http://dx.doi.org/10.18041/libemp.2017.v14n2.28210

The concept of Technology in the History of Economic Thought. From the Classics to Schumpeter, Evolutionism and today*

El concepto de Tecnología en la Historia del Pensamiento Económico. De los clásicos a Schumpeter, al evolucionismo de hoy

O conceito de Tecnologia na História do Pensamento Econômico. Dos clássicos a Schumpeter, ao evolucionismo de hoje

Alberto Gómez-Mejía
Economics (Universidad San Buenaventura, Cali, Colombia). M.A Economics (The University of Florida, Gainesville U.S.A.). Ph.D. Technology Management (Universidad de Querétaro, México). Professor of Econometrics, Capital Markets. Universidad Libre, Cali - Colombia
algomezme@hotmail.com; alberto.gomezm@unilibre.edu.co

F. Recepción: 30 abril 2017 F. Aceptación: 1 junio 2017

Abstract

All schools of economic thought prior to Schumpeter did not pay attention to the processes of technological innovation which was assumed to be included in the capital-machine variable. The different approaches used from Schumpeter to the present are described, including neoclassical and evolutionary schools, which are oriented to demonstrate that there can be neither growth nor development unless there are public policies that enhance the capacity of technological innovation from the educational and business. The study of technological innovation has gone from being an exclusive subject of macroeconomic policy to an issue of entrepreneurial and multidisciplinary dominance.

Keywords

Economic thought, technology, growth, neoclassical, evolutionist.

Resumen

Ninguna de las escuelas del pensamiento económico de preocuparon por el proceso de la innovación tecnológica la cual se dio como incluída en la variable capital-máquina. Los diferentes enfoques desarrollados desde Schumpeter hasta la actualidad son descritos,

* **Cómo citar:** Gómez-Mejía, A. (2017). The concept of Technology in the History of Economic Thought. From the Classics to Schumpeter, Evolutionism and today. Revista Libre Empresa, 14(2), 199-214 http://dx.doi.org/10.18041/libemp.2017.v14n2.28210

incluyendo los de las escuelas neoclásicas y evolucionista que demustran que no puede haber ni crecimiento económico ni desarrollo a menos que se implementen políticas públicas orientadas a estimular la capacidad de la innovación tecnológica desde el sistema educativo y empresarial. El estudio de la innovación tecnológica ha dejado de ser un tema de política macroeconómica para ser tratado como elemento micro a nivel empresarial e incluso desde variados enfoques multidisciplinarios.

Palabras clave

Pensamiento económico, tecnología, crecimiento, neoclásico, evolucionista.

Resumo

Nenhuma das escolas de pensamento econômico preocupado com o processo de inovação tecnológica que foi dado como incluído na variável capital-máquina. As diferentes abordagens desenvolvidas de Schumpeter ao presente são descritas, incluindo as das escolas neoclássicas e evolucionistas que demonstram que não pode haver crescimento econômico nem desenvolvimento a menos que políticas públicas sejam implementadas para estimular a capacidade de inovação tecnológica do sistema educacional e empresarial O estudo da inovação tecnológica deixou de ser um tema de política macroeconômica a ser tratado como um micro elemento ao nível dos negócios e mesmo de várias abordagens multidisciplinares.

Palavras chave

Pensamento econômico, tecnologia, crescimento, neoclássico, evolucionista

JEL: B2, O3.

1. Definition of technology and innovation

Dodgson (2008: 2) in "The Management of Technological Innovation" defines technology and innovation as:

"Technology is a replicable product with practical applications and the knowledge that allows it to be used and developed. Technology manifests itself in new products, processes and systems, including the knowledge and skills needed to functionally produce what is reproducible."

"Innovation is essentially the successful commercial exploitation of new ideas. Innovation includes the scientific, technological, organizational, financial and administrative activities that lead to the marketing of a new or improved product or service."

