Babbage: pioneer economist
by Nathan Rosenberg

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`. . . the arrangements which ought to regulate the interior economy of a manufactory, are founded on principles of deeper root than may have been supposed, and are capable of being usefully employed in preparing the road to some of the sublimest investigations of the human mind.[1]

Charles Babbage has recently been rediscovered as the "pioneer of the computer."[2] He needs to be rediscovered a second time for his contribution to the understanding of economics, especially for his penetrating and original insights into the economic role played by technological change in the course of industrial development. Indeed, it is fair to say that it was Babbage's book which first introduced the factory into the realm of economic analysis.

Babbage has lived a furtive, almost fugitive existence in the literature of economics. Joseph Schumpeter, in his magisterial *History of Economic Analysis*, refers to Babbage's book, *On the Economy of Machinery and Manufactures*, as "a remarkable performance of a remarkable man."[3]; Nevertheless, although Schumpeter's well-known book is more than 1,200 dense pages long, the treatment of Babbage is confined to a single footnote. Marl Blaug, in his *Economic Theory in Retrospect*, uses the same adjective as Schumpeter. He cites Babbage's book only to point out its influence on John Stuart Mill's discussion of increasing returns to scale in chapter 9 of book I of Mill's *Principles of Political Economy*. Mill's treatment of that N subject, Blaug states, "is heavily indebted to a remarkable book, *On the Economy of Machinery and Manufactures* (1833) by Charles Babbage."[4]

Babbage the economist deserves far better treatment than this. His book contains important contributions to economics which have received unduly short shrift. A book that, at the time of its publication, provided a considerable improvement upon a topic as seminal as Adam Smith's treatment of the division of labor and, at the same time, offered the first systematic analysis of the economies associated with increasing returns to scale, surely deserves to be rescued from the comparative obscurity of footnotes and parenthetic references.

I

Babbage's purpose in writing *On the Economy of Machinery and Manufactures* was to examine "the mechanical principles which regulate the application of machinery to arts and manufactures" (p. iii). The book is, in invaluable for its detailed, nontechnical descriptions of the manufacturing technologies that were employed in English workshops at the beginning of the 1830s. Babbage had, himself, travelled extensively through the industrial districts of England as well as continental Europe. And he was, as we know from his other remarkable accomplishments, no casual observer. On the contrary, he saw everything through the inquiring eyes of someone searching for more general underlying principles, categories, or commonalities. He sought, continuously, for some basis for classification and meaningful comparison. In brief, he wanted to illuminate his subject matter by rendering it subject to quantification and calculation.

In fact, the relationship of Babbage the economist to Babbage the inventor is a close one. That is to say, the book is, in an important sense, a by-product of Babbage's lifelong preoccupation with the

development of a calculating machine. Indeed, the opening sentence of the preface to the first edition of the book states that: "The present volume may be considered as one of the consequences that have resulted from the Calculating-Engine, the construction of which I have been so long superintending." Thus, the book shares a common provenance with the calculating engine. The power of systematic reasoning that Babbage invested in his attempt to develop such a machine is abundantly evident in the ways in which he organizes and classifies his data on the English industrial establishment in this books.[5]

This is particularly evident in chapter 11, "Of Copying," by far the longest chapter in the book. Babbage brings together in this chapter a wide array of industrial processes involving specific applications of printing, casting, moulding, engraving, stamping, punching, etc. The cheapness of machine operations in such processes turns upon the skill devoted to some original instrument or tool that subsequently may become the basis for many thousands of copies. The situation - involving the common denominator of a large fixed cost that lays the basis for cheap per-unit costs - is typical of the mass production technologies that were just beginning to emerge in Babbage's time.[6]

Babbage's travels through the manufacturing workshops of England were largely a consequence of the difficulties that he encountered in his own construction problems and his determination to become better informed concerning his technological options. Babbage's observations and descriptions are so informative that his book is well worth reading today just for its contribution to the history of technology, even if it were totally devoid of any other merit. Babbage even provides the reader with a guide for extracting useful and reliable information concerning productivity from factory visits.[7] The guide includes a suggested set of structured questions as well as some discreet methods of verifying the accuracy of responses by 2 checking for the internal consistency of answers. He also offers suggestions: when reliable information on factory output is not available:

`When this cannot be ascertained, the number of operations performed in a given time may frequently be counted when the workman is quite unconscious that any person is observing him. Thus the sound made by the motion of a loom may enable the observer to count the number of strokes per minute, even though he is outside the building in which it is contained. (p. 117)

Babbage would certainly have made a good industrial spy!

If Babbage at times seems to be writing with an excessively didactic hand, it is partly because he believes that greater attention to the empirical world, and especially the activities inside a factory, would significantly elevate the quality of economic analysis and reasoning generally.

`Political economists have been reproached with too small a use of facts, and too large an employment of theory. If facts are wanting, let it be remembered that the closet-philosopher is unfortunately too little acquainted with the admirable arrangements of the factory; and that no class of persons can supply so readily, and with so little sacrifice of time, the data on which all the reasoning of political economists are founded, as the merchants and manufacturer; and, unquestionably, to no class are the deductions to which they give rise so important. Nor let it be feared that erroneous deductions may be made from such recorded facts: the errors which arise from the absence of facts are far more numerous and more durable than those which result from unsound reasoning respecting true data.`(p. 156)

A person who could pen these words - especially the last sentence obviously has something of importance to say to the present generation of economists![8]

II

Babbage's distinctly economic contribution is taken up in section 11, the largest portion of the book,

where he considers the "economic principles which regulate the application of machinery," after the purely "mechanical principles" that were the focus of section I. The central point is that, as soon as one undertakes to produce a product in large volume, to become a manufacturer" rather than a "maker," it becomes necessary to devote careful and explicit attention to the organisation of production, to "the whole system" (p. 121) of the factory. Moreover, a manufacturer must be prepared to utilize, and perhaps to design, tools made expressly for a specialized purpose. One needs to consider, in other words, the division of labor.

