing direction of the thrust of science needs to be understood in terms of the changing requirements of industry.

II

In this section I will argue that, while the demand-oriented component of the argument just presented is indeed a major part of the Marxian view, there are also vital but less conspicuous elements in Marx's argument which have been ignored. Without these additional and more neglected elements one cannot explain a central thesis which emerges out of Marx's view: namely, that it is only at a particular time in human history that science is enlisted in a crucial way in the productive process. It is only at a very recent point in history, Marx argues, that the marriage of science and industry occurs. Moreover, this marriage does *not* coincide with the historical emergence of capitalism. In fact, Marx is quite explicit that the union of science and industry comes only centuries after the arrival of modern capitalism and the emergence of sophisticated bodies of theoretical science. If arguments based upon the existence of capitalist incentives and demand forces generally were a sufficient explanation, the full-scale industrial exploitation of science would have come at a much earlier stage in Western history. But it did not. Why?

Stripped to its essentials, Marx's answer is that the handicraft and manufacturing stages of production lacked the technological basis which would *permit* the application of scientific knowledge to the solution of problems of industrial production.[6] This essential technological basis

[6] Since the subsequent discussion turns directly upon the Marxian periodization scheme, it is important to remind the reader of the meaning which Marx attaches to the terms "handicraft," "manufacture," and "modern industry." Engels expressed Marx's meanings succinctly as follows: "We divide the history of industrial production since the Middle Ages into three periods: (1) handicraft, small master craftsmen with a few journeymen and apprentices, where each laborer produces the complete article; (2) manufacture, where greater numbers of workmen, grouped in one large establishment, produce the complete article on the principle of division of labor, each workman performing only one partial operation, so that the product is complete only after having passed successively through the hands of all; (3) modern industry, where the product is produced by machinery driven by power, and where the work of the laborer is limited to superintending and correcting the performances of the mechanical agent" (Engels 1910, pp. 12–13).

emerged only with modern industry. The immense and growing productivity of nineteenth century British industry was really, in Marx's view, the resultant of three converging sets of forces: (1) the unique incentive system and capacity for accumulation provided by capitalist institutions, (2) the availability of bodies of scientific knowledge[7] which were directly relevant for problem-solving activities in industry, and (3) a technology possessing certain special characteristics. It is this last category which is least understood and to which we therefore now turn.

Historically, capitalist relationships were introduced in an unobtrusive way, by the mere quantitative expansion in the number of wage-laborers employed by an individual owner of capital (Marx 1906, p. 367). The independent handicraftsman, operating with a few journeymen and apprentices, gradually shifted into the role of a capitalist as his relationship with these men assumed the form of a permanent system of wage payments and as the number of such laborers increased.[8] The system of manufacture, therefore, while introducing social relationships drastically different from the handicraft system of the medieval guilds which preceded it,[9] initially employed the same technology.[10]

From Marx's mid-nineteenth-century vantage point, the system of manufacture had actually been the dominant one throughout most of the history of capitalism—from "roughly speaking . . . the middle of the 16th to the last third of the 18th century" (Marx 1906, p. 369; see also p. 787).

[7] Actually, Marx's use of the term "science" was sufficiently broad that it included bodies of systematized knowledge far beyond what we ordinarily mean when we speak today of pure or even applied science—e.g., engineering and machine building. It was not a term which he attempted to use with precision. In *Theories of Surplus Value*, for instance, he refers to science simply as "the product of mental labour" (Marx 1963, pt. 1, p. 353).

[8] "With regard to the mode of production itself, manufacture, in its strict meaning, is hardly to be distinguished, in its earliest stages, from the handicraft trades of the guilds, otherwise than by the greater number of workmen simultaneously employed by one and the same individual capital. The workshop of the medieval master handicraftsman is simply enlarged" (Marx 1906, p. 353. Cf. Marx and Engels 1947, pp. 12–13).

[9] "With manufacture was given simultaneously a changed relationship between worker and employer. In the guilds the patriarchal relationship between journeyman and master maintained itself; in manufacture its place was taken by the monetary relation between worker and capitalist—a relationship which in the countryside and in small towns retained a patriarchal tinge, but in the larger, the real manufacturing towns, quite early lost almost all patriarchal complexion" (Marx and Engels 1947, p. 52).

