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A Critical Approach to the Principal Theories on Technological Change

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Abstract

This paper delves into the main theories on and approaches to technological change, aiming to demonstrate the currency of Karl Marx's precepts in contemporary discussions. Methodologically, the neoclassical and neo-Schumpeterian schools of thought were unified, pursuant to the conventional approach, when it came to technological change, despite their discrepancies; nevertheless, in the Marxist concept, Marx's analyses prevailed over those issued by other authors. The contrast between the two theoretical standpoints was predicated on four fundamental variables: *1)* systemic character, *2)* the nature of technological change, *3)* attitude toward the innovative process, and *4)* the scope of the explanation revolving around growth and development.

Keywords: Technological change, neoclassical and neo-Schumpeterian theories, Marxist theory, capitalist accumulation.

INTRODUCTION

Tremendous and fast-paced changes in science and technology have developed in recent decades; technological change is one of the thematic areas that has garnered the most attention and controversy. However, it is worth asking: to what extent do current notions recognize the validity of Marxist contributions? This paper demonstrates the theoretical reach of the Marxist concept of technological change, one hundred and fifty years after *Das Kapital* was published, in spite of the historical limitations of this masterpiece.

In his studies on capitalism, Karl Marx set forth an idea that convincingly explained the driving force of technological change as a response to the demands of capitalist accumulation. The objective of this paper is therefore to analyze bedrock notions of technological change from a critical stance, because in contemporary theories, the contributions from this school of thought have been disregarded.

THE CONVENTIONAL ECONOMIC THEORY PERSPECTIVE

The first author to conceive a recognized theory on technological change was Schumpeter,[2] who showcased that the innovation process becomes an internal mechanism that leads to the evolution of the capitalist system, motivated by the actions of an entrepreneur who pursues scientific recognition. From that standpoint, the innovative process emerges as a competitive tool, and the company and entrepreneurial endeavor its driving factors (Antonelli, 2008).

According to Schumpeter (2003, p. 119), the task of renovating the necessary equipment is unresolved in capitalism. Technological change reveals that the system is dynamic and functions through waves of innovations, endogenously spurred by industrial transformation. The capitalist dynamic has evinced that there is no so-called steady state in the economy, but rather, playing off many springs—technological change—it has managed to prevail over time (Schumpeter, 1978).

Schumpeter's notion depends on the appearance of innovations,[3] which alter the course of the *circular current.* As a result, technological change is endogenous, driven by the innovative attitudes of entrepreneurs. Thus:

> The function of entrepreneurs is to reform or revolutionize the pattern of production by exploiting an invention or, more generally, an untried technological possibility for producing a new commodity or producing an old one in a new way, by opening up a new source of supply of materials or a new outlet for products, by reorganizing an industry and so on" (Schumpeter, 2003, p. 132).

The Exogenous Theory of Technological Change

The principal neoclassical school of thought on technological change was made up of Abramovitz (1956), Solow (1956, 1957),[4] Swan (1956), and Kendrick (1956). To these authors, technological change is admitted as an exogenous variable; the contribution of technology is null, which is to say, there is no technological change within the model.[5]

> It is an interesting sidelight that a faster rate of technical progress actually prolongs the lifetime of capital in this particular

> model, though that is not a general truth. There are offsetting forces at work: faster technological change means that output grows faster, the volume of new investment grows faster, and this extra competition tends to shorten the lifetime of any given plant. On the other hand, the faster technological progress means that any given amount of new capacity provides fewer jobs, and this tends to keep capacity in service longer to maintain the required amount of employment (Solow, 1982, pp. 64-65).

The incongruence of the model resides in failing to explain its nature.[6] Nevertheless, Solow (1957, p. 312) set forth a thesis that would subsequently become foundational: "improvements in the education of the workforce [...] will appear as technical change." Thus, Solow (1962) concluded that economic growth depends not only on capital formation, but also that investment in human capital constitutes a better condition for growth. Its fundamental elements include research, education, and public health.

