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SUPPLY-PUSH AND DEMAND-PULL FACTORS OF TECHNOLOGICAL PROGRESS IN THE EARLY DECADES OF THE 19TH CENTURY (1800-1840)*

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The relationship between science, invention and innovation is fundamental in describing technological progress and economic growth. Two main models have been developed to portray such a process. One is based on a supply-push explanation, while the other is grounded on a demand-pull.
In this paper the various views and explanations for the generation and advancement of technological improvements expressed by some economists of early decades of the 19th century (mainly between 1800 and 1840), are investigated following the above distinction between the supply-push and demand-pull factors of technological progress. An important issue which is left aside in the present paper is the economic consequences of technological progress.
This paper is mainly engaged with "explanatory priority" and not "influential contribution" on the history of economics. On this spirit the conclusion drawn is that in the early decades of the 19th century where technological progress was the main characteristic of the economic transformation from "home" to "world" production, the ideas and arguments of some writers on the supply-push and demand-pull causes of technological improvement were very original regarding similar present days investigations.

1. Introduction

The relationship between science, invention and innovation is fundamental in describing technological progress and economic growth. Two main economic models have been developed to portray such a process. One is based on a supply-push explanation, while the other is grounded on a demand-pull. There are economists who maintain that there exists a process based on supply push or autonomous scientific progress, while

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others stress a demand pull mechanism based on economic factors. Such factors as production costs, profits, demand, etc. are seen to drastically influence the direction and rate of technological progress, through the demand of entrepreneurs (demand-pull)[1].
In the present paper the various views and explanations for the creation and advancement of technological improvements in the early decades of the 19th century (mainly between 1800 and 1840), are investigated following the above distinction between the supply-push and demand-pull factors of technological progress.
History of economics is a pluralistic discipline which, in addition to some approaches

(e.g. absolutist, relativist, Whiggish, etc) must elaborate on-let us say- the "pre-modern" ideas and solutions of the human mind to explain and describe the ways by which the "unknown" perfect happiness could be achieved[2]. Thus, the present analysis must not be considered only as a "litany" of past ideas but as a testimony to forgotten and unnoticed arguments which may be considered by modern economists as "dull". In other words, this paper is not a prayer-essay to the direct contribution of our predecessors on the issue in question, neither describes their weaknesses or false ideas and arguments, but is concentrating on the presentation of old fashioned ideas which nevertheless are- according to present days standards- pioneering in relation to theoretical (not formal) economic analysis. Thus, the present article is mainly engaged with "explanatory priority" and not "influential contribution" on the history of economics.

More specifically, the first section of the paper will concentrate upon analysing Smith's argument for the effect of the division of labour on the advancement of science and invention; basically a supply-push explanation of technological advance. It merits separate analysis as some very interesting comments and critiques have been made. The second section analyses the views of those writers who presented other supply-push factors, emphasizing the positive influence of scientific and empirical knowledge on the technological advancement. In this section also relevant arguments in favour of educational advancement of labourers are expounded.

The economists of the period in question also recognized and stressed demand-pull factors such as profit, cost, etc, to explain mainly

1. For a detailed analysis of such processes see ROSENBERG [1974]; MOWERY & ROSEN-BERG [1979]; Dosi [1988]; GEROSKI & WALTERS [1995]. In understanding the technological progress of the past some other influential factors such as religion, geographical environment, life expectancy, nutrition, etc, must be examined (see MOKYR [1990], ch. 7).

2. The significance of the scientific priority in the historiography of economics is discussed in KARAYIANNIS [1997].

the relationship between inventions and innovations. Some of them recognized that inventions emerge not only from scientific curiosity but also because of material incentives, and because of some problems caused by the scarcity of factors of production and resources. In the third section therefore some factors will be analyzed which influence technological progress, such as profit and increases in demand. In the fourth section, other demand pull-factors of technological advancement caused by a shortage of the factors of production or its increased rate of reward will be examined.

An important issue which is left aside in the present paper is the economic consequences of technological progress. This is an issue which has been analyzed by other historians of economic thought and needs a special investigation not undertaken here.

2. Division of labour- science- inventions

The role of basic research or the advancement of science on the progress of inventions and innovations, has always been emphasized, but with especial intensity in our century. Schmookler in his 1966 research stressed that scientific knowledge is the prime mover of inventions and technological change. This idea, however, was developed in the early days of the previous century in the peak of industrial revolution

by classical economists and "radicals" who emphasised scientific and empirical knowledge as the source of inventions. As it is known, Smith had already argued that the scientists are one of the main source of inventions and innovations[3]. Smith attributed inventions to the division of labour, and in extension, to the endeavors of three classes of men: (a) the labourers; (b) the specialized technicians; and (c) the scientists (1776, pp. 20-1)[4].

The relationship between division of labour-inventions-innovations stressed by Smith, was endorsed by some other classicists in the post-Ricardian period. More specifically, McCulloch showed a keen interest on the question of machinery and he was called as an "expert witness before the Select Committee on machinery of 1824" (O'Brien [1987], p. 261). He stressed that the division of labour facilitates labour-saving inventions and innovations ([1825], p. 41). The English mathematician

3. LINK ([1987], p. 2, ft. 1) notes that "Smith's view of innovation as a professional activity was indeed ahead of his time". ELMSLIE [1994] extensively analyzed Smith's thoughts on technological progress.

4. Sir James Steuart had already stressed the role of "scholars" in introducing inventions and new machines (KARAYIANNIS, [1988], p. 38).