[10] Machinery had sometimes been employed in earlier periods, but Marx clearly regarded these instances as exceptional. "Early in the manufacturing period the principle of lessening the necessary labour-time in the production of commodities, was accepted and formulated: and the use of machines, especially for certain simple first processes that have to be conducted on a very large scale, and with the application of great force, sprang up here and there. Thus, at an early period in paper manufacture, the tearing up of the rags was done by paper mills; and in metal works, the pounding of the ores was effected by stamping mills. The Roman Empire had handed down the elementary form of all machinery in the water-wheel" (Marx 1906, p. 382). In a footnote Marx makes the extremely interesting observation that "the whole history of the development of machinery can be traced in the history of the corn mill" (ibid., p. 382, n. 3).

Manufacture involved a significant regrouping of workers and a redefinition of the responsibilities of each. Whereas a medieval handicraftsman would himself perform a succession of operations upon a product, the manufacturing system divided up the operation into a succession of steps, each one of which was allocated to a separate workman.[11]

The essence of the manufacturing system, therefore, is a growing specialization on the part of the individual worker. While this in turn has psychological and social consequences of the greatest importance for the worker with which Marx was very much concerned,[12] it continued to share with the earlier handicraft system an essential feature. That is to say, although the product now passed through a succession of hands, and although this reorganization raised the productivity of labor, it nevertheless perpetuated the industrial system's reliance upon human skills and capacities.[13] Whereas the critical skill was formerly that of the guild craftsman, it is now the unremitting repetition of a narrowly defined activity on the part of the detail laborer. More precisely, the productive process now pressed against the constraints imposed by the limited strength, speed, precision, and, indeed, the limited number of limbs, of the human animal.

So long as the worker continues to occupy strategic places in the productive process, that process is limited by all of his human frailties. And, of course, the individual capitalist is, in many ways, continually pressing the worker against those limits. But the point which Marx is making here is of much broader significance: The application of science to the productive

[11] "The needlemaker of the Nuremberg Guild was the cornerstone on which the English needle manufacture was raised. But while in Nuremberg that single artificer performed a series of perhaps 20 operations one after another, in England it was not long before there were 20 needlemakers side by side, each performing one alone of those 20 operations; and in consequence of further experience, each of those 20 operations was again split up, isolated, and made the exclusive function of a separate workman" (ibid., pp. 370–71).

[12] "While simple co-operation leaves the mode of working by the individual for the most part unchanged, manufacture thoroughly revolutionises it, and seizes labour-power by its very roots. It converts the labourer into a crippled monstrosity, by forcing his detail dexterity at the expense of a world of productive capabilities and instincts; just as in the States of La Plata they butcher a whole beast for the sake of his hide or his tallow" (ibid., p. 396).

[13] "For a proper understanding of the division of labour in manufacture, it is essential that the following points be firmly grasped. First, the decomposition of a process of production into its various successive steps coincides, here, strictly with the resolution of a handicraft into its successive manual operations. Whether complex or simple, each operation has to be done by hand, retains the character of a handicraft, and is therefore dependent on the strength, skill, quickness, and sureness, of the individual workman in handling his tools. The handicraft continues to be the basis. 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 and of forming, in its way, a separate handicraft. It is just because handicraft skill continues, in this way, to be the foundation of the process of production that each workman becomes exclusively assigned to a partial function, and that for the rest of his life, his labour-power is turned into the organ of this detail function" (ibid., pp. 371–72).

process involves dealing with impersonal laws of nature and freeing itself from all dependence upon the organic. It involves calculations concerning the behavior of natural phenomena. It involves the exploitation of reliable physical relationships which have been established by scientific disciplines. It involves a degree of predictability of a purely objective sort, from which the uncertainties and subjectivities of human behavior have been systematically excluded. Science, in short, can only incorporate its findings in impersonal machinery. It cannot be incorporated in human beings with their individual volitions, idiosyncracies, and refractory temperaments. The manufacturing period shared with the earlier handicraft system the essential feature that it was a tool-using economy where the tools were subject to human manipulation and guidance. It is this element of human control, the continued reliance upon the limited range of activities of the human hand, and not the nature of the power source, Marx insists, which is decisive in distinguishing a machine from a tool.