"The central conclusion of the Solow model is that there is a long-term balanced growth path that depends only on the natural rate and the exogenous rate of technical progress" (Doimeadiós, 2007, p. 15). This model assumes perfect competition, full and constant employment, conducive to a stationary state, resulting from the declining marginal productivity of capital. In that context, only exogenous technological change can counteract this trend.

Nor is technological change incorporated into the capital factor and labor. It cannot be measured as a residual of the productivities of the two elements either (Katz, 1996 and 1997; Gutiérrez, 2010). Common to it are imbalances,[7] and it increases diminishing returns to scale. Paradoxically, Solow (1957) concluded that 87.5% of the growth in the production of goods in the United States in the period 1909-1949 was attributed to technological change. Nevertheless, he alleged that its growth rate was neutral. It was consistent with the axiomatic principles of neoclassical theory. Otherwise, it would mean gong against his own theoretical background.

Especially relevant is the recognition by Professor Sala-i-Martin (2000, pp. 5-6), who claimed that the theory's lack of congruence with reality made development theory the only school of thought studying economic growth applied[8] to concrete reality. For that reason, at the onset of the nineteen-seventies, growth theory was drowning in its own irrelevance.

Endogenous Approaches to Technological Change

The nineteen-eighties saw the rise of endogenous growth theories, relaxing the assumptions of the exogenous variant. This strain of thought admitted the importance of knowledge and learning. That led to an improvement of the Solow concept, supplanted by the Romer approach (1986, 1991, and 1994), which incorporates technological change[9] into the neoclassical theory of economic growth. The new theories of endogenous growth shifted from the theoretical baseline of perfect competition toward competition for innovation, with the State's explicit recognition of the monopolistic rights of innovative companies (Fernández, 2008, p. 33).

From these studies surged a clutch of models conceiving of the accumulation of physical and human capital as a source of growth (Romer, 1986, 1991, and 1994; Lucas, 1988; Jones and Manuelli, 1990; Barro, 1991). One of the key assumptions underlying this model was relaxed, specifically, constant returns to scale. The learning through practice preached by Arrow (1962)[10] introduced knowledge as a source of increasing returns to scale.

In Romer (1986), knowledge is held to be an asset in the productive process, whose principal objective is to raise marginal productivity. Therein arises a supposed break from the traditional neoclassical growth models, in which technological change not only seems to be an exogenous variable, but also returns are constant to scale.

According to Romer (1986, p. 1003), in the absence of technological change, the output of goods per capita should converge toward a steady state. This is a matter of a general equilibrium model with endogenous technological change, in which long-term growth is driven primarily by the accumulation of knowledge. To this author, technological goods are nonrival and partially excludable goods.[11] Non-rivalry indicates their simultaneous use in other activities, as is the case of knowledge (Sala-i-Martin, 2000). On the other side, exclusion alludes to the power of the owner to prevent the good from being used by another capitalist without paying for its use.

Romer (1991) posits that his model is similar to Solow's (1956) in terms of technological change. But at the same time, he distances himself from Arrow (1962), as his model does not contain evidence for any private maximizing behavior in the generation of technological change that responds to market incentives. Lucas (1988) remonstrated that human capital output, and not physical capital output, evinces this behavior. Romer (1991) discovered how to grow, what matters is not to join an economy abundant in people, but rather in human capital. In the newer growth theories, technological change is endogenized by human capital, the principal factor of economic growth. It is a matter of a continuation and improvement upon mainstream neoclassical theory.

Later contributions have asserted that growth depends directly on technological change (Aghion and Howitt, 1992). The Schumpeterian idea of creative destruction is incorporated, via the substitution that happens when a new capital good replaces an earlier one. Technological change arises from research and development departments as part of a technical-economic process. As labor and capital are analyzed as independent output factors, any sign that the former is subjected to the latter disappears altogether.

Neo-Schumpeterian Approaches

The genesis of the neo-Schumpeterian theory is found in Nelson and Winter (1982), who explained competition for innovation as a change in routine and the incorporation of incremental innovations. These authors, agreeing with Schumpeter, find the explanation for long-term structural evolution in technological change and view its consequences in terms of innovation (Gutiérrez, 2010).