Babbage begins his critical chapter 19, "On the Division of Labour," by asserting that "Perhaps the most important principle on which the economy of a manufacture depends, is the *division of labour* [Babbage's *italics*] amongst the persons who perform the work" (p. 169). Babbage's most distinctive contributions to the discipline of economics are generally regarded as his contributions to this subject. That view will not be challenged. However, I will suggest that his analysis of the division of labor constitutes an advance upon the classic treatment of the subject of much greater dimensions than has yet been recognized. Indeed, Babbage himself, a man who did not suffer from excessive modesty, also understated the extent of his own improvement upon Adam Smith.

As Babbage reminds his readers, Smith attributed the increased productivity flowing from the division of labor to "three different circumstances: first, to the increase of dexterity in every particular workman; secondly, to the saving of time, which is commonly lost in passing from one species of work to another; and, lastly, to the invention of a great number of machines which facilitate and abridge labour, and enable one man to do the work of many" (p. 175). Babbage goes on to assert that Smith has overlooked a key advantage that flows from the analysis of *The Wealth of Nations*, and that the analysis is therefore seriously incomplete.

When there is only a limited division of labor, each worker is required to perform a number of tasks, involving a variety of skills and physical capabilities. The supply of such skills and capabilities varies considerably for reasons having to do with length of training, previous experience, and natural differences in physical endowment. Accordingly, the remuneration received by workers who supply different skills will also vary considerably.

However, when there is a limited division of labor the employer is required, in effect, to purchase "bundles" of labor. Consequently, a workman who is capable of performing highly skilled work will need to receive a wage appropriate to these high skill levels, even though he will spend much, perhaps most, of his time performing work of lower skill, and pay, levels.

Seen from this perspective, the great virtue of the division of labor is that it permits an "unbundling" of labor skills, and allows the employer to pay for each separate labor process no more than the market value of the lower capabilities commensurate with such work. Under an extensive division of labor, the employer is no longer confronted with the necessity of purchasing labor corresponding to higher skill levels than those required for the specific project at hand.

In Babbage's own words,

`the master manufacturer by dividing the work to be executed into different processes, each requiring different degrees of skill or of force, can purchase exactly that precise quantity of both which is necessary for each process; whereas, if the whole work were executed by one workman, that person must possess sufficient skill to perform the most difficult, and sufficient strength to execute the most laborious, of the operations into which the art is divided (pp 175-176; emphasis Babbage's)

In elaborating his analysis of this point, and examining its implications, Babbage reverts to Adam Smith's time-honored example of the division of labor in a pin factory. He presents a detailed enumeration of the sequence of steps involved in the English manufacture of pins - wire-drawing, wirers straightening, pointing, twisting, and cutting the heads, heading, tinning, and papering. For

each separate step in the sequence, he identifies those who supply the labor - man, woman, boy, girl - and their rate of remuneration for each step. The wage rates of these separate labor inputs vary all the way from 4.5 pence per day up to 6 shillings per day (see table, p. 184). Taking into account the amount of time required for each step, and assuming that the highest-paid worker, the pin whitener (who earned 6 shillings a day at his speciality), could carry out each of the steps in pinmaking in the same amount of time as the individuals who perform each step under the prevailing division of labor. Babbage concludes that pins would cost 3.75 times as much as they actually did (p. 186). He then draws the generalisation: "The higher the skill required of the workman in any one process of a manufacture, and the smaller the time during which it is employed, so much the greater will be the advantage of separating that process from the rest, and devoting one person's attention entirely to it" (pp. ,168-187).

Years later, Babbage cogently restated his central point as follows:

`The most effective cause of the cheapness produced by the division of labour is this:

By dividing the work to be executed into different processes, each requiring different degrees of skill, or of force, the master manufacturer can purchase exactly that precise quantity of both which is necessary for each process. Whereas if the whole work were executed by one workman, that person must possess sufficient skill perform the most difficult, and sufficient strength to execute the most laborious, of those operations into which the art is divided.

Needle-making is perhaps the best illustration of the overpowering effect of this cause. The operatives in this manufacture consist of children, women, and men, earning wages varying from three or four shillings up to five pounds per week . Those who point the needles gain about two pounds. The man who hardens and tempers the needles earns from five to six pounds per week. It ought also to be observed that one man is sufficient to temper the needles for a large factory; consequently the time spent on each needle by the most expensive operative is excessively small.

But if a manufacturer insist on employing one man to make the whole needle, he must pay at the rate of five pounds a week for every portion of the labour bestowed upon it.[9]

This analysis of the benefits of an extensive division of labor was highly original. It did indeed constitute a major addition to Adam Smith's formulation, and it was precisely this point that exercised a heavy influence upon later economists, most especially, as we will see later, Marx. Nevertheless, Babbage also improved upon the formulation of Smith and others in several additional important respects that have not been widely recognized. This involved not only points of clarification but also points of analytical rigor.

Babbage observes that a more extensive division of labor leads to a reduction in the time required for learning, and therefore to a shortening of the time period during which a new labor force entrant is employed in a relatively unproductive and unremunerative way (p. 170). Then he makes the important observation, not to be found in Adam Smith, that conventional apprenticeship of five to seven years' duration was necessary in the past, not merely to allow the young man to acquire the requisite skill, but also "to enable him to repay by his labour, during the latter portion of his time, the expense incurred by his master at its commencement" (p. 170). If a new labor force entrant is required to learn only a single operation instead of many, he will much more quickly arrive at the stage where his employment generates a profit to his employer. If a competitive situations prevails among the masters, "the apprentice will be able to make better terms, and diminish the period of his servitude" (p. 170). Thus, the length of apprenticeship needs to be understood as determined not just by the timed necessary to acquire a skill, but also by the time necessary for the master to reap a normal rate of return upon his investment in the human capital of his apprentice (p. 170). One does not need to interpret Babbage's analysis here with excessive generosity in order to see it as a tantalizing precursor of the contemporary work of Gary Becker and Jacob Mincer on learning-by-doing.[10]

Babbage also makes an extremely significant qualification to Adam Smith's central point that specialisation leads to increased dexterity and therefore greater speed on the part of the workman who is no longer required to perform a number of separate operations. Babbage refers to Smith's example of nail-making. Smith had claimed that a smith, who was accustomed to make nails, but who was not solely occupied as a nailer, could only make 800 to 1,000 per day, "whilst a lad who had never exercised any other trade, can make upwards of two thousand three hundred a day (p. 173). In the case of the boys in his example, Smith had added the (perhaps not insignificant) qualification, "when they exerted themselves."[11] Moreover, Smith, as reported in his lectures, had used the lower figure of two thousand, although he also added "and those incomparably better."[12]