> The machine proper is . . . a mechanism that, after being set in motion, performs with its tools the same operations that were formerly sone by the workman with similar tools. Whether the motive power is derived from man, or from some other machine, makes no difference in this respect. From the moment that the tool proper is taken from man, and fitted into a mechanism, a machine takes the place of a mere implement. The difference strikes one at once, even in those cases where man himself continues to be the prime mover. The number of implements that he himself can use simultaneously, is limited by the number of his own natural instruments of production, by the number of his bodily organs. . . . The number of tools that a machine can bring into play simultaneously, is from the very first emancipated from the organic limits that hedge in the tools of a handicraftsman.[14]

III

What, then, is the distinctive technological feature of modern industry? It is that, for the first time, the design of the productive process is carried out on a basis where the characteristics of the worker and his physical

[14] Ibid., p. 408; see also p. 410. In his early work, *The Poverty of Philosophy*, Marx had stated: "The machine is a unification of the instruments of labour, and by no means a combination of different operations for the worker himself. 'When, by the division of labour, each particular operation has been simplified to the use of a single instrument, the linking-up of all these instruments, set in motion by a single engine, constitutes— a machine.' (Babbage, *Traité sur l'Economie des Machines*, etc., Paris 1833). Simple tools; accumulation of tools; composite tools; setting in motion of a composite tool by a single hand engine, by men; setting in motion of these instruments by natural forces, machines; system of machines having one motor; system of machines having one automatic motor— this is the progress of machinery" (Marx, n.d., pp. 132–33. This book was first published in 1847).

endowment are no longer central to the organization and arrangement of capital. Rather, capital is being designed in accordance with a completely different logic, a logic which explicitly incorporates principles of science and engineering.[15] The subjectivity of a technology adapted, out of necessity, to the capacities (or, better, the debilities) of the worker is rejected in favor of the objectivity of machinery which has been designed in accordance with its own laws and the laws of science.

> In Manufacture it is the workmen who, with their manual implements, must, either singly or in groups, carry on each particular detail process. If, on the one hand, the workman becomes adapted to the process, on the other, the process was previously made suitable to the workman. This subjective principle of the division of labour no longer exists in production by machinery. Here, the process as a whole is examined objectively, in itself, that is to say, without regard to the question of its execution by human hands, it is analysed into its constituent phases; and the problem, how to execute each detail process, and bind them all into a whole, is solved by the aid of machines, chemistry, etc.[16]

The shift from the hand-operated to the machine-operated process is a momentous one, for the simple reason that machine processes are susceptible to continuous and indefinite improvement, whereas hand processes are not.[17] The factory system makes possible the virtual routinization of productivity improvement.[18] By breaking down the productive process

[15] There is an important learning experience at the technological level before this can be done well. "It is only after considerable development of the science of mechanics, and accumulated practical experience, that the form of a machine becomes settled entirely in accordance with mechanical principles, and emancipated from the traditional form of the tool that gave rise to it" (Marx 1906, p. 418, n. 1). A typical aspect of the innovation process, therefore, is that machines go through a substantial process of modification after their first introduction (see ibid., p. 442).

[16] Ibid., pp. 414–15. Later, Marx adds: "The implements of labour, in the form of machinery, necessitate the substitution of natural forces for human force, and the conscious application of science, instead of rule of thumb. In Manufacture, the organization of the social labour-process is purely subjective; it is a combination of detail labourers; in its machinery system, Modern Industry has a productive organism that is purely objective, in which the labourer becomes a mere appendage to an already existing material condition of production" (p. 421).

[17] "As soon as a machine executes, without man's help, all the movements requisite to elaborate the raw material, needing only attendance from him, we have an automatic system of machinery, and one that is susceptible of constant improvement in its details" (ibid., p. 416).

[18] In a valuable article, "Karl Marx and the Industrial Revolution," Paul Sweezy argues that many of the important differences between Marx and his classical predecessors reduced to the fact that the classical economists "took as their model an economy based on manufacture, which is an essentially conservative and change-resistant economic order; while Marx, recognizing and making full allowance for the profound transformation effected by the industrial revolution, took as his model an economy based on modern machine industry" (Sweezy 1968, p. 115).

into objectively identifiable component parts, it creates a structure of activities which is readily amenable to rigorous analysis. "The principle, carried out in the factory system, of analysing the process of production into its constituent phases, and of solving the problems thus proposed by the application of mechanics, of chemistry, and of the whole range of the natural sciences, becomes the determining principle everywhere."[19] Thus, historical development has brought technology to a point where it has become, for the first time, an object of scientific analysis and improvement.