Technological regimes[12] seem to be drivers of innovation patterns across industries. These analyses underscore the fact that the economy as a dynamic system, whose actions are deployed in a unique and unrepeatable moment in history. Unlike the neoclassical theory, which revolves around different patterns of technological change, the neo-Schumpeterian-evolutionary authors explain how these patterns shift over time. Their analyses are more dynamic, evolutionary, and essentially qualitative (Bayón-Sosa, 2013).

According to Pérez (1983), the *technological style* is sort of an *ideal type* of productive organization, or rather, technological *common sense,* which develops in response to a stable dynamic of cost structure. In the fashion of *technological paradigms,* the idea is that common business owners make improvements throughout the natural trajectory of the installed technology. At the same time, they implement radical changes in the production spheres that have not yet reached the ideal type of productive organization.

The technological style or paradigm is based on a cluster of related innovations, attaining productivity levels higher than in the previous paradigm. This heralds the advent of a technology revolution, alluding to the qualitative leap in productivity, which they call the *key factor.*

Thus, technological change is cumulative,[13] tacit, and local.[14] Technological change is ongoing, derived from learning, which is path dependent and contextual. In contrast with Arrow (1962), there are costs involved in learning, so it is not automatic. The weight of institutions is key in this approach, as they can accelerate or slow down innovative processes.[15]

Technology revolutions, like hurricanes of creative destruction, drive capitalism to overcome the recessive phases of the economic cycle. Pérez (1985, 2009) posits that in every technology revolution, the *techno-economic* paradigm must readjust its *socio-institutional* framework.

Pérez (2001) suggested the possibility of reaching development through windows of opportunity (catching up), which temporarily open every time there is a technology revolution. Technological change emerges as a continuous process, contrary to Schumpeter, who described it as discontinuous and uncertain. Pérez (2022) creates a theoretical framework that complements evolutionary economics with long-term macro-dynamic notions. As such: "at the micro scale, the evolutionary foundation is a useful point of departure for a theory that demonstrates how technology gaps and national institutional differences can be jointly reproduced over time" (Cimoli and Dosi, 1994, p. 676).

The apex of this school of thought might be that it "has made an attempt to learn the history, calling into question the crucial problems of the neoclassical methodological individualism and reductionism" (Fernández, 2008, p. 38). These authors disregard the connection between the capitalist accumulation process and technological change, offering in its place historical, political, and social contexts with natural trajectories followed by the most adaptable technologies. Moreover, the vast majority contend that innovation is the motor for development, apart from its historical-social conditioning.

THE MARXIST CONCEPTION

The common thread running through Marx's analysis of the fundamental tenets and tendencies of capitalism is the role of technological change[16] as development potential. His stance toward technological change was positive, given that in his viewpoint, no system had as of yet managed to overcome the development of the productive forces of humanity as capitalism had. Analyzing commodities as the cell of bourgeois society, Marx (1973a) demonstrated the system's preference for appropriating the value contained in the commodities made by workers.[17]

> Thus, the full development of capital does not take place—in other words, capital has not set up the means of production corresponding to itself—until the means of labor is not only formally determined as fixed capital, but has been transcended in its direct form, and fixed capital in the shape of a machine is opposed to labor within the production process. The production process as a whole, however, is not subordinated to the direct skill of the worker; it has become a technological application of science. The tendency of capital is thus to give a scientific character to production, reducing direct labor to a simple element in this process (Marx, 2007, p. 221, emphasis in the original).

According to Marx (1973a), although absolute surplus is established on the basis of a given labor productivity, it plays a still incipient role in technical progress. In exchange, the relative surplus displays a higher degree of applicability[18] of science and technology to the worker's means of consumption. The result is a general reduction in the value of labor power and with it an increase in the work day for the time to produce the surplus, at the cost of individual labor time. In the incessant pursuit, the extraordinary surplus emerges as the driving force behind the system.

