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TECHNOLOGICAL CHANGE AND ECONOMIC DYNAMICS FROM THE SCOTTISH ENLIGHTENMENT TO CONTEMPORARY EVOLUTIONARY ECONOMICS

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The aim of this paper is twofold: first, we show that some theoretical continuities exist between the approaches of Bernard Mandeville, Adam Ferguson, and Adam Smith to the division of labor and the contemporary analyses of technical change and economic dynamics, which consider innovation as a process of technological creation. We thus offer a further exploration of the origins of evolutionary ideas in the history of evolutionary economics. Second, despite the existence of these theoretical continuities, we highlight the differences between the Scottish Enlightenment authors and the modern evolutionary economists on the issue of temporality and the place of history in their reflections.

I. INTRODUCTION

Mainstream economic analysis of the firm deals with innovation and technological change as exogenous phenomena, leading to a dichotomy between the technological fact and the productive fact. In microeconomic analysis of the producer, the producer is conceived as a rational agent who determines his optimal choices between various alternatives. These alternatives are defined by a key concept: the firm's production possibilities set. This gives a complete description of the technological possibilities facing the firm. It is thus supposed that the producer knows and has a perfect command of all available techniques. The technological patrimony is described as a "book of

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blueprints" in which the producer can choose the most efficient techniques. The shift of the production function displays the existence of technical progress.

However, this conception of technical change was not always dominant in past economic analysis. Adam Smith proposed in the *Wealth of Nations* an approach in terms of industrial dynamics. For him, technology, far from being an exogenous datum, is conditioned by increasing the division of labor. This provides a theoretical framework to deal with the issue of the endogeneity versus exogeneity of technical change itself. The topic of the division of labor, which takes up the first three chapters of the *Wealth of Nations*, expresses Bernard Mandeville's influence, even if Smith never mentioned this author in his work.[1] The division of labor is certainly an old idea, going back at least as far as Xenephon, but it is in Mandeville that one first finds a more profound statement of the division of labor theory.[2] Karl Marx ([1905–1910] 1974, p. 454) regarded the division of labor in Mandeville's analysis as the genuine mainspring of modern manufacturing production. Without wishing to resolve the question, I consider it important to underline at once that the division of labor generates technical progress in Mandeville. The invention of new techniques and improvements in existing ones are not the result of deliberate human intention, but of a gradual, continuous, and slow process. Technical progress is thus localized and endogeneized. It is firmly based on learning effects and the acquisition of know-how, and is anchored in a cumulative process. The topic of the division of labor, before finding its fortune with Smith, had been mobilized and developed by Adam Ferguson in *An Essay on the History of Civil Society.*[3] Ferguson, like Mandeville, had already adopted an evolutionary point of view in his discussion of the division of labor. The division of labor seems to be a natural effect, a spontaneous process, and the technical improvements are made by experimentation and accumulation. However, we can find in Ferguson's work the outline of a pattern of cumulative growth based on a dynamic articulation of the division of labor and the extension of the market. This pattern was to be taken up and deepened by Smith. A set of intuitions and theoretical conceptualizations that could be used to revive the industrial dynamics and the theory of production can therefore be found in Mandeville, Ferguson, and Smith. The revival of current interest in Smith's analysis of the division of labor illustrates both the richness and the fruitfulness of Smith's ideas and the permanence of his theoretical heritage.

Ideas akin to present-day evolutionary economics have a long history in the general field of economics. Norman Clark and Calestous Juma (1988) outline the evolutionary views of socio-economic development and analyze the place of biological or organic metaphors in the history of economic ideas. Geoffrey M. Hodgson shows that there has been a transfer of ideas from political economy to Darwin's biology, on the one hand, and discusses the vast variety in approaches now faring under the banner of "evolutionary economics," on the other hand (Hodgson 1993; 1999, part 2). Alain Marciano and Maud Pelissier (2000) reassess the relationship between Charles Darwin and the founding fathers of political economy. Olivier Brette (2006) proposes a framework based upon Thorstein Veblen's evolutionary economics to establish a conceptual

[1]However, Smith makes references to Mandeville in the *Theory of Moral Sentiments*.
[2]There are allusions to the division of labor concerning the making of a watch in William Petty's *Another Essay in Political Arithmetick, Concerning the Growth of the City of London* (1683).
[3]According to Marx, Smith's treatment of the division of labor owed much to Ferguson.

dialogue between institutional economics and contemporary evolutionary economics. The theory advanced by Richard R. Nelson and Sydney G. Winter (1982) has been identified by the authors as "Schumpeterian" in its interpretation of the process of economic change. Their theory is also pervaded by the concepts previously developed by Richard R. Cyert, James G. March, and Herbert Simon.

Evolutionary economics has a large range of research areas such as economic growth, industrial organization, game theory, learning dynamics, and bounded rationality, etc. Although there is no consensus on what the term "evolutionary economics" should mean, as pointed out by Hodgson (2011), some methodological assumptions are shared in evolutionary economics[4] (Witt 2008; Hodgson 2011). There are different waves of evolutionary economics and they overlay various theoretical frameworks. The roots of evolutionary economics can be Darwinian, Mengerian, Marshallian, Veblenian, or Schumpeterian, or evolutionary economics can be developed in the light of Nelson's and Winter's seminal work. "Evolutionary economics" catches a lot of ideas and since the 1980s many theoretical and empirical analyses described as "evolutionary" have been developed (Dosi and Nelson 1994).