Babbage believed that the case of nail-making is "rather an extreme one"(p. 173). Moreover, factories with an extensive division of labor tend also to pay on the basis of piecework, which renders comparisons of labor productivity more difficult, since this mode of payment provides stronger incentives to increase output. But he had a much more fundamental qualification to append to Smith's emphasis upon the greater dexterity acquired by the workman who continuously performs the same process. These advantages to repetition, he states, are merely ephemeral. Under stable conditions, less specialized workers will move more slowly down the relevant learning curves, but they will eventually approach, even if they never entirely attain, some lower labor cost asymptote. Thus, the gain from the constant repetition of a process "is not a permanent source of advantage; for, though it acts at the commencement of an establishment, yet every month adds to the skill of the workmen; and at the end of three or four years they will not be very far behind those who have never practiced any other branch of their art" (p. 173). Here, as elsewhere, Babbage makes skillful use of a primitive sort of time-period analysis, which enables him to distinguish between immediate and longer-term consequences.[13] Thus, even though Babbage makes these points in a context where he is ostensibly recounting what was, when he wrote, merely conventional wisdom, he in fact ended up providing a fresh and quite powerful new insight.

III

Adam Smith's third advantage of the division of labor was that it gave rise to inventions. Smith's treatment of the determinants of inventive activity is extremely sparse; the textual treatment of the subject in chapter I of the *Wealth of Nations* occupied not much more than a single page. In Smith's view, in the earlier stages of industrial development, most inventions were the work of the users, that is, workmen whose attention was increasingly upon a single object. Eventually, however, when the division of labor gives rise to specialized makers of machinery, the ingenuity of these machine makers comes to play an increasingly important role; and finally, a more prominent role comes to be played by those to whom Smith refers as "philosophers or men of speculation, whose trade it is not to do any thing, but to observe every thing; and who, upon that account, are often capable of combining together the powers of the most distant and dissimilar objects."[14]

Babbage's discussion of the determinants of invention is far richer than that of Smith, and there is of course a perfectly straightforward reason. Smith, writing in the late 1760s and 1770s, was writing about, and commenting upon, a society that was still essentially pre-industrial. Babbage, on the other hand, wrote his book some sixty years later. The interval between the writing of the two books constituted the heyday of the British industrial revolution. Babbage is therefore analyzing a society where the division of labor had been carried to far greater lengths than the society that was known to Adam Smith. Indeed, very little of the descriptive accounts in Babbage's book, aside from the examples that Babbage deliberately chose from Smith's own book, dealt with machinery that would have been recognizable to the author of the *Wealth of Nations*.

A central point for Babbage is that an extensive division of labor is itself an essential prerequisite to technical change. This is so for two related reasons. First of all, technical improvements are not generally dependent upon a few rarely gifted individuals, although the more "beautiful combinations" are indeed the work of the occasional genius (p. 260). Rather, and secondly,

combinations" are indeed the work of the occasional genius (p. 266). Rather, and secondly, inventive activity needs to be seen as a consequence as well as a cause of the division of labor. This is so because "The arts of contriving, of drawing, and of executing, do not usually reside in their greatest perfection in one individual; and in this, as in other arts, the *division of labour* must be applied" (p. 266; emphasis Babbage's).

It is also worth noting that Babbage shows an acute awareness of the economic forces that drive inventive capability in specific directions and that influence the timing of inventive effort. In fact, his observations deserve to be regarded as possibly the earliest treatment of the economic determinants of inventive activity. Technological change is not, for him, some totally exogenous phenomenon. On the contrary, he clearly sees the direction of technological improvements as responding to the relative prices of factor inputs, and the commitment of resources to the improvements of machinery as directly connected to the state of demand for the final product that the machines produce. In urging the importance of careful cost accounting, Babbage points out that one of its main advantages "is the indication which it would furnish of the course in which improvement should be directed" (pp. 203-204); a firm would invest in those technological improvement activities that offered the highest payoff in terms of cost reduction, but only if it had a close understanding of those costs. On the demand side, he observes that: "The inducement to contrive machines for any process of manufacture increases with the demand for the article" (p. 213). And he also observes that "over manufacturing" is likely to lead to efforts to reduce costs through machinery improvement or the reorganisation of the factory (p. 233). Babbage also suggests a highly valuable research project on the relationship between gluts and technological improvements. "It would be highly interesting, if we could trace, even approximately, through the history of any great manufacture, the effects of gluts in producing improvements in machinery, or in methods of working; and if we could shew what addition to the annual quantity of goods previously manufactured, was produced by each alteration." He then adds the conjecture: "It would probably be found, that *the increased quantity manufactured by the same capital, when worked with the new improvement, would produce nearly the same rate of profit as other modes of investment*."[15]

It seems to be a reasonable claim that Babbage is the first observer of the events of the industrial revolution to call attention in an explicit way to the causal links between economic forces and inventive activity.

IV

Chapter 27 of Babbage's book, "On Contriving Machinery," provides valuable insights into the difficulties associated with the innovation process in the period when Britain was attaining to the status of "Workshop of the World."

Babbage expresses great concern over the difficulties of executing a new machine design and putting it into operating form in close accordance with the specifications of the inventor. This chapter clearly bears the painful imprint of the author's numerous frustrating experiences in designing highly complex machines in an age when machine making was still a relatively primitive art. This was a period when precision in the design and execution of new machinery was only just coming of age, but when the establishment of a new production facility was still attended by innumerable uncertainties with respect to the cost and performance of machinery of novel design. To be sure, the master machine-tool designer and builder, Henry Maudslay, inventor of the slide rest, makes an appearance in the pages of Babbage's book, but his contributions represented only the beginning of a long process of learning to work metals with higher degrees of precision. Indeed, Babbage thought it appropriate to include a separate chapter enumerating precisely these difficulties, in which he placed particular emphasis upon the problems involved in calculating the cost of new machines.[16]

Babbage stresses in several places the importance of accuracy in the actual paper design of a new

Babbage observes in several places the importance of accuracy in the detailed paper design of a new machine. "It can never," he states, "be too strongly impressed upon the minds of those who are devising new machines, that to make the most perfect drawings of every part tends essentially both to the success of the trial, and to economy in arriving at the result" (p. 262). It is clear from his admonitions on this matter that high-quality draughtsmanship could by no means be taken for granted. Nevertheless, "if the exertion of moderate power is the end of the mechanism to be contrived, it is possible to construct the whole machine upon paper" (p. 261).