The introduction of new technologies is inextricably tied to the rise in exploitation, given the central role that the pursuit of higher surplus rates plays in technological change. This process is driven by the uncertain and convulsive movement of the law of value (Katz, 1997). The law of value establishes the erratic nature of the innovative process, pushing those innovations most appropriate to capitalist valorization.

Marx (1973a) discovered that cooperation guarantees a collective worker, as its point of departure resides in the meeting of a number of workers who work at the same time in coordination at the behest of a single capitalist (Marx, 1973a, p. 278). Cooperation represents on the one side a collective labor process and, on the other, a relative surplus production process (Rosenberg, 1979, p. 272). Capitalism turns the labor process into a social process.

In its historical transformation, cooperation led to manufacturing, whose degree of complexity is a higher degree of the capitalist development process.[19] The radical change came about in the labor process, which was transformed and subdivided into scattered operations. This rapid process of technological change has entailed, since the very beginning, a form of relative surplus that is much higher than in simple cooperation, at the same time destroying the previous artisanal base (Sánchez, 2009).[20]

> But to the degree that large industry develops, the creation of real wealth comes to depend less on labor time and on the amount of labor employed than on the power of the agencies set in motion during labor time, whose 'powerful effectiveness' is itself in turn out of all proportion to the direct labor time spent on their production, but depends rather on the general state of science and on the progress of technology, or the application of this science to production (Marx, 2007, pp. 227-228).

Following Marx (1973a, p. 294), the difference with respect to simple cooperation resides in the fact that manufacturing requires a production complex whose bodies are the workers themselves, regardless of the point of departure taken, insofar as this division of labor in the plant finds its origin in the social division of labor. Accordingly, "the manufacturing worker loses his technical independence, becoming a part of the whole, outside of which he cannot work" (Rosenberg, 1979, p. 282). The worker turns into a living organ of a large dead mechanism of machines displacing him, and at the same time, is obliged to be part of the system, outside of which is labor power loses all of its use value.

> Certain physical and mental qualities of the individuals are here seized upon, in order through their one-sided development to create in manufacture a total mechanism formed out of human beings themselves. Here, in the mechanical workshop, the body of this total mechanism consists of the differentiated machines themselves, each of which performs the particular special processes, following one upon the other in succession, which are required for the process as a whole […] There, the worker puts *into service* a particular instrument; here, particular groups of workers *serve* various machines, which perform particular processes (Marx, 1982, p. 168, emphasis in the original).

Cooperation constitutes the historical and logical jumping-off point for the capitalist system. On the one hand, it represents a process of collective labor, and, on the other, a process to produce a relative surplus. This accelerated technological change-cum-big industry solidified capitalism,[21] shaping the real subordination of the worker to capital. The Industrial Revolution entailed the elevation of the capitalist form to the dominant mode of production, In turn subjecting the production process to the logic of capitalist accumulation.[22]

Technological development contains its own limits.[23] On one side, the machine that arises expresses the extraordinary development of labor productivity—which supplants the role of the worker making machines and replaces it with machines making machines[24] —and at the same time drives salaries down due to the devaluing of labor power. Technological change cheapens the means of subsistence for the worker and reduces the value of his special commodity: labor power.

> To the degree that labor time—the mere quantity of labor—is posited by capital as the sole determinant element, to that degree does direct labor and its quantity disappear as the determinant principle of production—of the creation of use values—and is reduced both quantitatively, to a smaller proportion, and qualitatively, as an, of course, indispensable but subordinate moment, compared to general scientific labor, technological application of natural sciences, on one side, and to the general productive force arising from social combination in total production on the other side—a combination which appears as a natural fruit of social labor (although it is a historic product). Capital thus works towards its own dissolution as the form dominating production (Marx, 2007, p. 222).

The laws and trends Marx is aiming at (1973a) are driven by the dynamic nature of productive forces.[25] The capitalist capacity to develop these forces has subjected its laws to the advances made in science and technology.[26] Technological change has become a productive force able to act as a trend running counter to the eventualities of the accumulation process.