To the best of our knowledge, no systematic comparison between the Scottish Enlightenment authors and the contemporary evolutionary approaches to technical change exists, whereas it appears that the Scottish Enlightenment authors had provided significant contributions to the development of the evolution concept, even long before the idea of evolution became popular.

Our paper attempts to trace the roots of evolutionary economics back to the Scottish Enlightenment understanding of the evolution of technology. As pointed out by Joseph A. Schumpeter (1954, p. 4), "the state of any science at any given time implies its past history and cannot be satisfactorily conveyed without making this implicit history explicit." It is thus important to draw up clearly the filiation of ideas. We will show that there is a certain continuity between the approaches of Mandeville, Ferguson, and Smith to the division of labor and the contemporary evolutionary analyses of technical change and economic dynamics that consider innovation as a process of technological creation. We will present two points that underline the convergence of issues.

The first point is the idea of incremental improvement in techniques through trial and error. According to the authors belonging to the Scottish Enlightenment, techniques are improved in a progressive, continuous way, and by trial and error. This idea is also developed in contemporary evolutionary analyses. Indeed, in the stochastic models with positive feedbacks (David 1985, 1992; Arthur 1988, 1989), the choice of a technology generates positive feedbacks, related, for example, to the effects of learning by doing and to the positive network externalities, which determine the incremental improvements around this technology and increase the probability that the considered technology will subsequently be selected. The innovation is indissolubly linked to the process of diffusion, the mechanisms of learning, the dynamic returns to scale, and the structures of interdependence between the agents. In the evolutionary

[4]"The question in evolutionary economics is therefore not how, under varying conditions, economic resources are optimally allocated in equilibrium given the state of individual preferences, technology, and institutional conditions. The questions are instead why and how knowledge, preferences, technology, and institutions change in the historical process, and what impact these changes have on the state of the economy at any point in time" (Witt 2008, p. 67).

analyses based on "technological paradigms and technological trajectories" (Dosi 1982, 1988), firms develop, inside the paradigm, the trajectory of knowledge hitherto exploited. They generally innovate in an incremental way, by learning.

The second point is that the emphasis is laid on an organic approach (in Carl Menger's sense of the term), privileging the interactions between the agents. Indeed, the analyses of the Scottish Enlightenment authors and those of the "economics of technical change" share a common opposition to the figure of the lonely and unique inventor. There is no "great architect" behind the perfection of techniques. On the contrary, this perfection results from a mechanism of "blind" and spontaneous processes of selection.

However, if certain themes developed nowadays by the "economics of technical change" can be considered as the continuation of those already present in Mandeville, Ferguson, and Smith, an important theoretical difference should be underlined. The Scottish Enlightenment philosophy is a philosophy of progress. Nobody plans the efficient form of tools and techniques, and gradually an efficient and adapted form emerges and is selected. This idea of evolutionary progress does not exist in contemporary evolutionary theories. For example, Paul David and Brian Arthur insist, on the contrary, on the presence of lock-in to a possibly inferior technology. The process of selection is therefore not always optimal. The "small events," the "historical accidents" (Arthur 1989), determine the orientation of the process of evolution in one direction or another. In the path-dependent models, history matters in the selection of technologies; in other words, the objective factor of an earlier period can affect resource allocation at a later point in time, even when conditions are quite different.

The structure of this paper is as follows. In a second section, we show that one can discern an extension and a redefinition of older evolutionary schemes behind the contemporary analyses in the "economics of technical change." Despite the existence of these theoretical continuities, we highlight in a third section the differences between the Scottish Enlightenment authors and the modern evolutionary economists on the issue of temporality and the place of history in their reflections. A fourth section concludes.

II. THE ENDOGENOUS AND CUMULATIVE CHARACTER OF TECHNOLOGICAL INNOVATION: A CERTAIN CONTINUITY

This section aims to compare the development of the division of labor and its effects, such as they were analyzed by the Scottish Enlightenment authors, with the current conceptualizations in the "economics of technical change." The role of tacit knowledge in the improvement of the techniques, the description of technical trajectories determined by the procedures of trial and error, and the stress laid on the local structures of interaction are all topics common to the analyses of Mandeville, Ferguson, Smith, and the contemporary evolutionary economists.

The Scottish Enlightenment Authors and the Division of Labor

The Division of Labor as a Process without Subject: Mandeville's Analysis

Mandeville first introduced the idea of the division of manufactures in "A Search into the Nature of Society," an essay published in 1723: "The greater the variety of trades

and manufactures, the more operose they are, and the more they are divided in many branches, the greater numbers may be contained in a society without being in one another's way, and the more easily they may be render'd a rich, potent and flourishing people" (Mandeville 1723, p. 367). Mandeville presented the division of labor as a solution to the modern problem of social regulation.[5] The division of labor was, in fact, a factor of socialization and progress. It ensured the spontaneous coordination of various works, connected the men between them, and contributed to the production of the largest goods for the society. The example given by Mandeville of the clothing industry established a relation between "social machinery" and the existence of dynamic increasing returns on scale ([1723] 1988, p. 356). A cloth, underlined Mandeville, was the result of the division of the tasks, so that the productive powers of a great number of workers and their different competences were combined. The division of labor was an unintentional and endogenous process; it did not obey any conscious intention. In "A Search into the Nature of Society," the origin of the spontaneous division of labor was related to the theme of the virtues of adversity. Hardships and calamities, such as the Great Fire of London (1666), allowed the blacksmiths, carpenters, bricklayers, craftsmen, etc., to link their efforts and to exercise their talents in the construction of new works: "The necessities, the vices and imperfections of man, together with the various inclemencies of the air and other elements, contain in them the seeds of all arts, industry and labor" (Mandeville [1723] 1988, p. 366). The division of labor is one of those human inventions that make it possible to face the adversities of nature. However, this invention is not an artifice rationally or intentionally set up. Human intelligence and capacity for adaptation lie within the processes of cumulative learning by trial and error. It is from this point of view that we should understand the traditional example of the boat, given by Mandeville. The evolution in techniques is shaped by the natural events that modify the environment but that occur accidentally.