> A characteristic feature is, that, even down into the eighteenth century, the different trades were called "mysteries" (mystères); into their secrets none but those duly initiated could penetrate. Modern Industry rent the veil that concealed from men their own social process of production, and that turned the various spontaneously divided branches of production into so many riddles, not only to outsiders, but even to the initiated. The principle which it pursued, of resolving each process into its constituent movements, without regard to their possible execution by the hand of man, created the new modern science of technology. The varied, apparently unconnected, and petrified forms of the industrial processes now resolved themselves into so many conscious and systematic applications of natural science to the attainment of given useful effects. Technology also discovered the few main fundamental forms of motion, which, despite the diversity of the instruments used, are necessarily taken by every productive action of the human body; just as the science of mechanics sees in the most complicated machinery nothing but the continual repetition of the simple mechanical powers.
>
> Modern Industry never looks upon and treats the existing form of a process as final. The technical basis of that industry is therefore revolutionary, while all earlier modes of production were essentially conservative.[20]

In its most advanced form, therefore, "modern industry . . . makes science a productive force distinct from labour and presses it into the service of capital" (Marx 1906, p. 397).

Before capitalism could reach this stage of self-sustaining technological

[19] Marx 1906, p. 504. The manufacturing stage needs to be seen as an essential step in the introduction of science into the productive process. The application of science required that productive activity be broken down into a series of separately analyzable steps. The manufacturing system, even though it continued to rely upon human skills, accomplished precisely this when it replaced the handicraftsman with a number of detail laborers. In this important sense it "set the stage" for the advent of modern industry.

[20] Ibid., p. 532. Marx (1959) examines the vast possibilities for capital-saving innovations and improvements in an advanced capitalist economy in *Capital*, vol. 3, chaps. 4 and 5.

dynamism, however, another critical condition needed to be fulfilled. Machinery cannot fully liberate the economy from the output ceiling imposed by dependence upon human skills and capacities so long as these things continue to be essential in the production of the machines themselves. In the early stages of modern industry, machines were, inevitably, produced by direct reliance upon human skills and capacities. The manufacturing system responded to the demand for the new inventions by creating new worker specializations.[21] While this sufficed in the early stages of the development of modern industry, improvements in machine design and performance and increasing size eventually came up increasingly against the limitations of the human machine maker.

> 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 on the muscular development, the keenness of sight, and the cunning of hand, with which the detail workmen in manufactures and the manual labourers in handicrafts, wielded their dwarfish implements. Thus, apart from the dearness of the machines made in this way, a circumstance that is ever present to the mind of the capitalist, the expansion of industries carried on by means of machinery, and the invasion by machinery of fresh branches of production, were dependent on the growth of a class of workmen, who, owing to the almost artistic nature of their employment, could increase their numbers only gradually, and not by leaps and bounds. But besides this, at a certain stage of its development, Modern Industry became technologically incompatible with the basis furnished for it by handicraft and Manufacture. The increasing size of the prime movers, of the transmitting mechanism, and of the machines proper, the greater complication, multiformity and regularity of the details of these machines, as they more and more departed from the model of those originally made by manual labour, and acquired a form, untrammelled except by the conditions under which they worked, the perfecting of the automatic system, and the use, every day more unavoidable, of a more refractory material, such as iron instead of wood—the solution of all these problems, which sprang up by the force of circumstances, everywhere met

[21] "As inventions increased in number, and the demand for the newly discovered machines grew larger, the machine-making industry split up, more and more, into numerous independent branches, and division of labour in these manufactures was more and more developed. Here, then, we see in Manufacture the immediate technical foundation of Modern Industry. Manufacture produced the machinery, by means of which Modern Industry abolished the handicraft and manufacturing systems in those spheres of production that it first seized upon" (Marx 1906, p. 417).