Charles Babbage followed Smith's position that the division of labour is the main source of inventions and new technology ([1832], p. 173). He advanced the "Babbage Principle" (Berg, [1987], p. 167) by stressing that in addition to five more important advantages ([1832], pp. 170-4) the main result of the division of labour is "that it enables us to purchase and apply to each process precisely that quantity of skill and knowledge which is required for it" (p. 201)[5]. The positive influence of the division of labour on the advancement of science and inventions is also envisaged by some other authors of the period such as, Longfield ([1833], p. 92), Scrope ([1833], pp. 74-5), and Newman ([1835], pp. 42, 77).

The Smithian thesis that inventions are the product of the division of labour were attacked by some authors. One of them was Lauderdale who considered that "the history of man shows us, that the simplest and most efficacious machines for supplanting labour... are introduced, at an early period of society when the division of labour is comparatively un-practiced and unknown, for the purpose of supplanting the personal labour of man in the conduct of agricultural history" ([1804], pp. 291-2; see also pp. 294-5).

Thomas Hodgskin, one of the first anti-capitalists (Jaffe [1995], pp. 493-4), questioned the Smithian argument that invention and innovations are the result of the division of labour ([1827], pp. 53-4; see also Jaffe [1995], p. 505). In justifying his position he took as an example the production process of Indians in America, which was divided among different men but had not resulted in any significant progress in technology ([1827], p. 81).

Hodgskin by considering science and inventions as the original source of the division of labour ([1827], p. 80) claimed also a feed back effect of population growth on technological progress, viz:

"a progress in knowledge, and division of labour, mutually promote each other; that observation, introducing new practices, leads to extended division of labour; and extended division of labour, allowing those, whose principal business it is to make observations, to confine their attention to some small part of the material world, enables them, and of course enables society at large, more speedily to become acquainted with it: but I contend, that observation must have preceded division of

labour, and some progress must have been made in a knowledge of the external world, before men could have thought of devoting themselves to different employments" ([1827], p. 79).
However, "The chances of improvement, it is plain, are great in proportion as the persons are multiplied whose attention is devoted to any particular subject" (p. 93), and "As the world grows older, and as men increase and multiply, there is

5. For Babbage's theory of the division of labour and its main extensions, see BERG ([1980], pp. 184-9), ROMANO ([1982], pp. 390-3), SCHEFOLD ([1996], pp. 27-35).

a constant, natural, and necessary tendency to an increase in their knowledge, and consequently in their productive power" (p. 95).
Some years later, the Scots-Canadian writer John Rae based his criticism of some of Smith's leading principles on historical documentation and induction, thereby inferring some new principles ([1834], pp. iv-v). He criticized Smith mainly on two grounds: First, "he falls into the error of taking, what in truth are the results of general laws governing the course of this class of events for the laws themselves, and so of elevating effects into causes" (p. 4). Second, on his "exact identity of the causes giving rise to individual and national wealth" (p. 8)[6].
Rae moreover denunciated Smith's principle that the accumulation of capital determines the division of labour and thus productivity and total wealth. He argued instead that the division of labour took place because of inventions and technological improvements, and productivity was therefore increased, something which led to an increase in the rate of profit and capital accumulation (pp. 20-3). Rae contended that Smith was wrong in considering that capital is increased by savings and argued that the main sources of capital increase are the skill, knowledge, dexterity, and inventions of the people (pp. 61-2,65)[7].
Rae also turned against the Smithian proposition that the increase of labour and its extended division will increase wealth, stressing that inventions were the main cause of the increase in the volume of labour and capital which in its turn increased wealth (pp. 28-30), as:
"Before population can advance, there must be something on which it can subsist; before capital can increase, there must be something in which it may be embodied.... It is invention, which showing how profitable returns may be got from the one, and how subsistence procured from the other, that may most fitly be esteemed the cause of the existence of both" (p. 31)[8].

6. Rae's first chapter "Of the Identity of Individual, and National Interest considered as a Simple Principle" is turned against the Smithian proposition. His argument is that the wealth of individuals is acquired but that of the state is created, thus these two kinds of wealth are not identical (RAE [1834], p. 15).
7. Rae considers that capital is augmented in terms of quality and quantity as well from other causes such as "the strength of effective desire for accumulation, the rate of wages, (and) the progress of the inventive faculty" (RAE [1834], p. 109). For an analysis of these causes see Book II, ch. V, VI, VII, VIII. For the similarity of Rae's and Fisher's capital theory which is based on the equality of the marginal rate of time preference and the marginal rate of return over cost, see ROBBINS ([1968], pp. 51,53).
8. As HEERTJE ([1973], p. 82) comments, "Rae a somewhat neglected figure whose importance is now being recognized, was not only a pioneer of the theory of capital but also made a significant contribution to the theory of technical change". Similarly, BREWER ([1991],

In the early 19th century the maxim "Knowledge is power" was used by some economists to indicate the strong relationship between science, invention and technological progress which has been deeply researched in modern times by Schmookler [1966][9].

The relationship between knowledge-inventions-innovations which describes a significant supply-push factor of technological progress was developed in two directions: from knowledge to inventions and vice versa. Let us firstly analyse those views which emphasized the influence of knowledge on inventions and then those which claimed the contrary effect.