In *The Fable of the Bees*, especially in the third dialogue between Cleomenes and Horatio, Cleomenes, used by Mandeville to express his own views, draws a parallel between the genesis of politeness and civility and the division of labor. Good manners are the result of the multiple efforts made by men to suffocate their pride or their self-love in order to obtain the approbation of others. Without passing by the mediation of reflection, but by experience, imitation, and the implementation of stratagems, man has gradually learned the importance of manners, which are a spontaneous invention, based on the dissimulation of self-love. In other words, pride and vanity compel us to wear a mask in public, to perform in acceptable ways.

According to Mandeville, the division of labor and the improvement of arts are likewise the fruit of long-accumulated experiences. He insisted particularly on the slowness of progress and the test of time in the improvement of productive techniques:

> There are many sets of hands in the nation, that, not wanting proper materials, would be able in less than half a year to produce, fit out, and navigate a first-rate: yet it is certain, that this task would be impracticable, if it was not divided and subdivided into a great variety of different labors; and it is as certain, that none of these labors require

[5]Like the other authors of his time, Mandeville does not clearly distinguish between the technical division of labor—i.e., division inside manufacture—and the social division of labor—i.e., division between professions and industries.

> any other than working men of ordinary capacities. That we often ascribe to the excellency of man's genius, and the depth of his penetration, what is in reality owing to length of time, and the experience of many generations, all of them very little differing from one another in natural parts and sagacity. (Mandeville [1729] 1988, p. 142)

The improvement of arts and techniques, generated by the division of labor, involves mechanisms of learning that incorporate know-how and tacit knowledge. This knowledge cannot be codified into a theoretical or symbolic system. However, it can be transmitted by procedures of learning and progressive experimentation. On this subject, Mandeville ([1729] 1988, pp. 143–144) quoted the example of a fifteen-year-old boy who could instinctively operate a boat after one year spent on the sea without, however, having the slightest mathematical knowledge to calculate which angle the rudder should make with the keel.

In the Sixth Dialogue, Mandeville ([1729] 1988, p. 284) used the example of the clock industry to demonstrate the advantages of the division of labor, thanks to which production was multiplied, thus making the nation more opulent. It was in the division of labor that Mandeville situated the origin of the historical production of technical progress. It went hand in hand with civilization. When peace and safety had been ensured, men, endowed with language and writing, gradually learned by trial and error to divide and subdivide their work. Initially, the division of tasks and functions generated a certain interdependence and solidarity between men.[6] Later came the perfection of the various arts and professions.

Adam Ferguson and the "Separation of Arts and Professions" as a Fact of Civilization

The topic of the division of labor, like the spearhead of civilization, which led from the "barbarous nations" to the "civilised nations," also ran through Ferguson's analysis:

> It is evident, that, however urged by a sense of necessity, and a desire of convenience, or favoured by any advantages of situation and policy, a people can make no great progress in cultivating the arts of life, until they have separated, and committed to different persons, the several tasks, which require a peculiar skill and attention (Ferguson [1767] 1991, p. 180)

Ferguson associated skill with attention. Skill required of the craftsman that he concentrate his attention on a precise object. The increase in skill explained the increase in both the quantity and the quality of manufactured goods. The division of labor was an infinite process of subdivision whose results largely exceeded what a human brain could expect. According to Ferguson, three agents developed an ever finer division of labor through their joint actions: the craftsman who, while concentrating on a precise operation, improved his production and increased his income; the entrepreneur, whose interest was to subdivide the tasks of his workers in order to

[6]It seems that we can connect this conception of the division of labor with that of Emile Durkheim. Indeed, according to Durkheim, initially, the function of the division of labor is to produce social solidarity. It is a paramount factor of social cohesion (Durkheim [1893] 1973).

increase his profit; the consumer who, as the division of labor was developing, became ever more demanding about the quality of goods (Ferguson [1767] 1991, p. 181). Thus, "the progress of commerce is but a *continued* subdivision of the mechanical arts" (Ferguson [1767] 1991, p. 181, emphasis added). The division of labor increased skill and dexterity. It also introduced changes into the methods of production, making it possible to improve the quality and quantity of manufactured goods. The technical change induced thus became an essential and determining factor of market demand. Ferguson here sketches the rough outlines of a process of cumulative sequence.