However, for more complex machinery where performance will depend heavily upon "physical or chemical properties" (p. 261), optimum design cannot be determined on paper alone, and testing and experimentation ("direct trial") will be unavoidable. One can piece together, from various chapters of the book, a vivid account of the difficulties confronting would-be innovators during a period characterized by rapid technical change, particularly in the realm of machine making itself.

Chapter 29, "On the Duration of Machinery," deals with what a later generation would call "technological obsolescence," especially as the problem applies to capital goods with long useful lives, "such as wind-mills, water-mills, and steam-engines" (p. 283). Babbage introduces a table (p. 284) of the average annual duty performed by steam engines in Cornwall over the period 1813-1833, as well as the "average duty of the best engines." These engines, which were employed in Cornwall's extensive mining operations, provide impressive evidence of improvements in the construction and management of such engines. One wishes one had more information concerning their operation; nevertheless, on the face of it, they show a strong upward trend in performance. For the 21 -year period as a whole the average duty of the *best* engines more than triples, from 26,400,000 in 1813 to 83,306,092 in 1833. Over the same period the average duty of all the engines rose from 19,456,000 to 46,000,000.

In such an environment, technological obsolescence is a dominating commercial consideration, and the physical life of a capital good becomes of secondary importance. Babbage here offers a powerful insight that, its seems fair to say, is still not fully absorbed today.

`Machinery for producing any commodity in great demand, seldom actually wears out; new improvements, by which the same operations can be executed either more quickly or better, generally superseding it long before that period arrives: indeed, to make such an improved machine profitable, it is usually reckoned that in five years it ought to have paid itself, and in ten to be superseded by a better.' (p.285)

The effect of such obsolescence was a rapid downward revaluation of the market price for older machinery, which indeed is soon rendered commercially worthless. Babbage cites technological improvements in frames for making patent-net "not long ago." As a result, a machine that had cost [[sterling]]1200 and was still "in good repair" a few years later, sold for a mere [[sterling]]60. But even more extreme evidence of the impact of rapid ongoing technological improvements in that trade was the decision to abandon the construction of unfinished machines "because new improvements had superseded their utility."[17]

Babbage ends this chapter by pointing out that the effect of competition with respect to durable goods had been to render them even less durable. When manufactured articles are transported a considerable distance, it is not uncommon for broken articles to be deemed unworthy of the cost of repair if the price of labor is higher than in its original place of manufacture. It is cheaper to purchase a new article (p. 292). This appears to be a practice of recent vintage when Babbage wrote.

V

In examining the innovation process specifically from the point of view of the developer of a potential new machine, rather than its possible user, Babbage warns his readers of the peculiar

uncertainties of the technical problems involved. In situations that require testing what we would today call a prototype, the outcome of the tests may be especially sensitive to the quality of workmanship that was employed in producing the contrivance. Otherwise "an imperfect trial may cause an idea to be given up, which better workmanship might have proved to be practicable" (p. 264).

But there is another reason why the outcome of such a test may be inconclusive. The "art of making machinery" was undergoing such improvement "that many inventions which have been tried, and given up in one of art, have at another period been eminently successful" (p.264). This statement might serve as a remarkably appropriate epitaph to the author's celebrated technical accomplishments. Indeed, one may read his conclusion as both an astute observation on the uncertainties associated the innovative process during his own lifetime, and also as a personal correct premonition concerning his own ambitious technical enterprise. "These considerations prove the propriety of repeating, at the termination of intervals during which the art of making machinery has receive any great improvement, the trials of methods which, although founded upon just principles, had previously failed" (p. 265).

For the subset of inventions that survives the rigors and uncertainties of this experimental period, the commercial risks may prove to be as hazardous as the purely technical risks that had been overcome. The reason is simplicity itself. The machine may work perfectly well but produce its output "at a greater expense than that at which it can be made by other methods" (p. 265). Babbage at several points in the book had urged his readers to pay the most careful attention to all the costs that would be incurred in some prospective new machine, while at the same time admitting the difficulties of arriving at accurate estimates.

But there is still a further and final irony concerning the plight of the would-be innovator. Assuming that all previous hurdles and initial "teething troubles" had been overcome, subsequent units of the product could be produced far more cheaply than the first. Babbage clearly identifies what later generations would refer to as a "learning curve." His words deserve to be quoted in full:

`It has been estimated roughly, that the first individual of any newly-invented machine, will cost about five times as much as the construction of the second, an estimate which is, perhaps, sufficiently near the truth. If the second machine is to be precisely like the first, the same drawings, and the same patterns will answer for it; but if, as usually happens, some improvements have been suggested by the experience of the first, these must be more or less altered. When, however, two or three machines have been completed, and many more are wanted, they can usually be produced at much less than one-fifth of the expense of the original invention.' (p. 266)

But the subsequent financial fortunes of such an innovator are by no means assured. Much would depend not only upon the subsequent demand for the innovation but upon the ability of the innovator to control and capture the flow of profits generated by the innovation. In a highly competitive environment of the sort described by Babbage, the profits might well be captured by others unless the innovator had some specific means that allowed him to appropriate the benefits - patents, secrecy, tacit knowledge, access to scarce skills, etc.