3. "Knowledge is Power"

The positive influence of knowledge on inventions was well recognized by economists in the early part of the 19th century, although in those times the majority of inventions having direct economic consequences were introduced mainly by "men of affairs" and not by academicians[10].
J.B. Say extended much more than Smith the argument for the positive effects of science on economic growth. He stressed that scientific inquiry is the first stage of any new production process and a main prerequisite for inventions which are turned to innovations not by the scientists but by the entrepreneurs ([1821], p. 80). Thus, although Say regarded the advancement of science and the role of scientists to be very important for the advancement of inventions and the decrease of ignorance (p. 81, fn.; see also Berg [1980], p. 92) he also considered the role of innovators to be crucial for economic growth: "a country well stocked with intelligent merchants, manufacturers, and agriculturists has more powerful means of attaining prosperity, than one devoted chiefly to the pursuit of the arts

p. 11) claims that "Rae's conception of growth as wholly driven by invention was genuinely original". For Rae's argument for the usefulness of inventions on the advancement of technology see also ROBBINS ([1968], p. 89).
9. BERG made clear ([1980], ch. 7) how in the early 19th century in England the "scientific movement was also to link the perception of technology to the promotion of economic improvement" (p. 145).
10. As MOKYR has shown ([1985], pp. 11-2) engineers played a key role in the technological advancement in the period in question. He argues that "the impact of pure science on technological progress in this period was modest and indirect at best.... From the list of the fifty most important inventions made between 1760 and 1830, only a handful would qualify as having any direct connection with science or scientists, and even in those cases the relation was tenuous" (p. 11). MacLeod also notes that the machine-makers played "a vital role in the development of radical inventions, first through the technical expertise they offered to inventors who sought their help in implementing their ideas, and secondly by making incremental inventions that improved new machines" (MACLEOD [1994], p. 754).

and sciences" (1821, p. 82)[11]. Say justifies his argument on the following grounds: (1) the scientist has other motives, e.g. scientific reputation, than the pursuit of economic profit (p. 82); (2) science can be freely and universally circulated, while innovations can be patented and thus be kept as "a secret" (pp. 82,329); (3) the necessary qualities of scientists and inventors are different from innovators who dispose of special market knowledge and assume the risk of their innovations (pp. 83,330-1)[12].
Say, by stressing the usefulness of scientific advancement for economic progress, noted that the profits gained by innovation belong to the innovator and not to the scientist whose knowledge was the main impetus for such an attempt (p. 328)[13]. Therefore, "it is from a sense of this injustice, that every nation, sufficiently enlightened to conceive the immense benefit of scientific pursuits, has endeavoured, by special favours and flattering distinctions, to indemnify the man of science" (p.

329).
Say's French contemporary Count Destutt Tracy ([1817], pp. 37-8) similarly stressed that "the man of science" is an indispensable factor of production and deserves a special reward as by his knowledge the introduction and extension of new technology is made possible. Thus he (p. 39) justified scientists' reward on the basis that they offer labour-saving technology which diminishes the cost of production.
The American Jacob B. Cardozo in his *Notes on the Political Economy* [1826] envisaged the usefulness of inventions, mentioning that by such an activity man is able to multiply "his enjoyments by enlarging his dominion over nature" (p. 5). Inventions, according to Cardozo, emerged

11. Hoselitz in an important piece of research (HosELlTZ [1955]) has shown that Britain's rate of growth was much higher than France's during and after the industrial revolution, because the entrepreneurial spirit and activities in those two countries were different. The British entrepreneurs were much more innovative and inclined to risk taking than the French. It seems, however, that the particularity of British entrepreneurial contributions were not so much stressed by the classical authors although some of them recognized specific activities (see KARAYIANNIS, [1990], pp. 249-251).
12. Say, by distinguishing the necessary characteristics of the successful inventor from that of successful innovator seems to be right as the facts prove. For example, Maclaurin examining the innovative process in the industry of radio telecommunications indicated that for the promotion of innovation the availability of funds and of entrepreneurial skill were of crucial importance (MAcLAUWN [1950], pp. 96-7). Maclaurin gives some cases where invention was very important and funds were abundant but the process were missed by non-effective management" and concluded that some original inventors were not proven successful entrepreneurs (pp. 97-107).
13. Say however, recognized that there is a possibility that the activities of inventor and innovator can be carried out by the same person who "in this particular case the manufacturer combines two different operations of industry: that of the man of science, whose profit he engrosses himself, and that of the adventurer too" (SAY [1821], p. 329).

from "either skill or science" and made practicable or marketable "with the arts that minister to our wants or our enjoyments" (p. 6).
The Briton Thomas Rowe Edmonds gave much emphasis to the influence of knowledge on the wealth of nations. He emphatically stated that technological progress is the main characteristic of a rich country ([1828], pp. 162-3). In his chapter XI titled "Knowledge is Power" Edmonds claimed that pre-existing knowledge is a prerequisite for further inventions - as Schmookler has recently shown ([1966], p. 11) - and he considered that advancement in science must be directed to technological improvements which in turn will increase the quantity of necessary goods ([1828], p. 163). He also argued that the encouragement of the diffusion of knowledge is of paramount importance for a nation and must be pursued by the government (p. 164).
Charles Babbage in his *On the Economy of Machinery and Manufacture* [1832] stressed the usefulness of pure science in the discovery of machines and the advance of technology (Robbins, [1968], p. 88). He maintained that "the accumulation of skill and science... diminish the difficulty of producing manufactured goods" ([1832], pp. 3-4). Then, he used the maxim "knowledge is power" (p. 388) to show that the main source of inventions is the applied and abstract sciences (p. 379). The increase of knowledge for Babbage has a tremendous consequence in increasing the volume of production as "human labour becomes abridged" (p. 8) and hence "forming those conveniences of which so large a quantity is consumed by almost every class of the community" (p. 3).
Babbage described the process by which an invention is transformed to an innovation in the following three steps: (a) "to construct the whole machine upon paper" (p. 261);