However, this pattern requires further clarification in Ferguson. One can distinguish two points in his analysis. The first point is concerned with the role of experience or learning. The division of labor is a cumulative process arising out of, and nurtured by, learning. Two forms of learning coexist and they are not clearly distinguished in Ferguson's analysis. Indeed, learning is sometimes portrayed as a process in which the individual learns alone, by trial and error, according to a more or less reflexive and evolutionary mode, and sometimes as a process of socialization and submission to a pre-existing rule. In the first case, the accumulation of the data of learning makes it possible to work out new rules of behavior. The division of labor forms part of a network of empirical, groping, unconscious behavior. It progresses in time because the accumulated experience creates progress. In the second case, learning is not a discovery or an innovation, but submission to a rule and assimilation of pre-existing art. The archetype of this form of learning is the craft allowing the apprentice to acquire know-how (Ferguson [1767] 1991, p. 181). Concentrating one's attention on a precise operation develops skill and updates the individual talents that, in the absence of attention, would remain in a latent state. "Learning" refers both to a process of transmission (of codified and/or tacit knowledge) and to a process of socialization, contributing therefore to the reproduction and the preservation of the professions. The subdivision of tasks and operations, by obliging each agent constantly to achieve the same typical gestures, contributes to the formation of "routines," generating forms of quasi-automatic response to a given problem. Applying the division of labor to the administration and the government, Ferguson wrote:

> Statesmen divide the business of civil government into shares; and the servants of the public, in every office, without being skilful in the affairs of state, may succeed, *by observing forms which are already established on the experience of others*. They are made, like the parts of an engine, to concur to a purpose, without any concert of their own. ([1767] 1991, pp. 181–182, emphasis added)

The second point is concerned with the topic of the division of labor as natural artifice, a topic that one already finds in Mandeville. The division of labor is an infinite movement of division and simplification, whose very complex result, however, does not obey an intentional design:

> The artifices of the beaver, the ant, and the bee, are ascribed to the wisdom of nature. Those of polished nations are ascribed to themselves, and are supposed to indicate a capacity superior to that of rude minds. But the establishments of men, like those of every animal, are suggested by nature, and are the *result of instinct*, directed by the variety of situations in which mankind are placed. Those establishments arose from *successive improvements* that were made, without any sense of their general effect;

> and they bring human affairs to a state of complication, which the greatest reach of capacity with which human nature was ever adorned, could not have projected. (Ferguson [1767] 1991, p. 182, emphasis added)

Invention is not something exceptional, it requires only ordinary capacities. Genius is expelled from the field of invention to the profit of knowledge and learning. We find the same structure of reasoning as in Mandeville, resulting in an emphasis on the passage of time, the insensitive and gradual march of progress, and the incremental improvements that are made by accumulation, by instinct, without the agents' understanding the progression or predicting the future effects.

But if Ferguson recognized the beneficial character of the division of labor from the economic point of view (perfection of the arts and increase in the wealth of the country), he was more "sceptical" as regards its moral efficiency. The division of labor not only splits up work into hierarchical operations, but also divides society into classes, and the individuals into parts of themselves. It produces inequalities of property and introduces hierarchy. It also creates a false solidarity while making individuals dependent on others. Indeed, division condemns individuals to specialization and confines each one in a repetitive task, in a precise activity. By so doing, over the long term it renders the workers ignorant, but increases the ingenuity of the leaders. Everything takes place as if the leaders had stripped the workers of their intellectual or mental powers and appropriated them: "Even in manufacture, the genius of the master, perhaps, is cultivated, while that of the inferior workman lies waste.… The former may have gained, what the latter has lost" (Ferguson [1767] 1991, p. 183). Ferguson ([1767] 1991, p. 218) also stressed the effects of the division of labor on human nature. Constrained to be specialized, man gives up a part of himself and alienates himself. There are, in *An Essay on the History of Civil Society*, developments that prefigure Emile Durkheim's analysis of anomic division of labor and Marx's analysis of alienation.[7] For Ferguson, the division of labor is a source of wealth, but, paradoxically, it is also at the origin of the decline of societies[8].

Division of Labor and Smith's Analysis of the Determinants of Technical Change

On the basis of the above discussion, it should be noted that the explanation of the division of labor in Mandeville and Ferguson follows the same evolutionary scheme: the division of labor is a natural effect; it has not been developed according to rational design. We find the same scheme in Smith's theoretical framework:

> This division of labor, from which so many advantages are derived, is not originally the effect of any human wisdom, which foresees and intends that general opulence to which it gives occasion. It is the necessary, though very slow and gradual consequence

[7]Marx readily quoted Ferguson about the division of labor. According to Marx, Ferguson had underlined quite well that manufacturing division made man more and more split up and fragmented (Marx [1867] 1948, pp. 44, 51). Even if Ferguson did not analyze the passage from the division of labor in manufacturing to the division of labor in society, his description of the workshop as a big machine whose men are assimilated to the parts looks like what Marx called "the collective worker made up of a combination of a great number of fragmented workmen" (Marx [1867] 1948, p. 39).

[8]We will not develop Ferguson's thesis on the decline of societies here (see Jack 1989).