One central variable of Marxist theory is the organic composition of capital, which explains the system's historical trend. With that, Marx (1973a) exposes the propensity of the constant piece of capital to rise and, at the same time, for its variable portion to fall. Likewise, he found that the capitalist development potential resides in a mechanism that tends to reduce the value of labor power, at the expense of augmenting that of the means of production.

> Marx uses the organic composition of capital to show the effects that the changes in this composition can have on the demand for labor, that is, how as technology evolves, a burgeoning organic composition of capital means more and more labor is needed for a given mass of capital. In other words, in the modern terminology, we would say that more capital-intensive techniques are used (Sunkel and Paz, 1973, p. 168).

Innovation turns into a vehicle the valorization crisis (falling earnings rate) and the realization (tightening of purchasing power with respect to rising output) of capital, as the consequence of the compulsive dynamic imposed by mercantile competition. There is an imbalance between the technical organization and the maximization of benefit, which structurally destabilizes the accumulation process. Nevertheless, technological change temporarily oxygenates the sharp contradictions of the capitalist accumulation process, operating as a potential counterweight (Katz, 1997).

Marx projects the factors that counteract the falling earnings share, admitting the possibility of continuous accumulation via economic crises. Changes to the organic composition of capital express alterations in technological change. The capitalist development process advances via the contradictions spurred by technological change and at the same time overcomes them via crises. The earnings share thus becomes the variable regulating the technological change process, in which expected profit sets the investment level for the innovative process.

Mandel (1979, p. 191) held that accelerated technological innovation and the pursuit of extraordinary technological gains constitute the basic features of late capitalism. He also held that reduced fixed capital turnover time is another consequence of the speed of technological change.

Marx (1973c) rationalized that the declining trend tenet for the profit share expresses the progress of labor productivity.

These changes in the conditions of capitalist production foretell technological changes in the pursuit of extraordinary surplus, with which the system changes its technological base.[27] The capitalist accumulation process develops via the constant increase in the organic composition of capital, that is to say, through permanent technological change.[28]

The very nature of the capitalist development process produces the displacement of labor power, while the moral wear[29] on the means of production is greater (Marx, 1973b).

The Marxist conception of technological change admits this as a consequence and not a cause of the socioeconomic process, which expresses the contradiction between the rising socialization of science and technology and the incessant privatization of its fruits in the form of patents. "Before, capital only employed the machine to the extent that it permitted the laborer to work for capital for a longer portion of his time..." Marx, 1982, p. 222). The innovative process is connected to the historical and specific demands of the accumulation process. It is not fortuitous. It responds to the designs of a greater force: the growing need to increase fixed capital with respect to living labor.

CONCLUSIONS

Having analyzed the main tenets pertaining to technological change, the conclusion is that Marxist contributions have been missing from the contemporary debate. It should be underscored, however, that this research does face limitations in terms of the mathematical treatment formalized around the mainstream neoclassical models of technological change. Nevertheless, a critical reading of these authors and the neo-Schumpeterian authors is meant to look at four useful variables to contrast them with the Marxist conception of technological change, specifically: *1) the systemic nature* (micro, meso, and macroeconomic vision), *2*) *the nature of technological change*, *3) the attitude toward the innovative process,* and *4) the explanatory scope,* when it comes to economic growth and the development process.

In terms of the systemic nature of technological change, the conventional neoclassical strain is essential microeconomic, but contemporary authors evince improvements with respect to the exogenous growth authors, as they admit that returns on productive factors are increasing in the long term. The neo-Schumpeterian notions, on their side, overcome the neoclassical microeconomic approach and are centered on the mesoeconomic level, underscoring the technological trajectories that result in macroeconomic extrapolations. The Marxist conception is totalizing in the macroeconomic sense. In it, the micro and mesoeconomic behaviors are subordinated in an overall dynamic of capitalist functioning, that is to say, systemic.