(b) "the next stage in the progress of an invention, after the drawings are finished and the preliminary experiments have been made,... is the execution of the machine itself" (p. 262); and (c) the machine to be brought "into general practice" (p. 265)[14].
George Poulett Scrope, another British author, claimed that by inventions the productivity of economy has been increased ([1833], p. 280), "but poverty, on the other hand, has increased likewise, or at least, has not proportionaly diminished" (p. xiv)[15]. He then concluded that, "Skill, knowledge, art and science are daily improving in an accelerated ratio. All then that can be wanting, besides protection from force and fraud, is a

14. For Babbage, inventions took place through a trial and error procedure (BABBAGE [1832], p. 3). He analyzed the various causes which may be result in the failure of innovation in each stage of its development (pp. 261-7; see also HEERTJE [1973], pp. 68-9).
15. SCROPE ([1833], pp. 293-339) attributed this maldistribution of products to the mismanagement of resources.

judicious adaptation of these boundless means to their great end, the boundless augmentation of the wealth and happiness of society, individual and collective" (p. 455). John Rae's main argument was that invention is the prime force for the increase of productivity and of wealth, and therefore statesmen must encourage by all means scientific research ([1834] pp. 15-6). He considered that all inventions and technological "instruments" are based on experience and science (p. 86; see also pp. 239-40). Rae called all the means of production except labour, instruments and "the power that renders it an instrument is the art and industry of him who makes, and of him who uses it" (p. 89).
The argument that knowledge is the main source of invention[16] is emphasized by the American Samuel P. Newman. Considering Smith's distinction between productive and unproductive labour, he maintained that the labour of scientists and investors must be included in the first category ([1835], p. 23). He also distinguished between inventors whose sole employment is scientific research and discoveries, and innovators whose main contribution is the application of scientific discoveries (p. 24). Moreover, he argued that inventions are increased through an increase Df basic scientific research (pp. 76-7) and technological progress is made possible through an increase "in knowledge and intellectual advancement" (PP. 79-80)'[7].
Apart from the above views, some "radicals" of the period developed very interesting thoughts on the supply-push orientation of techno-ogical progress.
More specifically, Simonde de Sismondi explained the usefulness of ion-muscular "force" in advancing science and invention ([1847], p. 128) nd maintained that "intellectual progress.... gives rise to new wants among he rich, and opens a new employment for wealth" (p. 129).
The Ricardian socialist Thompson, a leading figure of the coopera-ive movement of the 1820's, stressed knowledge as a source of increase in he productivity of the factors of production. By using the dictum " Knowledge becomes a source of power" ([1824], p. 273), he tried to show that its

16. ROSENBERG ([1982], pp. 11-3) reviewing some recent historical studies stressed the 'crease of knowledge as among the prime factors in the emergence of modern technology i Europe.
17. Similarly, some modern scholars (e.g. SCHMOOKLER, [1966], pp. 2-3) define tech-ology as human knowledge applied in production. LINK ([1987], p. 4) mentions that "con-:ptualizing technology as the physical representation of knowledge provides a useful foun-Mion for understanding technological change and its determinants. Any useful technolog-al device is, in part, a proof of the knowledge-based

distribution to all members of society is fundamental for the increase of wealth (pp. 277-8).

Thomas Hodgskin, noted that until then [1827], the various authors on economic subjects did not investigate deeply "the means by which the industry of man may be rendered most productive" ([1827], p. 39)[18]. Hodgskin mainly argued that all inventions are generated through observation, knowledge, ingenuity and experiments ([1825], pp. 63-4; [1827], pp. 54, 57)[19], while innovations which increase the productivity of the factors of production are made possible because of the increased knowledge, skill and dexterity of the labourers' ([1825], pp. 46, 57-63; 1827, pp. 46-7)[20]. Thus, he concluded that basic research is of paramount importance for the advancement of inventions ([1827], p. 74), and that the fruits accrued from inventions, innovations and the division of labour belong to the labourers ([1827], p. 108). He defended his view for the redistribution of wealth by the argument that machines are nothing more than "the produce of previous labour" ([1825], p. 54; see also Jaffe, [1995], pp. 499-500), and thus the capitalists' profit is not justified as it belongs to the labourers ([1825], pp. 23, 54-5).

Moreover, Hodgskin by distinguishing between investors and innovators argued that the first are exploited by the second, viz:

"For a nation to have fixed capital, then, and to make a good use of it, three things, and only three things, seem to me to be requisite. First, knowledge and ingenuity for inventing machines. No labourer would, I am sure, be disposed to deny to these their reward. But no subject of complaint is more general or more just than that the inventor of any machine does not reap the benefit of it... Thousands of capitalists have been enriched by inventions and discoveries of which

18. Hodgskin comments that "no one of them (i.e. other economists) has it been treated of (i.e. the influence of knowledge on productive capacity) with a view to explain or discover the general laws which influence, regulate, and limit the progress of knowledge" (HODGSKIN [1827], p. 76; brackets added).