> of a certain propensity in human nature which has in view no such extensive utility; the propensity to truck, barter, and exchange one thing for another. ([1776] 1976, vol. I, p. 25)

It is the natural propensity of men to exchange that urges the expert or the craftsman to increase the division of labor and specialization. This greater division of labor is a factor that increases productivity and consequently increases the quantity produced. First, it enhances the skill of various workers through specialization. The efficiency of the division of labor consists in the continuous repetition of the same gestures. By fixing the attention of the workers on small segments of production or particular tasks, the division of labor enables them to benefit (without necessarily knowing it) from the experience of the others and to take part in a process of transmission–reproduction in the action of an accumulated social knowledge. The subdivision of the tasks prevents the workers from wasting their time in passing from one occupation to another. Focusing the attention of the workers on one sole task stimulates the propensity to invent, by encouraging them to invent new machines and to find more efficient methods of production. The invention of machines results from a simple gradual evolution: "A great part of the machines made use of in those manufactures in which labor is most subdivided, were originally the inventions of common workmen" (Smith [1776] 1976, vol. I, p. 20). Technical change is also due to scientists or "philosophers" who are occupied with improving tools and production techniques. In modern terms, we see how Smith had in mind the concept of learning by doing, endogenous technological progress, and the idea that increasing returns mainly take the form of industrial fragmentation.[9]

The division of labor is the cause of "that universal opulence which extends itself to the lowest ranks of the people" (Smith [1776] 1976, vol. I, p. 22). However, it is limited by the extent of the market. Indeed, only the extension of the market can enable and render necessary specialization of production and its processes. Productivity gains, generated by the division of labor, permit a decrease in the price of manufactured goods. Increase in the workers' purchasing power, due to a fall in relative prices, in turn generates a rise in demand, which thus contributes to the growth of the market (Smith [1776] 1976, vol. I, p. 22). The widening of the market resulting from the rise in relative income, combined with improvements in transport, generates effects of propagation from one market to another and consequently sustains a cumulative process of growth.[10]

Technological Competition and Selection in Evolutionary Analyses

Giovanni Dosi (1988b, p. 1163) asserts at the end of his article on the determinants and effects of innovative activities in the contemporary market economies that some of the themes developed by the "evolutionary school" can be considered as an extension of

[9]According to James Buchanan and Yong Yoon (2000, p. 45), "the Smithean proposition that relates the division or specialization of labor to the extent of the market is best captured by the notion of generalized increasing returns."

[10]Smith did not sufficiently analyze either of the mechanisms of the propagation of growth: on one hand, the stability and the growth of market, and on the other hand, the effects of productivity gains on the demand.

hypotheses and points of view already present in the writings of classical economists and later in Joseph Schumpeter. According to the contemporary and "evolutionary economists," the search and innovation processes are endogenous and produce irreversibility. The mechanisms of learning are predominant in the explanation of the dynamics of productive organizations.

Technological Paradigms and Technological Trajectories

The "technological paradigm" is a conceptual transposition by Dosi (1982, 1988a, 1988b) of Thomas Kuhn's "scientific paradigm." It participates in the selection *ex ante* of research projects and so of innovation. It

> can be defined as a "pattern" for the solution of selected techno-economic problems based on highly selected principles derived from the natural sciences. A technological paradigm is both a set of *exemplars*—basic artefacts that are to be developed and improved … and a set of *heuristics*—"Where do we go from here?" "Where should we search?" "On what sort of knowledge should we draw?" etc. (Dosi 1988a, p. 224)

The technological paradigm frames the innovative activity by providing a definition of problems to be solved and some procedures to resolve them.

For Dosi, innovation is similar to a "problem-solving activity" (1988b, p. 1125). In general, "the problems are 'ill structured', in that the available information does not provide by itself a solution to the problem" (Dosi 1988b, pp. 1125–1126). Therefore, to solve the problems with which they are faced, firms mobilize generic knowledge, widely spread through society and tending to have the properties of "publicness" and universality, and specific knowledge, drawn from their own routines. These routines contain tacit knowledge, which is uncodified and difficult to transfer. An important implication of the technological paradigms and the distinction between generic knowledge and specific knowledge is that "innovative activities are strongly selective, finalized in rather precise directions, often cumulative activities" (Dosi 1988a, p. 225). They are strongly selective insofar as the mechanism of selection and learning aims to delimit the space of the acceptable technological choices. They are specific because firms make use of routines founded on tacit and non-transferable know-how. They are cumulative because the accumulation of knowledge, based on localized learning, is oriented towards the directions defined by the paradigm. In these conditions, the development of technologies is fundamentally irreversible. Technologies develop along ordered trajectories, which are shaped by techno-economic properties, procedures to solve the problems, and generic and specific knowledge accumulated in the "knowledge base" of the firm. The properties of irreversibility and path dependency (present technological choices are largely determined by those made in the past) are the cause of "technological trajectories." These technological trajectories characterize, on the one hand, the modes of exploitation of the technological potentialities of a given paradigm, and, on the other hand, the direction of technical change within the field defined by this paradigm. According to Dosi (1982, p. 154), "a technological trajectory (i.e., the 'normal' problem-solving activity determined by a paradigm) can be represented by the movement of multidimensional trade-offs among the technological variables

that the paradigm defines as relevant."[11] The nature of innovation in Dosi's theory is similar to a process of incremental innovation along the technological trajectories.[12] Flows of innovations are generated in a continuous process. The majority of innovations are developed in a progressive way, on the back of humdrum technical progress. The fundamental logic of the processes of accumulation of incremental innovations is based on learning. We can compare this conception of innovation with that of Abbott Usher. In fact, Usher ([1929] 1954) considered innovation as the fruit of a series of efforts and small advances, none of which could alone constitute the definitive step. One rediscovers here the slowness of progress, the passage of time, and the successive improvement of techniques: so many favorite themes of the Scottish Enlightenment authors. Opposed to the Schumpeterian thesis, according to which technical innovation is the invention of a scientific genius, Usher showed that it results, on the contrary, from a series of experimentations during which it is defined, refined, and improved as the domain of application extends. The variety of the domains of application generates new information and increases accumulated technical knowledge. Technical progress, in Usher's view, makes it possible to fill to some extent a "hole" in knowledge, since certain technical problems present at any given time do not find solutions in the knowledge currently available.