2. From Adam Smith to Schumpeter

Throughout history it has been evident that technological development and economics are components of the same process: economic activity stimulates technological innovation and this in turn drives economic growth, an infinite mechanism of feedback which

academics, until very recently, have begun to systematize theoretically. Most of the great theoretical economists have ignored or superficially dealt with the concepts of invention and technological innovation. It was commonly understood that invention leads to an increase in the formation of physical capital or machinery, however, there was no analysis on the management of invention and technological innovation and its impact on the economic process and development. Hodgson (cf. 1997: 9 ff.)[1] argues that Smith, Marx, Menger, Marshall, and Walras did not prioritize technology. Evidently, in *An Inquiry into the Nature and Causes of the Wealth of Nations*, Smith emphasized international trade and economic growth but neither technology nor technique nor innovation are found in the text[2]. On the contrary, the word machinery is broadly used. The word invention appears in general form to mention the invention of the printing press, gunpowder, etc. On the contrary, Marx (cf.1887: 287 et seq.) uses the word technology in book *Capital* [3], chapter 15, "The strife between workman and machine" to describe the generation of surplus value:

"The principle which it pursued, of resolving each process into its constituent movements, without any regard to their possible execution by the hand of man, created the new modern science of technology. The varied, apparently unconnected, and petrified forms of the industrial processes now resolved themselves into so many conscious and systematic applications of natural science to the attainment of given useful effects. Technology also discovered the few main fundamental forms of motion, which, despite the diversity of the instruments used, are necessarily taken by every productive action of the human body; just as the science of mechanics sees in the most complicated machinery nothing but the continual repetition of the simple mechanical powers".

Menger, Marshall[4] and Walras gave it no priority. Menger, Marshall and Walras being pioneers of the neoclassical school, concentrated on the structure of markets as did their followers in the nineteenth and twentieth centuries.

The first thinker to write about the evolution of technology throughout history was Lewis Mumford.[5] In *"Technics and Civilization"* (1934: 14) he proposed the study of the development of mankind from the perspective of the development of the machine and technique as well as recognizing the strong dependence of technology development on capitalism:

"From the outset machines, factory production and armaments, demanded more capital than small advances to provide tools to the artisan. Capitalism used the machine not to promote social welfare, but to increase private profit".

1 Similar conclusions can be found in any book on the history of economic thought such as Eric Roll (1994). History of economic doctrines. Fondo de Cultura Económica - Mexico.

2 Inquiry implemented by the author of this article used a word explorer to find these words in Smith's book.

3 A word explorer was used to find the word technology in Marx´s Capital, volume 1. The word is found five times as a synonym of machinery and invention.

4 Supported by the search of words technology and innovation. Machimery is the word broadly used.

5 Lewis Mumford (1895-1990). American historian, sociologist and philosopher of technology.

Mumford's approach is historical and integral, since it relates the development of technology with the other fields of action of humanity but not with economic crises even though his book is published when the United States lives the great depression. His definition[6] of "technics" throughout the book is controversial because he defines "technology is a part of the technique". Using the Greek definition of "tekhne" which not only means technology but also art, skill, dexterity; technique refers to the relationship between the social environment and technological innovation: desires, habits, ideas, goals as well as the industrial processes of a society.

Keynes (*cf.* 1936: 136 et seq) uses the technique as an exogenous variable:

"I sympathise, therefore, with the pre-classical doctrine that everything is produced by labour, aided by what used to be called art and is now called technique, by natural resources which are free or cost a rent according to their scarcity or abundance, and by the results of past labour, embodied in assets, which also command a price according to their scarcity or abundance". (p. 136).

"In a given state of technique, resources and costs, the employment of a given volume of labour by an entrepreneur involves him in two kinds of expense…". (p. 24).