> with a stumbling-block in the personal restrictions which even the collective labourer of Manufacture could not break through, except to a limited extent. Such machines as the modern hydraulic press, the modern powerloom, and the modern carding engine, could never have been furnished by Manufacture.[22]

The vital step, therefore, is the establishment of the technological conditions which would make it possible to use machinery in the construction of machines, thus bypassing the central constraint of the old manufacturing system. "Modern Industry had therefore itself to take in hand the machine, its characteristic instrument of production, and to construct machines by machines. It was not till it did this, that it built up for itself a fitting technical foundation, and stood on its own feet. Machinery, simultaneously with the increasing use of it, in the first decades of this century, appropriated, by degrees, the fabrication of machines proper."[23] Marx singles out, not only the new power sources which offered gigantic quantities of energy subject to careful human regulation, but also that indispensable addition to the equipment at the disposal of the machine maker, the slide rest. This simple but ingenious device of Henry Maudsley replaces, as Marx perceptively notes, not any particular tool, "but the hand itself" (Marx 1906, p. 408). In this sense it is a strategic technological breakthrough, fully comparable in importance to the steam engine.

The improvements in the machinery-producing sector constitute a quantum leap in the technological arsenal at man's disposal. They make it possible to escape the physical limitations of a tool-using culture. They do this, ironically as Marx points out, by providing machines which reproduce the actions of a hand-operated tool, but do so on a "cyclopean scale."[24]

[22] Ibid., pp. 417–18. Marx saw the improvements in the means of communication and transportation as particularly significant in pushing the productive process beyond the limitations inherent in the manufacturing system. "The means of communication and transport became gradually adapted to the modes of production of mechanical industry, by the creation of a system of river steamers, railways, ocean steamers, and telegraphs. But the huge masses of iron that had now to be forged, to be welded, to be cut, to be bored, and to be shaped, demanded, on their part, cyclopean machines, for the construction of which the methods of the manufacturing period were utterly inadequate" (pp. 419–20).

[23] Ibid., p. 420. Marx saw this process as culminating during his own time. "It is only during the last 15 years (i.e., since about 1850), that a constantly increasing portion of these machine tools have been made in England by machinery, and that not by the same manufacturers who make the machines" (p. 408).

[24] "If we now fix our attention on that portion of the machinery employed in the construction of machines, which constitutes the operating tool, we find the manual implements reappearing, but on a cyclopean scale. The operating part of the boring machine is an immense drill driven by a steam-engine; without this machine, on the other hand, the cylinders of large steam-engines and of hydraulic presses could not be made. The mechanical lathe is only a cyclopean reproduction of the ordinary footlathe; the planing machine, an iron carpenter, that works on iron with the same tools that the human carpenter employs on wood; the instrument that, on the London wharves, cuts

IV

Thus, I would interpret the Marxian position to be that it is the changing requirements of industry and the altering perception of economic needs which provide the stimulus to the *pursuit* of specific forms of scientific knowledge. But I would also conclude that the Marxian position cannot be adequately described as a demand-induced approach without doing a severe injustice to the subtlety of Marx's historical analysis.[25] For the ability to apply science to the productive sphere turns upon industry's changing *capacity* to utilize such knowledge, a capacity which Marx explicitly recognizes has been subjected to great changes over the course of recent history. Indeed, Marx himself, as I have tried to establish, devoted considerable effort to the elucidation of the factors which have shaped society's altering capacity to absorb the fruits of scientific knowledge.[26]

Nor did Marx argue that the historical sequence in which scientific disciplines actually developed was also directly determined by economic needs. For example, in discussing the relative pace of development in industry and agriculture, he states that productivity growth in agriculture had, historically, to await the development of certain scientific disciplines, and therefore came later, whereas industry progressed more rapidly than agriculture at least in large part because the scientific knowledge upon

the veneers, is a gigantic razor; the tool of the shearing machine, which shears iron as easily as a tailor's scissors cut cloth, is a monster pair of scissors; and the steam hammer works with an ordinary hammer head, but of such a weight that not Thor himself could wield it. These steam hammers are an invention of Nasmyth, and there is one that weighs over 6 tons and strikes with a vertical fall of 7 feet, on an anvil weighing 36 tons. It is mere child's play for it to crush a block of granite into powder, yet it is not less capable of driving, with a succession of light taps, a nail into a piece of soft wood" (ibid., p. 421; see also pp. 492–93).