Babbage's analysis here takes on additional importance because it powerfully influenced Marx, who quoted Babbage's estimate approvingly.[18] In this particular context Marx was anxious to emphasize how the technological improvements in a machine shortened its life expectancy and thereby intensified the forces making for the prolongation of the working day on the part of the capitalists anxious to recoup their large investment as quickly as possible.[19] On the other hand, in volume III of *Capital* Marx again drawing upon Babbage's treatment, called attention to "the far greater cost of operating an establishment based on a new invention as compared to later establishments, arising *ex suius ossibus*. This is so very true that the trail-blazers generally go bankrupt, and only those who later buy the buildings, machinery, etc., at a cheaper price make money out of it."[20] This is an intriguing statement on Marx's part, insofar as it portrays the

money out of it. [20] This is an intriguing statement on Marx's part, ironical as it portrays the capitalist, or at least the innovating capitalist, in a distinctly sympathetic way. But, more importantly, it would be essential to know how "generally" such bankruptcy occurs. Moreover, if this *were* generally the case, and if technological change were as central to long-term capitalist growth as Marx consistently asserted, it would constitute a powerful argument for the social necessity of high profits in order to compensate the occasional successful innovator for undertaking such great risks. Not surprisingly, Marx does not draw this implication.

VI

Babbage's concern with the division of labor as it relates to technological improvements leads him to a significant extension of his analysis into the field of international trade. His main concern was with a special issue: the restrictions that had recently been imposed by parliament upon the export of certain classes of machinery. Such restrictions, in his view, represented a needless and, indeed, counterproductive pandering to the interests of the makers of machinery, who feared the prospect of commercial competition from foreigners equipped with the latest machinery. But Babbage perceives[21] that Britain was already well on the way to developing a dynamic comparative advantage in the making of machinery. In his view, if the country could maintain its superiority in the manufacture of machinery, it would have little to fear from the acquisition of high-quality machinery by overseas competitors.

Babbage distinguishes sharply between the ability to contrive new machines and the ability to manufacture them. Even if the ability to contrive were equally distributed among countries, "the means of execution" are nevertheless different (p. 365). These means of execution obviously include the highly skilled makers of machinery, a class of workers who are "as a body, far more intelligent that those who only use it" (p.364). In a regime of rapid technological change, the country with a higher skill capability will continue to have much speedier access to the best machinery. By allowing domestic manufacturers the opportunity to sell their products abroad, the country will in fact solidify its superiority in machine making (pp. 370-373). It will enrich itself by enlarging the class of machine makers. Such workmen `possess much more skill, and are paid much more highly than that class who merely use it; and, if a free exportation were allowed, the more valuable class would undoubtedly, be greatly increased; for, notwithstanding the high rate of wages, there is no country in which it can at this moment be made, either so well or so cheaply as in England. We might, therefore, supply the whole world with machinery, at an evident advantage, both to ourselves and our customers. (p.372; emphasis Babbage's)

The separate strands of Babbage's argument in this chapter are not entirely distinct. On the one hand, he asserts that, in the absence of trade restrictions, English machine users will always have the advantage of prior access to the best machines. On the other hand, he also asserts that such access is not a sufficient condition for commercial success. Even if foreign competitors have equal access to the best technology, they will not compete successfully so long as they fail to achieve the admirable organizational adaptations of the industrial economy that have already been achieved in England. Here Babbage seems to have come full circle, to the overarching theme of the book: the advantages accruing to a society that manages to organize its economic life in close accordance with the dictates of the division of labor.

This seems to be the spirit of his response to the charge that the elimination of restrictions on machinery exports will provide foreigners with machinery that will threaten England's competitive advantage.

`It is contended that by admitting the exportation of machinery, foreign rnanufacturers will be supplied with machines equal to our own. The first answer which presents itself to this argument is supplied by almost the whole of the present volume; *That in order to succeed in a manufacture, it is necessary not merely to possess good machinery, but that the domestic economy of the factory should be most carefully regulated.*'[22]

should be most carefully regulated.[22]
Of course, for the larger economy outside the "domestic economy of the factory," appropriate regulation should be understood to include the force of competition: "it is only in countries which have attained a high degree of civilization, and in articles in which there is a great competition amongst the producers, that the most perfect system of the division of labour is to be observed" (p. 169). And countries that can maintain a more advanced division of labor, in this enlarged sense, than their foreign competitors, need not be excessively concerned over their prospective competitiveness.

VII

Chapter 20, "On the Division of Mental Labours," is a fascinating chapter for several reasons. It involves, to begin with, a direct application of Babbage's reasoning on the division of labour in the previous chapter, to the specific realm of the activities of the human mind. Second, it contains an extensive discussion of Babbage's own work on a "calculating engine," placed in the larger context of his analysis of the application of machine methods to industrial production. And, third, it provides an absorbing historical account of the project that culminated in Babbage's own efforts to develop a calculating-engine.

Starting with this third point, these efforts had their origin, remarkably enough, in the accidental perusal of Smith's *Wealth of Nations* by a French government official who happened upon the volume in a bookstore. A Monsieur Prony had been charged by the French government with the Herculean task of superintending the production of a series of logarithmic and trigonometric tables that would facilitate the transition to the recently adopted decimal system.[23]

The tables that M. Prony was to calculate were to occupy no less than seventeen large folio volumes.

`Il fut aise a M. de Prony de s'assurer que meme en s'associant trois ou quatre habiles co-operateurs, la plus grande duree presumable de sa vie, ne lui suffirai pas pour remplir ses engagements. II etait occupe de cette facheuse pensee lorsque, se trouvant devant la boutique d'un marchand de livres, il appersut la belle edition Anglaise de Smith, donnee a Londres en 1776; il ouvrit le livre au hazard, et tomba sur le premier chapitre, qui traite de *la division du travail,* et ou la fabrication des epingles est citee pour exemple. A peine avait-il parcouru les premieres pages, que, par une espece d'inspiration, il consut l'expedient de mettre ses logarithmes en manufacture comme les epingles. `(p. 193; emphasis Babbage's)

M. Prony then proceeded with a threefold division of labor including (I) "five or six of the most eminent mathematicians in France," (2) seven or eight persons, not eminent mathematicians, but persons possessed of a "considerable acquaintance with mathematics," and (3) a group whose number varied between sixty and eighty, who generated the final tables "using nothing more than simple addition and subtraction" (p. 194).

M. Prony's procedure, Babbage astutely observes, "much resembles that of a skillful person about to construct a cotton or silk-mill, or any similar establishment" (p. 195). None of the well-educated groups involved in the project played any role in the "dog-work" of actual calculation. It was, of course, Babbage's intention that his calculating engine would provide a machine substitute for all of the work performed by the third group.