19. William Godwin, an exponent of philosophical anarchism who had some influence on Hodgskin's thoughts (JAFFE [1995], p. 495), similarly argued (GODWIN [1831], pp. 190-1, 200) that the increase of knowledge is the prime cause of inventions and innovations.

20. Hodgskin was not far away from the truth when he insisted that the increase of knowledge and labours' skill and dexterity is of primary importance for increasing total productivity. In recent empirical measurements of total factor productivity, particularly for the U.S.A. economy after World War II, it is estimated that advances in knowledge from R & D, learning by doing, and related experience, contribute 1.1 out of 1.4 percentage points of total increase, while changes in labour quality which covers changes in education, health, etc. contribute 0.5 percentage points (see LINK [1987], pp. 25-6). Relatively SCHMOOKLER mentions ([1966], pp. 4-5) that "the accumulation of intellectual capital... has been much more important than the accumulation of physical capital in explaining the rise of output per worker in advanced counties".

they were not the authors, and capital, by robbing the inventor of his just reward, is guilty of stifling genius" ([1825], pp. 63-4)[21].

From amongst the major members of the orthodox English classical school, McCulloch claimed inventions, the product of observation and "inquiry", to be enhanced through "the education now so generally diffused" ([1825], p. 69)[22]. He then stressed an important indirect effect of the introduction of machines for labourers: the

advancement of the labourers' knowledge. He made explicit that by the introduction of machines and the learning-by-using (or doing) process[23]:
(1) "introduces them [i.e. the labourers] to a higher species of employment" (p. 154; brackets added);
(2) "Their curiosity [i.e. of the labourers] is awakened, and instead of confining themselves to the application of rules laid down by others, they endeavour to simplify and improve existing processes, and to contrive and invent others that may better answer their ends. In this way the position of the work-people in highly manufacturing countries is progressively elevated. Their higher faculties are cultivated and improved, and the labour of the head is made to lighten that of the hands and make it more powerful" (p. 154; brackets added), and
(3) "By teaching the labourers to avail themselves of the powers and resources of nature, it improves their intellectual capacities at the same time that it raises their position. It makes them a sort of quasi-engineers instead of drudges; for it partially engages them in scientific occupations, at the same time that it relieves them of much severe work and of some of the most disagreeable duties necessary to the existence of society" (p. 155; see also MCCULLOCH [1826], p. 94).
In other words, according to McCulloch, by the introduction of new technology the labourers: (1) increase their knowledge, (2) increase their capacity of problem solving, and (3) become specialized.
On the subject of national education and its influence on economic growth, Scrope's ideas and arguments were outstanding. He considered the people's education to be one of the elements which constitute the

21. HODGSKIN ([1825], pp. 88-9) recognized the usefulness and the productive contri-
bution of the "master manufacturer" i.e. the entrepreneur, in organizing and conducting the
production process and justified his reward as a "right" one. However, he ignored the sim-ilar and more risky activities taken in the process of innovation.
22. McCulloch, stressed the importance of an educated working population on the efficient use of technological instruments and thus considered general education and knowl-edge to be an important factor in economic development (see ROBBINS, [1968], pp. 75-6).
23. ROSENBERG ([1982], pp. 120-140) analyzed the consequences of the learning by using process in technological progress.

welfare of society and one of the main responsibilities of the government ([1833], pp. 32-3). He regarded the acquired skill and knowledge of individuals as composing the human capital of society (pp. 138-9) and thus he emphasized the usefulness of "a general scheme of national education" (p. 456)[24]. He said that through technological progress, new employment opportunities are opened which need special skill and training. Those labourers who invest money and time in acquiring such knowledge and skill will receive a reward above the normal one (pp. 90-1,205).
4. Stimulating factors
After examining the supply-push factors in determining technological progress it is time to turn our attention to those demand-pull factor; recognized and analyzed by some authors in the period in question. Generally speaking, they emphasized the following demand-pull factors: (a) the rate of expected profits; (b) an increased demand; and (c) a change of the amount of labour or its real wage rate. These are factors which more or less direct the invention-innovation process and have been recently investigated (see e.g. Brozen [1953]; Boland [1954]). However, as we shall show they were well recognized by some economists in the period in question.
The profit motive principle is one of the main factors influencing the direction and

progress of technological advancement. Adam Smith claimed that inventions and innovations are not produced only through curiosity but because of the expected profits, thus the patent system in encouraging such an incentive is clearly justified ([1762-3], p. 83)[25]. The argument that the profit motive and its expected rate is a main cause of the introduction of new technology shared also by other economists. For example, Colonel Torrens disregarded the possibility advanced by Ricar-do that through machinery the production of subsistence will be diminish, and identified in the profit motive (and particularly in its expected rate) the prime factor for innovations ([1821], pp. xii, ft, 142-3). Cardozo, specified that because of the function of self interest and the competitive

24. SCROPE maintained that the inventions of writing and printing tremendously increased the level of human capital ([1833], pp. 92-3).
25. In our days USHER ([1955], pp. 60-1) stressed that through the patent system the short-run monopolistic profit gained by the innovator is a stimulus for further inventions and innovations. Also, SCHMOOKLER ([1962], pp. 117-8,120-1) argues that the allocation of resources to inventive activities depends on economic phenomena and mainly can be substantially explained in terms of individuals acting in response to expectations of future profit.

process of the equalization of profits of capital in every investment ([1826], p. 50), entrepreneurs will try to introduce production cost relucing technological improvements in every sector of production (p. 6*).* Babbage exaggerated the stimulus of profit in innovative activity. **He** specifically mentioned that the diminution of the rate of profit will be *n* stimulus to the manufacturer for discovering a cost reducing technology

"by the diminution of profit which the manufacturer suffers from the diminished price, his ingenuity will be additionally stimulated;- that he will apply himself to discover other and cheaper sources for the supply of his raw material,- that he will endeavour to contrive improved machinery which shall manufacture it at a cheaper rate,- or try to introduce new arrangements into his factor, which shall render the economy of it more perfect" ([1832], p. 233)[26].