The Major Role of "Small Events" in the Selection of Technologies

In Dosi, innovative processes are considered as sequential processes by which a technological potential characterized by a knowledge base is exploited. The sequence of successive technical choices and the accumulation of experience influence future choices, thus generating forms of irreversibility and consequently ordering the evolution of the technological trajectories. The properties of irreversibility and path dependency are also at the center of the competing technologies models (Arthur 1988, 1989), even if their theoretical framework is a little different from those. To account for the technological development of the economy, Paul David (1985) and Brian Arthur (1988), for example, underline both the mechanical and inflexible trajectories that produce irreversibilities and the crucial role of "small events" or "historical accidents." These "small events" may create the process itself or they may, at certain decisive

[11]We can establish a parallel between the concepts of "technological paradigm" and "technological trajectories" and Nelson's and Winter's concept of "technological regime" and "general natural trajectories" (1977), or again with Devendra Sahal's concept of "technological guideposts" and "technological avenues," and also with Christopher Freeman and Carlotta Perez's concept of "techno-economic paradigm" (1988). The techno-economic paradigm is in fact a "macro-technological" concept, which may embody several "technological paradigms" and has a broader signification. It aims to integrate all economic transformations generated by the diffusion of new technological trajectories. In this perspective, Perez had already referred, in 1983, to "technological styles"; i.e., "a kind of 'ideal type' of productive organization or best technological 'common sense' … for a given period of capitalist development" (1983, p. 361). These "techno-economic paradigms" are articulated more or less well with the socio-institutional framework, to what would be the main element of the long cycles.

[12]Even if Dosi (1991, p. 354) asserts that the idea of discontinuity or sudden changes is not excluded from the contemporary evolutionary view of economics, incremental innovations are privileged in his analysis. The technological paradigm, such as it was conceived, is exogenous. There is only an explanation of the genesis of innovations for a given paradigm, while the origins and the changes of different technological paradigms remain mysterious.

times, tip the whole process of evolution to one side or the other. Innovation is analyzed in the models with "positive feedbacks" as a dynamic process of adoption and diffusion. A technology is not chosen because it is more efficient: it becomes more efficient because it has been chosen. In the field of technology, individual choices generate positive feedbacks and increase the probability that the technique adopted at first is selected again in the future. Arthur (1988, p. 591) emphasizes five sources of locally positive feedbacks or of "increasing returns to adoption": 1) learning by using; 2) network externalities; 3) scale economies in production; 4) informational increasing returns; 5) technological interrelatedness. This provides us with a set of conceptualizations in the economics of technical change, based on the existence of "increasing returns to adoption," which have four important and well-known properties: unpredictability, path dependency, inflexibility, and potential inefficiency.

Paul David's story (1985) of the evolution of typewriter keyboards in the United States and their progressive standardization underlines the "essentially historical character" (1985, p. 332) of the process, which led to the triumph of a type of keyboard known as the standard "QWERTY" keyboard. The term "historical" has two senses: first, the crucial role of some events or "historical accidents," which can tip the whole process over the edge into one direction or another; and, second, the fact that the process is always related to the past and excludes any reconsideration. Thus, in the selection of standards, when the lock-in effect is taking place, the outcome becomes irreversible.

The QWERTY keyboard was born in quite particular circumstances. Technically, it corresponded, on the one hand, to a text, which the typist could not see appearing as he struck, and, on the other hand, to the perfecting of an original keyboard, which had many defects, especially the problem of type bar clashes. It took six years for Christopher Latham Sholes, one of the three inventors of the initial keyboard, to obtain a more satisfactory arrangement of the original model's alphabetical key ordering, making it possible to obtain a faster rate of striking.

Built by the Remington firm, the first machines with QWERTY keyboards survived the economic downturn of the last quarter of the nineteenth century, and then the QWERTY keyboard ran up against competition from other keyboards and finally became the dominant one. Today, it is certain that other, better keyboards are possible.[13] But the domination of the QWERTY keyboard is well established, a perfect illustration of the fact that the initial technological choices, considered as simple "historical accidents," determine the future development of technical progress, and no reconsideration is really possible. It also shows that selection is not optimal, as Sydney Winter underlines (1987, p. 616): "It [the story of QWERTY] stands as a warning against simplistic ascriptions of optimality to the outcomes of evolutionary processes."

Indeed, it was between 1890 and 1900 that the destiny of the future keyboards of typewriters (and computers) evolved in favor of the QUERTY keyboard. David (1985, p. 334) explains this by the fact that the typewriters were an integral part of a complex system of production: "In addition to the manufacturers and buyers of typewriting machines, this system involved typewriter operators and the variety of organizations (both private and public) that undertook to train people in such skills."

[13]David gives the example of the keyboard arrangement (DSK) invented by A. Dvorak and W. L. Dealey in 1932 and successfully experimented with during the 1940s by the US Navy.

Three mutually reinforcing factors were going to "lock in" the direction of the evolution: first, technical interrelatedness; i.e., complementarities between certain keyboards and skilled typists trained on these keyboards. Any change of keyboard would have required retraining of the labor force. Social blocking was soon total.[14] Furthermore, economies of scale and quasi-irreversibility of investments exerted a great influence on the selection of the standard.