Babbage completes the specification of the neat parallelism of the division of labor between the mechanical and mental domains:

`We have seen, then, that the effect of the division of labour, both in mechanical and in mental operations, is, that it enables us to purchase and apply to each process precisely that quantity of skill and knowledge which is required for it: we avoid employing any part of the time of a man who can

get eight or ten shillings a day by his skill in tempering needles, in turning a wheel, which can be done for sixpence r day; and we equally avoid the loss arising from the employment of an accomplisheed mathematician in performing the lowest processes of arithmetic.' (p 201)

But the improvements in the cost of calculation which are now on the horizon, and which are the offspring of the division of labor, are by no means exhausted by purely financial considerations. For, in Babbage's view, as a country progresses in its arts and manufactures, continued progress comes to depend increasingly upon a growing intimacy between science and industry. In the final chapter of the book (chapter 35), "On the Future Prospects of Manufactures as Connected with Science," Babbage argues that science itself is becoming subject to the same law of the division of labor that is the central theme of the book. Science needs to be cultivated as a full-time, specialized activity by those with the "natural capacity and acquired habits" (p. 379). Such specialization is unavoidable because "the discovery of the great principles of nature demands a mind almost exclusively devoted to such investigations; and these, in the present state of science, frequently require costly apparatus, and exact an expense of time quite incompatible with professional avocations" (p. 380). Babbage's reference to "costly apparatus" is especially apposite. One of the most costly of all research instruments today is a large Cray computer!

Babbage closes a long apotheosis to science by pointing out that the progress of science itself will be increasingly governed by progress in the ability to calculate: "It is the science of *calculation,* - which becomes continually more necessary at each step of our progress, and which must ultimately govern the whole of the applications of science to the arts of life."[24]

In short, it is Babbage's view that mankind's future prospects will be dominated by the fact that "machinery has been taught arithmetic" (p. 390). Babbage was of course remarkably prescient, but the possibility of teaching machinery arithmetic would have to await the age of electronics.

VIII

Thus Babbage's analysis involves a long chain of reasoning that has its origin in the division of labor; from there, Babbage spells out what he perceives as its far-reaching implications through the realms of technology and then even science. But one further feature, of great significance, has so been neglected. The extension of the division of labor can and was necessarily leading to the establishment of large factories.[25] Indeed, Babbage provides the first extended discussion in the literature of economics of an issue of immense future significance: the economies associated with large-scale production. The chapter devoted to this topic, chapter 22, "On the Causes and Consequences of Large Factories," in turn powerfully influenced the treatment of this topic by two of the most influential, perhaps the two most influential economists of the nineteenth century, John Stuart Mill and Karl Marx.

Babbage had shown in chapter 19, "On the Division of Labour," that a critical advantage of that division was that it enabled the employer to purchase only the precise amount of each higher skill category, and no more, that was required by the different processes under his roof. Ideally, although the ideal was hardly ever fully achieved, no worker was ever paid at a rate that was higher than that appropriate to his assigned activity. But in chapter 22 he specifies an important implication of such an arrangement. In order to produce at minimum cost, it will be necessary to expand the factory by some multiple whose size will depend upon the specific labor requirements imposed by the division of labor. It follows from the principle of the division of labor that " *When the number of processes into which it is advantageous to divide it, and the number of individuals to be employed by it are ascertained, then all factories which do not employ a direct multiple of this latter number, will produce the article at a greater cost*" (p. 212; emphasis Babbage's).

Babbage adds a variety of other circumstances that, he believes, will offer advantages to manufacturing establishments of great size. The most common denominator involves the

manufacturing establishments of great size. The most common denominator involves the indivisibility of certain valuable inputs which fail to be fully utilized in smaller establishments. These would include the availability of higher-wage workmen who are skilled in adjusting or repairing machines;[26] a small factory with few machines could not fully utilize such a highly skilled worker. Similarly, the introduction of light for night work, or an accounting department, involve sizable fixed costs that are also under-utilized at low levels of output. The possibilities for effectively utilizing waste materials are greater in a larger plant, and this is sometimes further facilitated by "the union of the trades in one factory, which otherwise might have been separated" (p. 217) Agents who are employed by large factories frequently provide services that cost little more than those provided to smaller establishments, even though the benefits of the service to the large factory are far more valuable.

Finally, Babbage quotes approvingly a Report of the Committee of the House of Commons on the Wool Trade (1806) which asserts that large factories can afford the risks and experiments to generate technological change that are not feasible for the "little master manufacturers."

`it is obvious, that the little master manufacturers cannot afford, like the man who possesses considerable capital, to try the experiments which are requisite, and incur the risks, and even losses, which almost always occur, in inventing and perfecting new articles of manufacture, or in carrying to a state of greater perfection articles already established . . . The owner of a factory . . . being commonly possessed of a large capital, and having all his workmen employed under his own immediate superintendence, may make experiments, hazard speculation, invent shorter or better modes of performing old processes, may introduce new articles, and improve and perfect old ones, thus giving the range to his tastes and fancy, and, thereby alone enabling our manufacturers to stand the competition with their commercial rivals in other countries.`(p 223)

IX

Babbage's treatment, although obviously of limited scope, was nevertheless a pioneering first effort to identify the economic advantages of bigness on which first John Stuart Mill and later Karl Marx drew extensively.[27] It has often been asserted that Marx was the first economist to identify the sources making for a tendency for firms to expand in size. But that priority, if denied to Babbage, certainly belongs to Mill, whose analysis well preceded that of Marx. Chapter 9, book I, of Mill's hugely successful *Principles of Political Economy* (1848), titled "Of Production on a Large, and Production on a Small Scale," is the first systematic treatment of increasing returns to large-scale production. Mill acknowledges his debt to Babbage in the opening paragraph of this chapter. He points out that there are advantages to large-scale enterprise

`when the nature of the employment allows, and the extent of the possible market encourages, a considerable division of labour. The larger the enterprise, the farther the division of labour may be carried. This is one of the principle causes of large manufactories. Even when no additional subdivision of the work would follow an <<enlargement of the operations, there will be good economy in enlarging them to the point at which every person to whom it is convenient to assign a special occupation, will have full employment in that occupation.'[28]

Mill illustrates this statement by an extensive quotation from Babbage's chapter "On the Causes and Consequences of Large Factories." The extract covered most of the points that we have just discussed and it amounted to two full pages of Babbage's original text. Mill included an even more extensive extract from Babbage on the optimal payment arrangements for workers in the first (1848) and second (1849) editions of Principles.