According to Hodgson (*cf.* 1998: 416 et seq.) the integration of the concept of innovation into the economy required three phenomena in economic thought: first, the emergence of the American institutionalist school led by Thorstein Veblen7 who was the first to apply Darwinian ideas to the economy; second, the emergence of Keynesianism as a fiscal and countercyclical theory and third, the popularity of Marxism with its crisis theory of capitalism. The three phenomena influenced Schumpeter who not only pointed out technological innovations as a force for change in capitalism, but was the first to relate them to economic crises. Schumpeter emphasizes the evolutionary and non-stationary temperament of capitalism. Joseph Alois Schumpeter (*cf.* 1939: 132 et seq.) argues that innovations are not generated continuously but intermittently and explosively (periodic clusters) which has been evident since the English industrial revolution: there have been waves of technological change that have caused ups and downs in economic growth, that is, the cycles of expansion and contraction are the result of technological revolutions or radical technological innovation. In "*Capitalism, Socialism and Democracy*" (1943) he makes a brilliant defense of the capitalist system for its ability to stimulate entrepreneurship. The entrepreneur, according to him, faced with the threat of competition and willing to remain in the market, is forced to be innovative and adapt inventions to the needs of consumers, market new products, new resources, test new forms of production and organizations in a continuous process called "Creative destruction" or destructive creation; a process that ends in the selection of the most efficient forms of production and organization, destroying those technologies, machinery or ideas that did not succeed making them obsolete. The

6 Contrary to the current definition of Technology, which is equal to technique plus science. See Manuel and Teresa Kwiatowska. (2000). Coeditors. Ciencia, Tecnología, Naturaleza y Cultura en el siglo XXI. Anthropos. Universidad Autónoma Metropolitana.

7 Thorstein B. Veblen (1857-1929), father of the american institutionalist school used the word "evolutionary" in (1898a), Why is Economics Not an Evolutionary Science?, 24, 296-303. Reprinted in Veblen (1934).

process is continuous and rapid, an eternal creation-destruction sequence leading to an improvement in the quality of life of the population.

Schumpeter, expert in the history of economic thought, in "*History of Economic Analysis*" (*cf.* 1954: 827 et seq.) considers Leon Walras[8] as the greatest economist of all time, however, does not agree with him or with Alfred Marshall[9] who developed the "*Theory of Partial Equilibrium*" by constructing simple models that explained the market equilibrium under hypothetical conditions of perfect competition. Walras constructed the "*General Balance Theory*"; with multi-country models describes the functioning of the market in perfect competition, establishing the conditions necessary for all markets to be simultaneously in equilibrium. Since all goods are complementary to each other or substitutable by others to a greater or lesser degree, since all markets for goods and services are interdependent, any factor that produces an unexpected change in the break-even point in the single good market will cause changes in the equilibrium points in the markets of some goods, these in those of others and so on until gradually all the markets are regaining their equilibrium, not necessarily the prices and quantities equal to the original equilibrium, but they will recover the previous conditions of stability and interdependence, i.e. a new general equilibrium with different prices and quantities in all markets for goods and factors of production. This gradual mechanism of recovery of the balance was called *tâtonnement*. Now, the new equilibrium or realignment of market forces can occur as long as there are no exogenous factors, i.e. the market lacks its own dynamics. Here is the source of the disagreement: Schumpeter criticized the Walrasian model for not taking into account dynamic elements originating internally within markets that can explain economic crises or cycles. He complained that despite the experience of the 1930s depression, economics as a science had focused on the stability and effectiveness of macroeconomic policies to prevent recessions following the keynesian fashion, but there was no concern for the causes, technological innovation among them, which produced the ups and downs of industries and how these in turn affected aggregate indicators and economic cycles.

Schumpeter critizices microeconomics because it concentrates on the structure of the firm and markets; Microeconomics does not care about the managers of the firm: the entrepreneurs who motivated by innovation, see the possibility of being successful in the process of product marketing in order to satisfy the demand and obtain the return of the investment. The aspects of the marketing process must be previously known to the innovators to know if it is appropriate to develop and market the innovation. The role of the investor or entrepreneur was described by Schumpeter (*cf.* 1939: 65 et seq.) in the innovation model Mark 1: it is the investors who take advantage of the inventions of the new science and technology that open new firms. The model describes typical financing conditions in small and medium-sized enterprises. Schumpeter (*cf.* 1943: 87 et seq.) developed what is known as the Mark 2 model for oligopolistic firms with the ability to invest in state-of-the-art, highly capital-intensive technology. Today, it can be explained with current examples (Windows, Twitter, Snapchat) followed by companies that follow

8 Leon Walras, (1834-1910), Swiss preclassic economist publishes his *Elements of Pure Economics*. Harvard University Press. (1877, Reprinted in 1954).