In terms of the nature of technological change, the conventional conception is also contradictory. The traditional models are the exogenous and the endogenous, from Solow and Romer, respectively. The former was externalized, in spite of the fact that the contribution of technological change in the model explained more than 80% of economic growth, which was corrected in the endogenous variant. The neo-Schumpeterian authors admit technological change as an endogenous and cumulative variable, in both the classic conceptions of Schumpeter and the more recent neo-Schumpeterian notions. However in none of its strains does conventional theory recognize that Marx was, at minimum, the precursor to the endogenous nature of technological change. Conceiving of it as a material form adopted by the development of productive forces in the capitalist framework sheds a lot of light on the controversies upheld by the growth economists in past decades. The empirical evidence ended up proving Marx right.

Attitude to the innovative process is barely visible in the neoclassical exogenous perspective, as it speaks of static productive factors with declining productivities. This element has been corrected in the endogenous growth theories, indicating that investment in human capital and growing returns from research and development play a role, in which knowledge is the core of innovative activity. The neo-Schumpeterian authors also find it to be a central theme, as they emphasize the importance of tacit knowledge and learning through practice as the result of innovative activity dependent on the knowledge trajectory of the key technology. Accordingly, none of these mainstream authors furnishes a consistent explanation as to why innovative activity is inherent to capitalist entrepreneurs or business owners. According to Marx, the capitalist accumulation process is driven by the outsized attainment of surplus, which finds its natural limits in the erratic behavior of the law of value. To achieve earnings rates above the mean, there must be permanent innovative behavior, in which the capitalist individually appropriates a surplus for a given time period. In this way, the capitalist competition obliges the entrepreneur to seek out technological changes. Without the perennial introduction of new technologies, the business owner does not obtain the surplus needed to be in the market on the cutting edge against the competition. This behavior is conditioned by the laws of the accumulation process and not by factors of another nature.

The explanatory scope of technological change in terms of growth and development in the neoclassical variant is controversial. By giving it an exogenous character, the standard model limited its ability to explain the development process, in terms of detailed growth with irrelevant assumptions to the real world. They took a step backward from Schumpeter, losing ground in the theoretical discussions of the age. It is not surprising, then, that the development conceptions that emerged in Latin America in the post-war period revolved around the slow and scant diffusion of technological change to the capitalist periphery.

Thus, technological change became a central variable in Latin American development theory, both to explain the underdevelopment in the region and to devise development strategies around the region’s industrialization, while in the mathematical world of neoclassical growth theory, it was a variable distant from economic dynamics. The neo-Schumpeterian viewpoints have fueled these debates, and have produced significant theoretical approaches among each other and the ECLAC-led authors of the contemporary age. The proposal has been to create national and regional innovation systems which turn out to be decisive for Latin America, given its technological lagging.

Now, even when Marx did not theorize specifically for Latin America, the expansion to the global scale of capitalist relations of production and with it the incorporation and subordination of the periphery to the laws of capital accumulation became an important element counteracting the falling trend of the profit share. Given that in the Marxist conception, technological change is a trend running counter to the accumulation process, the peripheral condition of Latin America makes it a functional element in the Metropolitan capitalism development process and a factor behind disparate peripheral growth.

As can be seen, after long decades of controversies revolving around technological change, theoretical constraints remain in the contemporary authors, although the constraints of the past have been overcome. This is to be somewhat expected in economic theory, but the four variables contrasted here between the mainstream and Marxist schools on technological change reveal that one century and a half after the publication of *Das Kapital,* Marx's ideas continue to be current. The notion is also that Latin American countries ought to pay more attention to Marx, as many unresolved matters in terms of the weak generation and dissemination of technological changes pursuant to the development process could be explained even long before the advent of Latin American development theory.

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2 In *Theory of Economic Development*—published in 1912—although somewhat incipient, since it was only in Chapter 2 of the book, the Austrian author exposes the endogenous nature of waves of innovations. In his judgment, it is these waves of innovation that make it possible to overcome the Walrasian circular flow. Later, in *Business Cycles*—published in 1939—he points to the expanding supply of commodities via the change in production methods, the opening of new markets, or the discovery of new supply sources. That is to say, doing and thinking differently in the kingdom of economic life (Schumpeter, 1939, p.80). However, theoretically speaking, the author is more relevant in *Capitalism, Socialism, and Democracy*—published in 1942—in which he uses technological change to explain the survival of the capitalist system. Here, he shows himself to be pessimistic about how investment opportunities fade to the extent these changes spread through the system. See Schumpeter (2003, pp. 111-121).