[25] At one point Marx presents what one might be tempted to call a Toynbeean "challenge-response" mechanism to account for the emergence of high productivity societies. It is not true, he says, "that the most fruitful soil is the most fitted for the growth of the capitalist mode of production. This mode is based on the dominion of man over nature. Where nature is too lavish, she 'keeps him in hand, like a child in leading-strings.' She does not impose upon him any necessity to develop himself. It is not the tropics with their luxuriant vegetation, but the temperate zone, that is the mother country of capital. It is not the mere fertility of the soil, but the differentiation of the soil, the variety of its natural products, the changes of the seasons, which form the physical basis for the social division of labour, and which, by changes in the natural surroundings, spur man on to the multiplication of his wants, his capabilities, his means and modes of labor. It is the necessity of bringing a natural force under the control of society, of economising, of appropriating or subduing it on a large scale by the work of man's hand, that first plays the decisive part in the history of industry" (ibid., pp. 563–64).

[26] In this light, there is no necessary conflict between Marx's materialist conception of history and his treatment of science as a productive force under advanced capitalism. I therefore disagree with the following statement of Bober: "Marx intends to offer a materialistic conception of history. Yet he frequently stresses the power of science as a component of modern technique and production. The incorporation of science in the foundation of his theory is no more defensible than the inclusion of all other nonmaterial phenomena" (Bober 1965, p. 21).

which industry relied had developed earlier. "Mechanics, the really scientific basis of large-scale industry, had reached a certain degree of perfection during the eighteenth century. The development of chemistry, geology and physiology, the sciences that *directly* form the specific basis of agriculture rather than of industry, does not take place till the nineteenth century and especially the later decades."[27]

This strongly suggests at least some degree of independence and autonomy on the part of science in shaping the sequence of industrial change, in spite of the fact that, as we saw earlier, Marx and Engels usually emphasize the cause-effect relationships which run from industry to science. If the growth in agricultural productivity is dependent upon progress in specific subdisciplines of science, and if the existence of profitable commercial opportunities in agriculture cannot "induce" the production of the requisite knowledge, then factors internal to the realm of science must be conceded to play a role independent of economic needs.

Moreover, it is especially curious to find that Engels is content to state, as quoted earlier, that "from the very beginning the origin and development of the sciences has been determined by production" (Engels 1954, p. 247). For Engels himself, in the *Dialectics of Nature*, had also presented a classification scheme for the sciences which emphasized a hierarchy of increasing complexity based upon the forms of motion of the matter being analyzed. Increasing complexity is identified with the movement from the inorganic to the organic, from mechanics to physics to chemistry to biology.[28] Engels even goes so far as to speak of an

[27] Marx 1968, pt. 2, p. 110. In *The German Ideology* Marx and Engels stated that "the science of mechanics perfected by Newton was altogether the most popular science in France and England in the eighteenth century" (Marx and Engels 1947, p. 56).

[28] "Hegel's division (the original one) into mechanics, chemics, and organics, fully adequate for the time. Mechanics: the movement of masses. Chemics: molecular (for physics is also included in this and, indeed, both—physics as well as chemistry—belong to the same order) motion and atomic motion. Organics: the motion of bodies in which the two are inseparable. For the organism is certainly *the higher unity which within itself unites mechanics, physics, and chemistry into a whole* where the trinity can no longer be separated. In the organism, mechanical motion is effected directly by physical and chemical change, in the form of nutrition, respiration, secretion, etc., just as much as pure muscular movement" (Engels 1954, pp. 331–32; emphasis Engels's). For Engels's entire treatment of the subject, see ibid., pp. 322–408. In his book, *Herr Eugen Duhring's Revolution in Science*, Engels draws a sharp distinction between the sciences concerned with inanimate nature and those concerned with living organisms. The former group of sciences (mathematics, astronomy, mechanics, physics, chemistry) are susceptible to mathematical treatment "to a greater or less degree." No such precision is possible in the sciences concerned with living organisms. "In this field there is such a multitude of reciprocal relations and causalities that not only does the solution of each question give rise to a host of other questions, but each separate problem can usually only be solved piecemeal, through a series of investigations which often requires centuries to complete; and even then the need for a systematic presentation of the interrelations makes it necessary again and again to surround the final and ultimate truths with a luxuriant growth of hypotheses" (Engels 1939, pp. 97–99).