9 Alfred Marshall, (1842-1924), published *Principles of Economics* in 1890, Macmillan and Company Ltd. Eighth edition. 1920. London.

the mechanisms advised by an investment bank described by Allen, F. & Yago, G. (2010) as well as Ross, S., Westerfield , R. & Jordan, B. (2001).

3. Transition to evolutionary thinking of technology

The rebirth of Schumpeter's ideas came about with the development of international trade theory after World War II. The relations between international trade, technology and growth appeared in the 1960s, trying to explain the determinants of international trade: first, Leontief (cf. 1953: 332 et seq.) with his famous paradox,[10] proves that international trade trends in no way resembled what the theory predicted with its concepts of equilibrium, that is, there were imbalances and defaults in optimization processes.

The most popular response was given by Vernon (cf. 1966: 190 et seq.)[11] with the "theory of the product cycle at the international level": the imbalances were due to the constant technological innovations and their worldwide diffusion through the multinationals, altering the endowments of natural or technological factors between countries. From this moment a rupture took place: traditional neoclassical economics and its component of international economics considered technology as an "exogenous" factor. In explaining economic growth; technology was taken as given. Productivity and growth were the result of combinations of the three productive factors: land, labor, and capital; any missing explanations or residuals in econometric models, were due to technological changes, but there was no interest in explaining them. In addition, any investment in technology was considered to produce decreasing returns to scale.[12] With Vernon, a new theory of development is generated in which technological innovation is an "endogenous" variable inserted in the equations that describe the productivity of the factors and the levels of production and economic growth at both sectoral and national level. It is also recognized that investment in technology has increasing returns to scale through knowledge.

In the 1980s, Christopher Freeman,[13] one of the most eminent modern theoreticians of the Kondratiev waves and the economic cycle, stands out. Freeman contributed greatly to the revival of the neo-Schumpeterian tradition. In an account by Jan Fagerberg (cf. 2002: 17 et seq.), Freeman did studies on innovation, diffusion, growth, and trade in the chemical and electronic industries. The assumptions of the applied studies were that innovation was the main factor of change and growth in the economy and also responsible for the specializations or comparative advantages that occurred in international trade in the long term, while the other factors traditionally considered important now were displaced to a secondary level or important in the short term. He was concerned about structural change in the world economy, and the development efforts of East Asian and Latin American countries. Freeman also introduced the concept of "System of National innovation" (SNI).

10 Leontief´s Paradox.In the article (1953) he finds that the United States being a country with a high capital endowment, contrary to neoclassical theory, imports capital-intensive goods (like Petroleum) instead of importing labor-intensive goods.

11 It is evident that Vernon develops the product cycle on the basis of Schumpeter's waves and serves as an inspiration to the cyclical theories presented by Abernathy-Utterback (1978) and Carlota Pérez (2002).

12 Declining returns to scale means that any investment in technology or machinery will also follow a three-stage cycle: when it is innovative it will have increasing profitability at increasing rates, stable profitability when it reaches the stage of maturity and declining profitability when it becomes obsolete.

13 Christopher Freeman (1921-2010), economist, founder and first director of Scientific Policy Research Unit (SPRU) at the University of Sussex.

He was the mentor of several generations of economists and social scientists working on technological change, innovation and the knowledge society, including Keith Pavitt, Carlota Perez, Lundvall and Jan Fagerberg himself.

Keith Pavitt (cf. 1984: 343 et seq.)[14] stands out for his "taxonomy of innovative companies". It explains that the sources and effects of innovation are sector-specific and divide firms into four groups: (1) suppliers-dominated firms: acquire their know-how from their suppliers, (2) specialized suppliers of equipment and goods capital, which offer innovations to other companies; (3) those dominated by scale, where innovation is associated with scale and (4) companies based on science and innovate through their own R & D laboratories. He was the first to use patents as an indicator of technological development.