Second, this process of evolution can be interpreted in terms of tacit knowledge (Winter 1987). The know-how of typists consists largely of knowledge that cannot easily be transferred from one individual to another by means of a symbolic system or communication. The existence of tacit knowledge increases keyboard-conversion costs. The routines and the accumulated competence, "this somewhat obsessive social memory" (Winter 1987, p. 616), determine new routines and innovations.

Third, the existence of positive feedback reinforces the sequence of individual choices. The technology selected (the standard) depends completely on the first random choices. By choosing one of the technologies in competition, the first agents focus technical progress onto this technology and make it more attractive and more favorable for the next users. Here, we have the constitution of an inflexible trajectory due to increasing returns to adoption. Indeed, the more the agents choose the standard, the more they use it, and the more they produce self-reinforcement phenomena. This enhances the returns to adopt the standard. The dynamics of the structures of interaction between the agents' operating choices in a sequential process under the conditions of localized learning is thus quite decisive in understanding the global evolutions of the system, especially in the domains where individual decisions can generate positive feedbacks. It is precisely this idea that David (1993) underlines when he emphasizes the "weight of the history"; i.e., "the network contexts," these structures of interdependence between the agents that help to propagate, to spread the influence of exogenous events or of initial choices: "Each of these potential webs of interaction and positive reinforcement into which individual agents may be drawn provides a theatre for the unfolding of historical dramas" (David 1993, p. 248).

In the conceptualization of technology and technical change based on "technological paradigms" or "techno-economic paradigms" and in the competing technologies models, the technological path followed is determined by the first choices, the forms of organization, and heuristics of search. A principle of historicity and radical uncertainty is then introduced:[15] in a competition between technologies with increasing returns, different patterns of "small events" (randomness) can affect the build-up of adoptions. Thus, some technologies will be implemented and the others abandoned, so that if the selected technology leads to a dead end, this will only be known *ex post*.

[14]David (1985, p. 334–335). Here, it is essentially the form of wage-labor nexus (the technical and social division of labor and its implications for skilling/deskilling) that stops any possible retraining and so inhibits innovation.

[15]"A path-dependent process is nonergodic: systems possessing this property cannot shake off the effects of past events, and do not have a limiting, invariant probability distribution that is continuous over the entire space" (David 1993, p. 208).

III. TIME AND THE STATUS OF HISTORY

We have underlined the existence of theoretical continuities between the Scottish Enlightenment authors and the contemporary evolutionary economists in their conceptualization of technical change as an endogenous process (the importance of learning effects, tacit knowledge, and mechanisms of local interactions). We are going now to examine the way in which "the small events of history become important" (Arthur 1989, p. 127) in the selection of the final outcome, especially in a regime of increasing returns. In this section we will highlight the differences between the Scottish Enlightenment authors and the contemporary evolutionary economists on the issue of temporality and the place of history in their approaches.

To characterize the conception of history and the way in which history is taken into account in the evolutionary analyses, we refer here to the distinction suggested by Gilles Granger (1955) among three phenomenologies of time in economics. The first type of time is "causal time" with regard to classical mechanics. "Causal time" is not charged in content and memory: "Causal time is thus the empty and reversible variable in principle" (Granger 1955, p. 158). "Historical time," the second time, is defined by the fact that its "structure is such that the content of one given moment depends on the content of each moment which preceded it" (Granger 1955, p. 159). This time makes it possible to deal with the phenomena of accumulation. Periodization takes place here in an important way: "It is only when the division in periods, the discontinuity of the course of time becomes a different and fundamental element in the way to conceptualise time that we pass from a causal phenomenology to an historical phenomenology" (Granger 1955, p. 160). The third time is "stochastic time," for which "variable time can be characterized, in contrast with causal time and historical time, as full without necessarily being directed. Time is no longer a simple coordinate, outside of phenomena; events accumulate within it. But these are accidental events and not connected events that unfold" (Granger 1955, p. 161). Granger underlines the complementarities between historical and stochastic time through the formalization by "Markov chains."

In stochastic models with positive feedbacks, to express mathematically the idea that the evolution of a system cannot be defined only by the data of its structure and the initial conditions but that it is also relevant to take into account the path followed, one has recourse to "additively interdependent chains" (for more works illustrative of this idea, see David and Foray 1995; David 1993, 2001). In David's and Arthur's analyses, time is, in its constitution, a mixture of "historical time" and "stochastic time." The emphasis laid on the role of random factors and historical contingencies in the orientation of the dynamics of a system breaks not only with traditional economic dynamics, but also with the evolutionism of Mandeville, Ferguson, and Smith, and it does so in two ways.

First, the Scottish Enlightenment authors relate history to the notion of continuous progress and perfectibility. There is progress because men, always confronted with the same problem, the same natural forces, find new techniques by trial and error.[16]

[16]This conception of the evolution of techniques is similar to that of an historian of techniques, André-Georges Haudricourt, who shows that "the evolution of the tool is only explained by a constant adaptation to various techniques, to different needs" (1964, p. 42). He gives as an example the different forms of a plow over the last century, which are finally only adaptations to the constraints of the environment.