Babbage by stressing some of the sources of innovations as developed later on by Schumpeter[27], referred also to "the effect of gluts in producing improvements in machinery, or in methods of working" (1832, p. 233). Because, "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" (1832, pp. 233-4). Thus Babbage portrayed the lompetitive-innovative process in advancing technology[28].

Scrope seems to regard the short-run extra profit from a monopolistic situation as created by "the fair exercise of his [i.e. the monopolist's] natural, acquired, or accidental advantages", and to be used in irder to "encourage industry and excite emulation" ([1833], p. 176; brackets added)[29].

Rae claimed that inventions are stimulated by two "probabilities": (a) that of success in increasing the productivity of labour, and (b) that "of the future wealth to be derived from this new source" ([1832], p. 16). He

26. Babbage mentioned that by the innovative-competitive process somei entrepreneurs possessing "superior industry and attention", and "superior capital" will gain a superior profit compared with others (BABBAGE [1832], p. 240). The profit motive is emphasized by Babbage also in the process of imitation of an innovation (p. 214).
27. As it is known, SCHUMPETER ([1911], pp. 132-6; [1928], p. 32) stressedl the following kind of

innovations: (1) in the creation of new products; (2) in opening a new market; (3) in using a more productive process; and (4) in organizing the enterprise more efficiently.
28. In our century J.M. CLARK ([1961], p. 181) recognized the short-run monopolistic advantage gained by the innovating firm as the main factor in stimulating innovative activity. He also stressed that the competitive environment of imitators was a Stimulus for the innovative firm to continue its efforts for further improvement of its innovation or for the introduction of a new one.
29. Newman, similarly, considering the profit motive as a stimulus to innovations (NEWMAN [1835], pp. 74-5), justified the positive effects of the patent system is, "The immediate object of patent rights is remuneration for useful discoveries and inventions" (p. 73).

recognized the following profit opportunities which stimulate invention and innovation: (1) "some improvement of some of the employments formerly practiced in the community"; (2) "some discovery of new arts" (p. 22); (3) "The progress of commerce by the increase of some particular branch of it, or the opening of fresh branches"; and (4) "of the settlement of new countries" (p. 24). These creative (1 and 2) and acquisitive (3 and 4) causes of wealth accrued by innovative activities are similar to those developed by Schumpeter. Rae, moreover, under the factor of profit motive gave special importance to the role of imitators in diffusing technology and decreasing the super normal rate of profits of innovators through an increase in the wage rate (p. 53)[30].
From the "radical" voices of the period many interesting comments on the issue in question arose. More specifically, Sismondi in his paper "On the Condition of the Work Force in Manufacturies" published in *Reveu mensuelle d'Economie Politique* Quly and August 1834, edited in Sismondi [1847]) elaborated upon the changes in social and economic conditions of the labour class in England. Here he claimed that more labour-saving machines are being introduced through the motive of the capitalist manufacturers to undersell their rivals and to gain extra profit ([1847], pp. 211,217;241)[31].
Hodgskin, advancing a "theory of individual appropriation" (Jaffe [1995], p. 513) argued that the main stimulus for invention is the self-interest of the inventor, namely, his: "natural but insatiable desire of providing for his wants or bettering his condition" ([1827], p. 85).
Besides the profit motive as a stimulus of inventions and innovations, the rate of demand for machines and their products was also considered to be a very important factor determining the rate and direction of technological progress[32].
Malthus in his Book II section V which is titled "Of Inventions to save Labour, considered as a Stimulus to the continued Increase of Wealth"

30. The diffusion of technological improvements through foreign trade was well stressed by the economists of the period (see BLOOMFIELD [1978], pp. 613-5).
31. SISMONDI in his "Introduction..." characterized the competition between entrepreneurs as 'chresmatistics' actions or 'chresmatistism' ([1847], pp. 142-3)-obviously copying wrongly the Aristotelian unnatural economy of 'chrematistics'.
32. SCHMOOKLER ([1966], ch. II, IX) deeply investigated and analyzed the demand factor of technological progress. MOKYR ([1990], pp. 151-3) questioned the influence of demand in determining the various kinds of technological improvements. Some others modern economic historians stressed the influence of increased demand on inventions and innovations. For example, USHER ([1955], p. 52) specifies that the demand of some sort of goods, was the main cause for invention and innovations in the sector producing it. MOKYR ([1977], pp. 102-5) also investigated the argument that technological change is demand-induced which as he noticed "is far from new".

of the *Principles of Political Economy* [1820], stressed the rate of demand as the decisive factor influencing technological progress. He argued that "Inventions to save labour seldom take place to any considerable extent, except when there is a decided demand for them" ([1820], p. 351)[33].

Babbage claimed the increased demand for a product to be the main incentive for innovations. He noticed that:

"The inducement to contrive machines for any process of manufacture increases with the demand for the article; and the introduction of machinery, on the other hand, tends to increase the quantity produced, and to lead to the establishment of large factories" ([1832], pp. 213-4; see also pp. 26S-9)[34].