Faced with the growing Schumpeterian literature, the neoclassical school begins to consider technological innovation. Romer (cf. 1986: 1002 et seq.)[15] used technology as an endogenous variable giving special importance to technological innovation by labor: a model of long-run growth and competitive equilibrium in which knowledge is used as an input in production with increasing marginal productivity. This model is the opposite to those based on diminishing returns since growth rates of countries can increase in the long and large countries can grow faster than small countries. Lucas (cf. 1988: 17 et seq.)[16] unlike previous neoclassical models that consider human and physical capital as a single variable, presents a model in which human capital is differentiated from machinery. Education must be treated as an investment that increases human capital from which a double feature of human capital is derived: a technological one, since it is like the domain of a knowledge; the second is cumulative with economies of scale as the investment in physical capital since the knowledge is used to acquire new knowledge that generate economic growth in endogenous form.

Freeman and Carlota Pérez (cf. 1988: 39 et seq.)[17] describe technological revolutions as changes in the techno-economic paradigm. They identify five stages in which technological changes have produced radical transformations in the political, social, cultural structure, including economic cycles; however, the chronological dates of the stages do not necessarily coincide with those of the cycles, there may be lags. The five stages are: early mechanization in the european eighteenth century, steam engine and railways, heavy engineering and electricity, mass production, information technology and communications. According to this theory, countries that have mastered technology have achieved high growth rates while those that have not, have fallen behind or underdeveloped.

14 Keith Pavitt, (1937-2002), SPRU, University of Sussex.

15 Romer, whose doctoral thesis was directed by Lucas at The University of Chicago, is currently Chief Economist and Senior Vice President of the World Bank. He is on leave from his position as professor of economics at the Stern School of Business at New York University.

16 Nobel Prize of Economics in 1995 for his contributions in the theory of rational expectations into a dynamic general equilibrium model. Also a professor of Romer.

17 Perez is professor at the London School of Economics, and since 2006, Professor of Technology and Socio-Economic Development at Tallinn University of Technology, Tallinn, Estonia. She is also Honorary Professor at SPRU, University of Sussex.

Porter (cf.1990: 110 et seq.)18 develops "Systems of Regional Innovation", based on national structures, which must be integrated into the clusters. He builds "the diamond" with its four components: factor conditions; conditions of demand; related sectors and support; strategy, structure and rivalry of the company. The first includes the structure of the financial system and the cost of financing. The perfect interrelationship within the diamond guarantees the competitiveness of the conglomerates or clusters, which is the result of a combination of elements: infrastructure in roads and telecommunications, institutional norms, labor legislation, availability of factors, taxes, R & D centers and presence of the financial system among others, in which companies of certain sectors are integrated horizontally and vertically between them, in addition to being connected with demanders and providers of factors; from here the optimal conditions for technological innovation are produced.

In the 1980s, Bengt-Ake Lundvall (*cf.* 1994: 23 et seq.) was the creator of the concept of the "Innovation System" together with Freeman and pioneer of Bjorn Johnson's "learning economy" , according to which knowledge is a very important resource or production factor: the learning process is relevant in technological and economic development, a process that optimally occurs in a mixed economy and not purely in the market. In order to demonstrate the importance of the mentioned authors, the research by Fagerberg & Verspagen (*cf.* 2007: 13 et seq.) is cited in a survey of the most influential researchers in the field of innovation: the four most important are Schumpeter, Nelson, Freeman and Lundvall, all evolutionists.

Pérez Influenced by the growing role of the financial sector in the global crises of the 1980s and 1990s, emphasizes on the relationship between technological innovation, the institutional framework and economic development from a financial perspective. In *Technological Revolutions and Financial Capita*l (2002), she is the first to link technological innovation to finance. Pérez (*cf.* 2005: 44 et seq.) explains the relations between financial capital and technological revolutions. According to her, a sequence is given in the following order: technological revolution, financial bubble, prosperity season, political agitation. This sequence restarts every fifty years or so. A radical innovation based on an accumulation of scientific knowledge surrounded by political and social circumstances that promote it, attracts an avalanche of financial capital interested in production in order to obtain high returns. Great expectations are created about the profits that produce an overvaluation of assets related to the financial and productive processes. It follows an economic boom based on the production and generation of goods and services related to the original invention, which involves related and complementary goods, strengthening sectoral and intersectoral relations. At this stage there are companies that expand thanks to the new invention as others that fail to maintain the old technology. The massification of new technology is capable of altering social customs, consumption patterns, legislation and political institutions. After several decades, what was new technologically becomes current and the massive consumption of a technology that has gradually become obsolete has reduced the profitability of the companies which leads financial capital to promote the

18 Professor Porter is the most cited author in business and economics according to http://www.revistas.unifacs.br/index.php/rgb/article/view/199/207. He is also one of the founders of The Monitor Group.

development of new technologies. However, Pérez says that technological development must not only satisfy the financial need of the entrepreneur but have a social, cultural, educational purpose.