Marx's intellectual indebtedness to Babbage on the matter of increasing returns to large-scale production appears to be at least as extensive as Mill's, and is amply acknowledged, especially by the use of numerous citations and quotations. But Babbage's influence on Marx is even more pervasive, as would be revealed by a close textual comparison of Babbage's treatment of the causes

pervasive, as would be revealed by a close textual comparison of Babbage's treatment of the causes and consequences of the division of labor with that of Marx in two central chapters of volume I of *Capital*: chapter 14 on "Division of Labour and Manufacture," and chapter 15 on "Machinery and Modern Industry." It would take us much too far afield to explore this relationship in detail. The essential point is that Marx's most fundamental criticisms of capitalism as a social and economic system turn upon its peculiar division of labor. The degradation of the worker under advanced capitalism, especially the dehumanising effects of specialisation, and the systematic tendency to deprive the worker of skills and to incorporate those skills into machine, are all consequences of the division of labor as treated by Babbage.

Marx even takes his definition of a machine from Babbage. According to Marx, "The machine, which is the starting-point of the industrial revolution, supersedes the workman, who handles a single tool, by a mechanism operating with a number of similar tools, and set in motion by a single motive power, whatever the form of that power may be."[29] Marx here cites as his authority Babbage's statement from his chapter (19) on the division of labor: "The union of all these simple instruments, set in motion by a single motor, constitutes a machine."[30]

Much of Marx's critique of capitalism flows from examining exactly those characteristics of the division of labor that Babbage had identified sources of improved efficiency in the factory. However, Marx considers them from a very different perspective: specifically, from the point of view of the welfare of the worker. From Babbage's perspective, "One great advantage which we may derive from machinery is from the check which it: affords against the inattention, the idleness, or the dishonesty of human agents" (p. 54). Putting aside the matter of dishonesty, Marx sees the introduction of machinery as introducing an entirely new form of oppression and loss of the worker's essential humanity.

`In handicrafts and manufacture, the workman makes use of a tool, in the factory, the machine makes use of him. There the movements of the instrument of labour proceed from him, here it is the movements of the machine that he must follow. In manufacture the workmen are parts of a living mechanism. In the factory we have a lifeless mechanism independent of the workman, who becomes its mere living appendage. (Marx, *Capital,* p. 422).

Additionally, of the system of manufacture, Marx states: "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. 360). The freedom of the capitalist, under the division of labor, to purchase labor of lower skills, translates into "deskilling" from the laborer's point of view. Babbage's continuous citation of the "advantages" of the division of labor in making it possible to insert women, boys and girls at very low pay into jobs formerly performed by men readily translates into Marx's searing indictment of capitalism precisely because of its intensive exploitation of the division of labor.

` Within the capitalist system all methods for raising the social productiveness of labour are brought about at the cost of the individual labourer, all means for the development of production transform themselves into means of domination over and exploitation of, the producers; they mutilate the labourer into a fragment of a man, degrade him to the level of an appendage of a machine, destroy every remnant of charm in his work and turn it into a hated toil; they estrange from him the intellectual potentialities of the labour-process in the same proportion as science is incorporated in it as an independent power; they distort the conditions under which works, subject him during the labour-process to a despotism the more hateful for its meanness; they transform his life-time into working-time, and drag his wife and child beneath the wheels of the Juggernaut of capital. (Marx, *Capital,* p. 645)

It is tempting to conclude that Marx's analysis of the division of labor and its consequences is the same as that of Babbage, only considered dialectically!

I have attempted to show why Babbage continues to be deserving of our attention, not only as the pioneer of the computer, but as an original contributor to the development of economic ideas. Moreover, these two roles were, as we have seen, closely connected by Babbage's own personal experiences. His prolonged frustrations over the attempt to construct a working computer led him to many of the profound and precocious insights that are developed in his book. The book has much to offer to any reader today who wishes to understand the difficulties confronting the innovative impulse in the early days of industrialisation. Babbage's difficulties were, of course, far greater than those of most innovators because the goal he had set for himself was so breathtakingly ambitious. In confronting his own difficulties as a computer pioneer more than a century ahead of its time, Babbage in fact became, however reluctantly, a pioneer economist.

If the world has eventually beaten a path back to Babbage's door as a result of the computer revolution, a strong case can now be made that a second path to that door remains to be beaten. For Babbage, as we have seen, also pioneered in the analysis of technological change. The subject suffered a long neglect when the main thrust of economic analysis came to be dominated by the neoclassical analysis of comparative statistics in the late fifteenth century. With only a few notable exceptions, including the seminal work of Schumpeter and Kuznets, economists devoted little attention to either the causes or consequences of technological change until 1950s.

The revival doubtless owed a great deal to the reawakening of interest in problems of long-term economic growth in less-developed countries as well as in the industrialized west. The renewed interest was reinforced, within the economics profession, by the researches of Jacob Schmookler, Moses Abramovitz, Robert Solow, and others, which pointed forcefully to two things: (1) the existence of economic forces that powerfully shape both the rate and the direction of inventive activity; and (2) the prominent role played by technological change in generating long-term economic growth.

Babbage's book, *On the Economy of Machinery and Manufactures* continues to have much to say to readers who are concerned with the causes of as well as the consequences of technological change. But it can, of course, equally well be read for the sheer intellectual excitement it provides in following a first-class mind as it attempts to comprehend, and to impose order upon, newly emerging forms of economic activity and organisation

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The BABBAGE Pages: Political Economy

Footnotes: Babbage: pioneer economist by Nathan Rosenberg

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1. Charles Babbage's *On the Economy of Machinery and Manufactures*, fourth edition, 1835 reprinted by Frank Cass & co a London, 1963, p. 191. All further references to *On the Economy of Machinery and Manufactures* will mention only the page number of the 1963 edition.