By stressing the rate of demand as the main factor of innovative activity, Babbage argued that the rate of obsolescence is increased when the demand for goods or for new machines is increased (p. 285).

Whately specified that because of basic scientific research, the necessary knowledge for marketable inventions and innovations is accumulated. However, he regarded the expected demand of the product produced by new technology, and consequently the expected profits, as the main causes of many improvements in technology and innovations ([1832], p. 165).

From the "radicals" of the period, Hodgskin, examining the process of innovation, claimed that two conditions had to be satisfied: (1) "the commercial demand for means of abridging labour", i.e. demand for the product of the labour-saving innovation, and (2) "practical skill... and.... dexterous workmen". In their absence "the most ingenious contrivances must be classed merely as visionary dreams" ([1827], p. 91).

The abundance of capital as enhancing technological progress was another factor mentioned by Smith, and stressed by some other economists[35]. The well known Smithian principle that by increasing the volume of capital and the extent of market the division of labour is extended, was

33. McCulloch, similarly regarded the increased demand for specific goods as a stimulus for innovation, citing: "the increased demand for cottons, and the powerful stimulus which was thereby given to invention and discovery" (McCuLLOCH [1826], p. 93). Newman also emphasized the demand for products as a factor for induced technology (NEWMAN [1835], p. 78).

34. Babbage regarded demand as such a significant stimulus of innovation as to emphasize the necessity for conducting investigations of the expected sales of a product (BABBAGE [1832], p. 245).

35. Smith's linking of the rate of accumulation and investment with economic growth w terms of factors' productivity however is supported by empirical data. In recent studies 70 percent of the fall of total factor productivity after 1973 in the U.S.A. economy is attributed to the decline in capital formation (see LINK [1987], pp. 39-40).

used by George Ramsay in order to explain the fast technological progress in Britain[36]. Ramsay, despite his minor contribution to the subject of "machinery", investigated the role of large firms in promoting labour-saving technological progress ([1836], pp. 241-2). He did not completely contradict the principle that large scale firms are more innovative than small ones[37]. Ramsay seems to base this principle on the power of the volume of capital and not on the structure of the market (competitive, monopolistic) established in various large firms[38]. However, he was open minded indeed to question the argument in favour of the concentration of capital in the hands of few people, from the point of view that the profit accrued by a large firm is not as likely to be reinvested as in the case of a small firm (pp. 242,249-50).

5. "Necessity is the Mother of Invention"

Another main demand-pull factor influencing the direction and the rate of technological progress for the post-Ricardians was the response to pressing economic problems caused by a shortage of factors of production, or of an increased rate of reward. This was depicted by the maxim "necessity is the mother of invention"[39] and thus labour-saving innovations were acknowledged by the majority of the authors in the period in question to be the main expression of technological progress[40].

36. Sismondi similarly in his "Introduction to Inquiries into Political Economy" (edited in SISMONDI [1847]) emphasized that inventions were made possible because of the advancement of science and the accumulation of capital (1847, p. 130).
37. Recently many arguments and counter-arguments have been advanced for the role of large and small firms in promoting innovations (see e.g. KRASNER [1982]; UDELL [1982]).
38. Ramsay is nor far away from reality when he regards the abundance of funds as a decisive cause for the introduction of new technology. Barrere in an interesting paper (BAR-RERE [1961]) has shown that under specific assumptions the main factor in determining cap-ital deepening innovation is the adequate entrepreneurial funds.
39. This maxim was specifically mentioned by HODGSKIN ([1825], p. 86); WHATELY ([1832], p. 164); SCROPE ([1833], p. 66). \
40. Labour-saving technology is explicitly mentioned by the following authors: LAU-I DERDALE ([1804], pp. 167, 287); SAY ([1821], p. 86); TRACY ([1817], pp. 39, 153); RICARDO ([1817], p. 80); RAYMOND ([1820], vol. II, p. 104); SISMONDI ([1847], pp. 126,131); TORRENS ([1821], pp. 101); McCuLLOCH ([1825], Part I, ch. VII); CARDOZO ([1826], pp. 54-5); HODGSKIN ([1827], p. 59); EDMONDS ([1828], pp. 123-4, 162); BABBAGE ([1832], p. 268); SCROPE ([1833], p. 190); NEWMAN ([1835], pp. 69,79); TUCKER ([1837], pp. 53-4). Malthus although was mainly talking for labour-saving inventions (MALTHUS [1820], p. 351) in a passage (p. 178) he speaks for both labour and capital saving technological process (see also HEERTJE' [1973], p. 10).