3 "…if, instead of quantities of factors, we vary the form of the function, we have an innovation" (Schumpeter, 1939, p. 91).

4 The author refers to technological change interchangeably as: technical progress, technological progress, or technical change.

5 "I think there is virtue in analyzing the zero-technical-progress case because it is easy to see how technical progress can relieve and perhaps eliminate the drag on economic welfare exercised by natural-resource scarcity. The more important task for theory is to try to understand what happens or can happen in the opposite case" (Solow, 1975, p. 392).

6 That is why technical progress in Solow is known as total factor productivity or the Solow residual. This is due to the fact that a large portion of economic growth cannot be explained by traditional factors—labor and capital—and technological change appears as an exogenous variable. "It is possible to argue that about one-eighth of the total increase is traceable to increased capital per man hour, and the remaining seven-eighths to technical change" (Solow, 1957, p. 316). The Solow residual explains the rate of technical progress. "To change the growth rate of real output per person, the rate of technical progress must change" (Solow, 1982, p. 85).

7 "Changing technology, it is conceded, alters progressively and radically what can be obtained from any given supply of factors. But there is no way by which this intelligence can be developed at length in a textbook. So economic instruction concedes the important and then discusses the unimportant" (Galbraith, 1968, p. 64: note 1).

8 R. Prebisch (1986) wrote about the center-periphery theory on the basis of technological disparities across metropolitan countries and Latin America. Furtado (2003) held that underdevelopment is the way in which the economic structure was shaped, derived from a certain international spread of technical progress. According to Pinto (1965), Latin American structural heterogeneity is the result of the degree to which technical progress has been propagated. Fajnzylber (1990) rationalized the need to open the *black box* of technical progress to drive *authentic competitiveness.*

9 Understood as "improvement in the instructions for mixing raw materials lies at the heart of economic growth." "technological change arises in large part because of intentional actions taken by people who respond to market incentives [...] instructions for working with raw materials are inherently different from other economic goods" (Romer, 1991, pp. 441-442).

10 The first neoclassical author with an interest in responding to the Solow residual.

11 Human capital plays a fundamental role and is the externality that prevents the system from reaching a steady state. See, in this regard, Lucas (1998); Romer (1991); Aghion and Howitt (1992).

12 Dosi (1982) introduced the *technological paradigms*. "We shall define a 'technological paradigm' broadly in accordance with the epistemological definition as an 'outlook,' a set of procedures, a definition of the "'relevant" problems and of the specific knowledge related to their solution. We shall argue also that each 'technological paradigm' defines its own concept of 'progress' based on its specific technological and economic trade-offs. Then, we will call a 'technological trajectory' the direction of advance within a technological paradigm" (Dosi, 1982, p. 148). "In broad analogy with the Kuhnian definition of a 'scientific paradigm,' we shall define a 'technological paradigm' as 'model' and a 'pattern' of solution of selected technological problems. based on selected principles derived from natural sciences and on selected material technologies" (Dosi, 1982, p. 152).

13 "...cumulative means that current technological developments—at least at the level of individual business units—often build upon past experiences of production and innovation, and it proceeds via sequences of specific problem-solving junctures" (Castaldi and Dos, 2009, p. 83).

14 "...means that the exploration and development of new techniques is likely to occur in the neighbourhood of the techniques already in use" (Castaldi and Dosi, 2009, p. 83).

15 The National Innovation Systems explain these economies of agglomeration effects. See Freeman (1987, 1995); Dosi *et al.* (1988); Dosi (2001).

16 ""We have seen at the same time how the capitalist mode of production not only changes the labor process formally, but radically remolds all its social and technological conditions" (Marx, 1982, p. 188).