"inherent sequence,"[29] which he clearly believes has structured the *historical* sequence in which nature's secrets have been progressively uncovered. But, if one accepts this intuitively plausible view, then surely there is much more to "the origin and development of the sciences" than can be accounted for by the specific demands being generated in the productive sphere. Surely the historical fact that the biological sciences came to the assistance of agriculture long after the mechanical sciences were being utilized by industry is a sequence originating, not in economic needs, but in the differing degrees of complexity of these scientific disciplines. Engels's formulations particularly seem to overemphasize the importance of demand-induced incentives to the neglect of supply side considerations, even though he is obviously sensitive to these supply variables in other contexts.

In Engels's defense one must recall, of course, the unfinished, indeed often merely fragmentary condition of his *Dialectics of Nature*.[30] It is entirely possible that, had he the opportunity, he would have resolved these apparent inconsistencies. But it is expecting far too much to look to either Marx or Engels for the resolution of these deep and thorny problems. We are still, today, a long way from being able to incorporate the history of science in an orderly manner into our understanding of the economic development of the Western world.[31]

Conclusion

There are several possible meanings which can be attached to the statement that "the origin and development of the sciences has been determined by production."

1. Science depends upon industry for financial support.
2. The expectation of high financial returns is what motivates individuals (and society) to pursue a particular scientific problem.
3. The needs of industry serve as a powerful agent in calling attention to certain problems (Pasteur's studies of fermentation and silkworm epidemics).

[29] "Classification of the sciences, each of which analyzes a single form of motion, or a series of forms of motion that belong together and pass into one another, is therefore the classification, the arrangement, of these forms of motion themselves according to their inherent sequence, and herein lies its importance" (Engels 1954, p. 330; see also Zvorikine 1963, pp. 59–74).

[30] See Engels 1954, "Preface."

[31] The most ambitious attempt to fill this void is the fascinating but seriously flawed four-volume work by the late J. D. Bernal, *Science in History* (1971). His *Science and Industry in the Nineteenth Century* (London, 1953) is more restricted in scope and far more consistently persuasive. Nevertheless, *Science in History* displays an immense erudition, and all but the most remarkably well-informed readers will learn much from, and be greatly stimulated by, its contents.

4. The normal pursuit of productive activities throws up physical evidence of great importance to certain disciplines (metallurgy and chemistry, canal building and geology). As a result, industrial activities have, as a byproduct of their operation, provided the flow of raw observations upon which sciences have built and generalized.

5. The history of individual sciences, including an account of their varying rates of progress at different periods in history, can be adequately provided by an understanding of the changing economic needs of society.

I believe that Marx and Engels subscribed to propositions 1–4 without qualification. I believe they often *sounded* as if they subscribed to the fifth proposition. However, I think the preceding discussion has established that they subscribed to the fifth proposition only subject to certain qualifications—qualifications which strike me as being, collectively, more interesting than the original proposition.

References

Bernal, J. D. *Science and Industry in the Nineteenth Century.* London: Routledge & Kegan Paul, 1953.
———. *Science in History.* 4 vols. Cambridge, Mass.: M.I.T. Press, 1971.
Bober, M. M. *Karl Marx's Interpretation of History.* New York: Norton, 1965.
Engels, Frederick. *Socialism: Utopian and Scientific.* Chicago: Kerr, 1910.
———. *Herr Eugen Duhring's Revolution in Science.* New York: International, 1939.
———. *The Dialectics of Nature.* Moscow: Foreign Languages, 1954.
Marx, Karl. *A Contribution to the Critique of Political Economy.* Chicago: Kerr, 1904.
———. *Capital.* Vol. 1. Chicago: Kerr, 1906.
———. *Capital.* Vol. 3. Moscow: Foreign Languages, 1959.
———. *Theories of Surplus Value.* 3 pts. Moscow: Progress, 1963.
———. *The Poverty of Philosophy.* Moscow: Foreign Languages, n.d.
Marx, Karl, and Engels, Frederick. *The German Ideology.* New York: International, 1947.
———. *Selected Works.* 2 vols. Moscow: Foreign Languages, 1951.
Sweezy, Paul. "Karl Marx and the Industrial Revolution." *Events, Ideology and Economic Theory,* edited by Robert Eagly. Detroit: Wayne State Univ. Press, 1968.
Zvorikine, A. "Technology and the Laws of its Development." *The Technological Order,* edited by Carl F. Stover. Detroit: Wayne State Univ. Press, 1963.