2. See the valuable biography by Anthony Hyman, *Charles Babbage: Pioneer of the Computer*, Princeton University Press, Princeton (NJ), 1982.

3. Joseph Schumpeter, *History of Economic Analysis*, Oxford University Press, New York 1954, pa 541.

4. Mark Blaug, *Economic Theory in Retrospect*, Cambridge University Press, Cambridge, third edition. 1978. p. 198.

5. For further discussion of the context in which Babbage came to write this book, see Hyman, *Charles Babbage*, chapter 8.

6. see Babbage's discussion of the Navy Board's contract to make iron tanks for ships. Maudslay at first was reluctant to take the contract because it was "out of his line of business" but also because the holes for the large number of rivets ordinarily involved an expensive hand-punching process. The Navy Board subsequently offered a larger contract which Maudslay accepted because it then became worthwhile to introduce specialised tools. bathe magnitude of the order made it worth his while to commence *manufacture*, and to make tools for the express business (p. 121). Babbage's italics.

7. see chapter 12, "On the Method of Observing Manufactories."

8. At the same time, Babbage urged the undertaking of statistical estimation in order to improve decision-making within the business community: "The importance of collecting data, for the purpose of enabling the manufacturer to ascertain how many additional customers he will acquire by a given reduction in the price of the article he makes, cannot be too strongly pressed upon the attention of those who employ themselves in statistical ` inquiries" (p. 120). Babbage was the founder of the London Statistical Society.

9. Charles Babbage, *Passages from the Life of a Philosopher*, volume s in *The Works of Charles Babbage* William Pickering, London, 1989, p. 328.

10. Babbage also adds, as a separate point, that greater division of labor will lead to reduced. waste of materials in the learning process, and a consequent reduction in the cost and the price of the product (p. 171).

11. Adam Smith, *Wealth of Nations,* 1776; Modern Library Reprint, New York, 1937, p. 8

12. Adam Smuth, *Lectures on Justice, Police. Revenue and Arms*, reprinted by Kelley, & Millman, New York, 1963, p. 166.

13. See, in particular, Babbage's analysis of the impact of the introduction of machinery upon employment in chapter 32, "On the Effect of Machinery in Reducing the Demand for Labour."

14. Smith, *Wealth of Nations,* p. 10. For a more extensive treatment of Smith's views on this subject, see Nathan Rosenberg, "Adam Smith and the Division of Labor: Two Views or One?" *Economica*,

57, no. 3 (May 1965).

15. Pp. 233-234. Babbage's italics. See also pp. 158-159.

16. Chapter 35, "Inquiries Previous to Commencing Any Manufactory."

17. P.286. For a discussion of the complexity of the decision-making process when technological change is not only rapid, but is anticipated to continue to be rapid in the future, see Nathan Rosenberg, "On Technological Expectations," *Economic Journal* (September 6); reprinted as chapter 5 in Rosenberg, *Inside the Black Box*.

18. Karl Marx, *Capital,* vol. **1**, Foreign Languages Publishing House, Moscow, 1961, p. 405, footnote 1.

19. Ibid., especially footnote 2.

20. ibid., vol. III, Foreign Languages Publishing House, Moscow, 1959, p. 103. See also Chapter 5 below, pp. 95-97

21. Chapter 34, "On the Exportation of Machinery."

22. P.376. Babbage's italics. Substantially the same point is made several pages later.` The fact that England can, notwithstanding her taxation and her high rate of wages, actually undersell other nations, seems to be well established: and it appears to depend on the superior goodness and cheapness of those raw materials of machinery the metals, - on the excellence of the tools, - and on the admirable arrangements of the domestic economy of our factories.' (p 374).

23. The decimal system was, of course, adopted in France but not in England. Babbage points out the advantages of the decimal system in facilitating monetary calculations, and observes that sit becomes an interesting question to consider whether our own currency Most not be converted into one decimally divided. The great step, that of abolishing the guinea, has already been taken without any inconvenience, and but little is now required to adder the change complete" (p. 124). Babbage's countrymen were, of course, to wait for m<<e than a century before acquiring the conveniences of this conversion. For other purposes, such as measurement of length and weight, they are still waiting.

24. Pp. 387-388. Babbage's italics. It is interesting to note that, in the very next paragraph Babbage anticipates precisely the question that so troubled Jevons several decades later in his book, *The Coal Question,* Macmillan and co. London,1865. Babbage recognizes the threat posed to a society increasingly dependent upon the power of steam, that "the coal-mines of the world may ultimately be exhausted." Nevertheless, with the growth of knowledge he appears to be confident that substitute sources of power will be found. He identifies one possibility upon which research is presently being conducted in the United Kingdom: tidal power. "(T)he sea itself offers a perennial source of power hitherto almost unapplied. The tides, twice in each day, raise a vast mass of water, which might be made available for driving machinery (p. 388).

25. the importance of this insight cannot be overstated, for the rise of the large manufacturing enterprise is central to the arguments of both Marx and Schumpeter. For a further discussion, see chapters 3 and 5 below.

26. Although Babbage does not make it clear why such a worker needs to be in constant attendance so long as the machines are above some minimal threshold of reliability

27. Mill's treatment of the specific issue of the division of labor, although coming almost three quarters of a century after Adam Smith. constituted no substantial improvement over Smith's treatment. As

Blaug observes of Mill's *Principles of Political Economy*: "Book I chapter 8, on the division of labor, adds little to Adam Smith's treatment and may be passed over without loss, *Economic Theory in Retrospect,* p. 198.

28. Mill, Principles, p. 132

29. Marx. *Capital,* p.376.

30. See also Babbage, *Economy of Machinery*. p. 12, and Karl Marx, *The Poverty of Philosophy*, Foreign Languages Publishing House, Moscow, pp. l32-133.

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Charles Babbage KH FRS (/ËˆbÃ¦bÉªdÊ’/; 26 December 1791 â€“ 18 October 1871) was an English polymath. A mathematician, philosopher, inventor and mechanical engineer, Babbage originated the concept of a digital programmable computer. Considered by some to be "father of the computer", Babbage is credited with inventing the first mechanical computer that eventually led to more complex electronic designs, though all the essential ideas of modern computers are to be found in Babbage's Analytical Engine. His