17 "What capital adds is that it increases the surplus labor time of the mass by all the means of art and science, because its wealth consists directly in the appropriation of surplus labor time; since *value directly its purpose,* not use value" (Marx, 2007, p. 231, emphasis in the original).

18 "In the same way as the production process becomes an application of scientific knowledge, so, conversely, does science become a factor, a function so to speak, of the production process. Every invention becomes the basis of new inventions or new, improved methods of production. It is the capitalist mode of production which first puts the natural sciences [XX-1262] to the service of the direct production process, while, conversely, the development of production provides the means for the theoretical subjugation of nature. It becomes the task of science to be a means for the production of wealth; a means of enrichment [...]Capital does not create science, but it exploits it, appropriates it to the production process. There is at the same time a separation of science, as science applied to production, from direct labor, whereas at earlier stages of production the restricted measure of knowledge and experience is directly linked with labor itself" (Marx, 1982, p. 191, emphasis in the original).

19 "...a transitional stage to the mechanical workshop" (Marx, 1982, p. 165, emphasis in the original).

20 "Machinery has a negative impact on the mode of production resting on the division of labor in manufacture and on the specialized skills of labor capacity produced on the basis of that division of labor. It devalues the labor capacity specialized in this way, in part reducing it to simple, abstract labor capacity, and in part producing on its own basis a new specialization of labor capacity, the characteristic feature of which is its passive subordination to the movement of the mechanism itself; its complete annexation to the needs and requirements of the mechanism" (Marx, 1982, p. 163, emphasis in the original).

21 "The development of machinery […] occurs only when large industry has already reached a higher stage, and all the sciences have been pressed into the service of capital […] Invention then becomes a business, and the application of science to direct production itself becomes a prospect which determines and solicits it" (Marx, 2007, pp. 226-227).

22 The accumulation of knowledge and of skill, of the general productive forces of the social brain, is thus absorbed into capital, as opposed to labor, and hence appears as an attribute of capital, and more specifically of *fixed capital*, in so far as it enters into the production process as a means of production proper (Marx, 2007, p. 220, emphasis in the original).

23 "Insofar as science becomes a direct production factor and revolutionizes social labor productivity, it sharpens the internal contradictions of social capital, threatening the extent to which productive forces are able to develop in their capitalist enclosure, which is why the production

and reproduction of science and technology take place fundamentally as moments of obtaining surplus, transformed into fundamental factors that exacerbated the contradictions between productive forces and the social relations of production "León-Segura, 2001, p. 85). "Capital itself is the moving contradiction, [by reason of which] it presses to reduce labor time to a minimum while it posits labor time as the sole measure and source of wealth" (Marx, 2007, p. 229).

24 "It is a distribution of the workers among *specialized machines* rather than a division of labor among *specialized labor capacities*" (Marx, 1982, p. 169, emphasis in the original).

25 "The development of fixed capital indicates to what degree general social knowledge has become a *direct force of production*" (Marx, 2007, p. 230, emphasis in the original). This passage clearly indicates that Marx was the precursor to the so-called "knowledge society." Marx (1982, p. 152) exposes that the revolution in the productive forces is manifest in technology revolutions, as they reveal the power of man to transform nature through work.

26 "But the *development of science*, this ideal and at the same time practical wealth, is only one aspect, one form in which the development of the *human productive forces*, i.e. of wealth, appears" (Marx, 2007, p. 32, emphasis in the original).

27 The development of machinery along this pathway occurs only when large industry has already reached a higher stage, and all the sciences have been pressed into the service of capital; and, when secondly, the available machinery itself already provides great capabilities. Invention then becomes a business, and the application of science to direct production itself becomes a prospect which determines and solicits it" (Marx, 2007, pp. 226-227).

28 Several Neo-Ricardian authors have interpreted the process of technological change in Marx with union-related and political variables: "We hold that the increase in real wages at the dawn of the nineteen-twenties drove down the profit rate and generated a period of accelerated technological change2 (Duménil *et al.,* 1988, p. 523).

29 Referring to the process by which the fixed part of capital is renewed, expressing technological change as a resource of the capitalist in the pursuit of extraordinary surplus.

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