One of the main factors influencing technological progress is the increase of the wage rate. Such a factor was recognized by John Barton who, in his *Observations on the Circumstances Which Influence the Condition of the Labouring Classes of Society* (1817), stressed that a change in the rate of rewards causes a change to the composition of capital or a substitution of capital for labour. In the case where the wage rate is increased, the capitalist's interest is best served by employing more labour saving technology (Schumpeter [1954], p. 682; Hollander [1979], p. 350).
The same argument was used contemporaneously but indepentent-ly by David Ricardo (Hollander [1979], p. 352). He regarded the increase in the real wage rate as one main cause for the technological progress and mainly for labour saving technology. This factor of labour substitution which became known in the economic literature as the "Ricardo effect"[41] describes the direction of technological progress.
Ricardo, before writing his famous chapter "On Machinery" [1821], had already noticed that an increase in the wage rate will force the manufacturer to substitute labour for machines ([1817], pp. 40-1). In his chapter "On Machinery" he advanced this argument by stating that:
"With every increase of capital and population, food will generally rise, on account of its being more difficult to produce. The consequence of a rise of food will be a rise of wages, and every rise of wages will have a tendency to determine the saved capital in a greater proportion than before to the employment of machinery. Machinery and labour are in constant competition, and the former can frequently not be employed until labour rises" ([1821], p. 395)[42].
As is well known, Ricardo attributed the increase of the real wage to the functioning

of two unavoidable long-run forces: the multiplication of population and the diminishing returns in agriculture. Thus the main scarci-

41. HAYEK was the first [1939] to label Ricardo's principle the "Ricardo effect".
42. Many economists followed and developed further this Ricardian principle (see e.g. HICKS [1932], pp. 124-5; FELLNER [1961a, 1961b]. The principle that an increased reward of a factor of production or its scarcity is an important cause for the direction of technological improvement was used by HABAKKUK [1962] in explaining labour-saving innovations in the 19th century in American and British economies. For Habakkuk's thesis and related issues m regard to the factors stimulating technological progress in different economies see the excellent review article of USELDING [1977] on the recent research of economic historians. Contrary to Habakkuk and others, Mokyr maintained that in the early 19th century "Population growth tended to lower the relative price of manufactured goods and real wages, and thus was not likely to have stimulated a search for labor-saving innovations" (MoKYR [1985], P- 24).

ty factor in this case was not labour but the means for its maintenance. This factor also was noticed by Torrens who wrote:
"There can be no doubt that the Corn Laws have caused machinery to be employed in this country more extensively than it otherwise would have been. When the price of provisions is low, human labour may be cheaper than mechanical power.... In many branches of trade, it is the price of corn which determines whether machinery can be advantageously introduced or not" ([1834], p. 124)[43].
This demand-pull factor, the scarcity of resources, was also well recognized by Hodgskin. He believed that an increase in population causes a scarcity problem to appear. This problem can be solved by various inventions and innovations which in their turn are made possible through the increased population, division of labour and knowledge ([1827], pp. 85-6; 128-9)[44].
The foregoing analysis makes it clear that the economists of the early decades of the 19th century recognized some significant causes, such as expected profit and demand, capital abundance and factor prices, for the direction and advance of technology. Thus the determined technological progress was well recognized as a feature of economic growth in the literature of the period. Schumpeter, however, seems not to agree with this argument commenting rather that:
"Technological improvement may impinge upon the productive process from outside, that is to say, through some innovation that revolutionizes the technological horizon of producers (changes their production functions). The classic writers thought exclusively or almost exclusively of this case and hardly every realized- an exception was Barton- that there is another case the effects of which differ substantially from the first: machines may also be introduced that are no novelties to producers and, so far as technological knowledge is concerned, could have been introduced but were not introduced before, because it would not have been profitable to do so. Owing to a change in the relative prices of factors (e.g. an increase in wage rates), their introduction may, however, become profitable" ([1954], p. 679, fn. 94).

43. McCuLLOCH ([1826], p. 12) also claimed that the scarcity of resources was an important cause of technological progress and commented that "As it becomes more difficult to obtain supplies of new land, a better and more careful system of tillage will be applied to the old land" (p. 12). The scarcity problem as the main determinant of direction of technological progress was also mentioned by Longfield, who additionally stressed general education and improved means of communication as instruments for its promotion (LONGFIELD [1833], p. 237). Carey similarly claimed that in order to economize a scarce resource, a "saving" technological improvement must take place (CAREY [1837], p. 19).

44. W.A. COLE recently [1973] has shown that during the Industrial Revolution the increased rate of population had stimulated inventions.

6. Conclusions

The previous analysis, though it does not exhaust the huge literature of the period on the "machinery question", clearly shows that some writers of the early decades of the 19th century in Britain, the Continent and America recognized the supply-push and demand-pull motives of technological progress.

The supply-push causes of technological improvement were attributed by followers of Smith to the advancement of science induced by the division of labour. Some others claimed that the advancement of science and knowledge produced the division of labour. Furthermore, under the maxim "knowledge is power", the supply-push factor of knowledge and scientific advancement as a cause for technological progress was stressed. Some authors developed the following arguments which have a real modern sound: (1) increases in knowledge and skill were the main factors for promoting inventions and innovations; and, (2) by increasing knowledge the productivity of the factors of production is increased. These arguments were shared not only by British but also by some Continental and American writers. Thus Berg's comment that the English economists did not show "any interest in advances in scientific knowledge" ([1980], p. 92) is not perfectly valid.

On the other hand, by examining the various demand-pull factors influencing both the direction and the rate of technological progress, other important findings were made. Some authors of the period clearly recognized some stimulating and determining economic factors such as expected profits, the rate of demand, scarcity of the factors of production, etc. which through the demand of entrepreneurs shape technological progress.

All the above supply-push and demand-pull factors which were recognized and some of them adequently developed by the various economists of the early decades of the 19th century, have been recently examined by economic historians (see, e.g. Sullivan [1990]) in order to estimate the extent of their influence on technological progress. Therefore, in the early decades of the 19th century where technological progress was the main characteristic of the economic transformation from "home" to "world" production, the ideas and arguments of some writers on various causes of technological improvement were very original regarding similar present days investigations.

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