Following with Perez, another manifestation of the impact of technology on the economy is evident in the massive use of technology in education, administration and production. The sustainability of economic growth depends on the speed of innovation; there is a need for continuous technological innovation to keep industries competitive internationally. This has led to the importance of the training of the workforce: the generation of intellectual capital. Although this was already understood since the time of Adam Smith and the liberal neoclassical theory that has always included human capital, specialized or not, within the functions of production, only hitherto with the development of information and communication technologies, has theorized about the "Knowledge Economy" in which knowledge is considered as a specific asset, differentiable from a machine or a building; Knowledge is taken as a dynamic asset, able to reproduce itself through continuous learning: the capacity to create human capital, which in addition to creating machines can generate more knowledge, which is why governments are required to allocate growing resources in education.

Ruttan (*cf.* 2006: 6 et seq.)[19] initially focused on innovation oriented to agricultural development and gradually he moves on different field: wars and national security are the main engines of technological innovation; the cycles of economic expansion and contraction depend directly on the beginning and end of wars; when a war is over, the United States enters a recession and therefore the world, Ruttan studies the cases of: the Aircraft Industry, Nuclear Power, the Computer Industry, the Semiconductor Industry the Internet and the Space Industries in order to argue that large scale and long term government investment is necessary for the development of general purpose technologies and economic growth. However, it is widely accepted that the economic cycles of expansion and contraction have been determined in part by the strong investment that is made in innovation projects aimed at consumer welfare.

4. Technology in Evolutionary models

No other school of economic thought has integrated technology in all its aspects. The rebirth of the Schumpeterian theory has been called "*Evolutionary school*". It has been developed with an eclectic orientation because the subjects it deals with are topics of study of other disciplines: sociology and institutional economics, adding cultural, political, and historical elements among others. However, it is important to explain the biological basis of the evolutionary school. Murmann (*cf.* 2003: 10 et seq.) describes how a firm faces the evolutionary process: every fact of economic life refers to past events, causes and connections that include several steps

19 Student at the University of Chicago and profesor at the University of Minnesota. Ruttan held positions earlier in his career at the Tennessee Valley Authority, Purdue University, the President's Council of Economic Advisors, the Rockefeller Foundation at the International Rice Research Institute in The Philippines, and President of the Agricultural Development Council.

1. A transmission and preservation mechanism
2. A mechanism for creating procedural varieties
3. A selection mechanism which already has or can be reinforced by
4. A segregation mechanism between different "populations"

The first step means that a repetitive and routine operating process in economics is akin to the gene in biology. Both are transmission and preservation units. The standard operating process is the result of learning, gradual innovations based on experience, which also makes it the mechanism of preservation of the species (business or industry). The second step refers to needed sources of variation: collection or storage of ideas, practices, new technologies and innovations in products and procedures, products tested in the past, experiences of successes and failures. Hence the justification of the presence of new managers promoting new ideas, taking risks, testing new strategies. This implies dynamism, aggressiveness, adaptation to the changing environment; a struggle for the survival of business and industry; the development of abilities that allow the survival of the species; routines are adapted if they are successful, the others disappear; some companies succeed and survive, the others are extinguished

The third necessary step is the existence of a darwinian system of selection or retention of the abilities that work best (selection by creation), which constitute new information that will be stored in the genes and that will be transmitted to the new generations to shape new human beings in economic aspects through education forming business leaders. Transmission occurs through interaction in society. Firms that have developed skills are imitated; individuals imitate successful individuals; ideas are copied, improved; successful practices or routines are transmitted from one firm to another, from one generation to another, on the contrary, bad ideas or nonprofitable firms are eliminated (selection by destruction).