This is particularly explicit in Mandeville, through his example of the construction of a great vessel. On the contrary, the environment of selection in David's and Arthur's analyses is not irreversible. It is shaped by the strategies of the firms and the competition between technologies or standards: "The adoption process is inherently unstable, and it can be swayed by the cumulation of small 'historical' events, or small heterogeneities, or small differences in timing.… What we have in this simple model is 'order' emerging from 'fluctuation'" (Arthur 1988, p. 595). It is "a self-organizing process," an example of a system in evolution where the mechanism of selection is built during the process and the paths finally followed are created by the history of the phenomenon itself. In other words, in this type of competition, the firm (or institution) can set up and determine by its own action the future technical progress. Strategies, policies, and historical "accidental" events become decisive. The evolution is no longer "natural," but historical (Arthur 1988, p. 604). The process is by no means optimal. This inefficiency can be explained by the inflexibility of the process and the "small historical events" that may tip evolution over the edge in one direction or another.

Second, the break between the Scottish Enlightenment authors and the contemporary evolutionary economists also concerns the way in which time is taken into account in economics. Indeed, according to the Scottish Enlightenment authors, the division of labor and the technical change induced fit into a wider explanatory frame of reference; i.e., the "natural history of humanity" or the "conjectural history." The historical theory of the Scottish Enlightenment authors established the essential irreversibility of the development progress. This model of society's "natural progress" is focused on the idea that the progressive changes are slow, unconscious, mostly gradual, and lead towards perfection. In this perspective, even if Smith, for example, underlined in his analysis of the division of labor the existence of dynamic increasing returns associated with forms of irreversibility, which were themselves related to learning effects, his approach remained nevertheless ahistorical[17] insofar as the change is spread over a neutral and external time. "Time is a pure form" in this dynamics. Generally, for the Scottish Enlightenment authors, development is inseparable from the natural progress of humanity. Societies progress from the hunting and gathering stages to the agricultural and commercial stages.[18] The model of the "progress of society" developed by the Scottish authors is based on the behavioral axiom that man is governed throughout time and space by a natural desire to improve the material conditions of life. Another characteristic is the weight of emphasis that is placed on the historically inevitable development of productive forces and their links with the natural and insatiable desires of man (Skinner 1965, 1975; Hollander 1979). The drive for self-betterment is "so powerful a principle, that it is alone, and without any assistance, not only capable of carrying on the society to wealth and prosperity, but of surmounting a hundred impertinent obstructions with which the folly of human laws too often incumbers its operations" (Smith [1776] 1976, vol. I, p. 540).

[17]For example, Stephen Marglin (1974) has underlined the universal and timeless dimension of Smith's model. On Smith's use of history and his ideal account of historical evolution, see Skinner (1975) and Hollander (1979).

[18]Although Mandeville does not delineate in the *Fable of the Bees* a clear set of stages through which human societies develop invariability in several distinct steps, his analysis rests on the idea that society advances from a "rude" to a "polished" state.

History takes on a decisively progressive direction, and the diversity of social forms can be understood as variations in degrees of progress, responding to the environmental challenges.

Applied to the problems of origin and progress in the field of arts and techniques, this explanatory apparatus based on "conjectural history" emphasizes the continuous and gradual improvement of techniques. Time is then considered as continuity. On the contrary, in the contemporary evolutionary approaches, it is the dialectic between time conceived as contingency (i.e., as a succession of events) and time conceived as continuity that shapes the evolution of the economic system. Time conceived as contingency characterizes the first moments of structuring and emergence of the process. The evolution of the system is not predictable, and in the case of competition between technologies, one knows only *a posteriori* which of the competing technologies will be selected. Time as continuity then occurs when the increasing returns to adoption have located the learning effects on a technique. It is the dialectic between these two temporalities that perpetuates continuity and creates at the same time the factor of change and temporal bifurcation. In David's and Arthur's analyses, the decisive role of "historical events" in the orientation of the dynamics of a system makes it possible to combine randomness and necessity at the same time.

IV. CONCLUSION

We have combined the Scottish Enlightenment understanding of the evolution of technology with contemporary approaches such as those by Dosi, Arthur, and David to reveal common but also distinct patterns of thought.

Modern evolutionists' view of economic change as an evolutionary process, involving the technologies known and in use, can, to some extent, be regarded as a return to the Scottish Enlightenment authors. Indeed, Mandeville, Ferguson, and Smith highlighted learning effects, tacit knowledge, and the existence of dynamic increasing returns as factors explaining the technical change induced by the division of labor. To account for the heterogeneity of firms and industries, the technological trajectories and the differences in performances between firms, the contemporary evolutionary economics also mobilizes these elements.

Analyzing the transformations of the economy, and particularly technical change and innovation, requires a consideration of time as an analytical category. Here, the conceptions are different. The improvement of tools and techniques in Mandeville, Ferguson, and Smith lies within a broader framework concerning the evolution of societies (the natural "history of humanity" or the "conjectural history"). Time is then considered as continuity: the process of evolution is oriented and predictable.

There is nothing comparable in contemporary evolutionary economics. Heraclitus's metaphor concerning the impossibility of having a bath twice in the same river exemplifies the general philosophy of the research program of evolutionary economists. There is no reversibility in time and no possibility of fully predicting the future. The final state of the system can depend to a decisive extent on certain remote events occurring in the initial state. Moreover, small modifications in the initial conditions generate cumulatively increasing differences in the resulting trajectories. The theoretical consequences of such an approach are unpredictability and the importance of the

history of the process itself for understanding the dynamics of a system. Finally, contemporary evolutionary economics renews our understanding of the links between economy and history by putting themes like irreversibility and "path dependence" at the center of its research.

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