The fourth step is given by the differentiation that the environments establish. These require firms to adapt (lamarckian evolution) to different economic environments determined by political borders, legislation, institutional factors, culture, among others, that lead to industries producing the same good or service have different competitive characteristics in different countries, firms facing different degrees of protectionism, incentives or disincentives to business activity, availability of financing mechanisms, degree of technological innovation, research and development possibilities; degree of competition in the markets; ease of development of individual initiative. Hence there are environments or scenarios where the process of evolution and adaptation is easier or more difficult. An adaptation can be successful (innovation by growth) or failure (innovation by decrease). Statistically speaking, it can be inferred that the selection process implies an increase of the variance within the population while the innovation process adds a variance to the business population.

The selection process implies that survivors passed the filters by developing new technologies. The reason for the existence of the current economic systems is that they survived, proved to be more efficient, functioned better; the most profitable companies are

those that capture most of the resources for research and development of new products. Unprofitable ones disappear from the market. Successful ideas or practices are adapted by other societies, companies or cultures that want to benefit from them.

Economic developments are full of randomness as the development of technology is full of uncertainty. While there is certainty about the new research being conducted, no one knows for sure about their success and its consequences. The changing realities of markets, unexpected political changes, the emergence of new technologies or new raw materials put pressure on firms to change, so over the years firms can move to new areas or products that were not their target at the beginning. They adapt, transform or disappear. However, economic evolution is not completely random as the genetic evolution in which mutations can occur. In the economy there are initial orientations, goals, directions established, but when giving the unexpected results a random component is obtained

For the evolutionary school, wealth creation is given, inter alia, through synergies or joint efforts to increase the capacity for success that would be impossible to achieve by individuals working in isolation; experimenting to produce alternatives and increase the likelihood of discovering new techniques and technologies or start again after facing failure. Innovations grow and compete with alternatives exploiting the benefits of scale, specialization, scientific review, investment and imitation; however, despite the cooperation, failures outweigh the successes which become the selection of the strongest and most capable.

Former explanations allow to explain a relationship between technology developments and the success of economic systems, for instance, the dismantling of the communist system and the strengthening of democracy since the 1990s increased the optimism of the evolutionary school over capitalism's ability to survive despite continued crises: the depression of the 1930s; the energy crisis of the 1970s; the collapse of communism in 1989; the expansion of the market economy and democracy in the world and the financial crisis of 2008. The above facts are part of an evolutionary process in which the market system and firms had been affected by periods of expansion and contraction, crises, adaptations, etc., to get stronger. The development of the company and the market is tied to two particularities: the strengthening of democracy and technological development.

In conclusion, the Evolutionary school presents a new point of view to explain the history of the economy and the processes of development undergone by the firms within the market economy. As a new school, it is building models to strengthen its analysis. It takes positions in common with economic liberalism and the neo-institutionalist school although it differs in other respects as in the way of dealing with technology. Undoubtedly their contributions help to understand the history of the economy and the measures to be taken in order to accelerate our economic development from the business field.

Parallel to the evolutionary school, neoliberal thinkers also considered institutional factors as a key element to promote technological development; Porter (*cf.* 1990: 839 and 840) comments on how democracy presents more opportunities for all. Freedom of expression generates the environment for the debate of scientific ideas, the development

of technology and its applications, stimulating those willing to take risks as entrepreneurs determined to conquer markets. Participation generates competition and successful processes are replicated and institutionalized; the economy grows faster. Contrary in countries with authoritarian governments, the freedom of ideas and proposals is eliminated and it is assigned to the government that defines specific plans without allowing the proliferation of alternatives (monopoly of knowing how). It can be inferred that economic underdevelopment and technological backwardness is a consequence of the low level of entrepreneurial spirit discouraged by political-economic regimes that restrain individual entrepreneurial initiative. While democracy and the market economy are not perfect, they are more likely to be receptive to the multitude of ideas that are conducive to economic growth and social welfare. Economic evolution will always need the inevitable parasites and predators but will tend to exploit cooperative synergies and move communities to move from unstable "laissez-faire anarchy" to societies with organized freedom within a law aimed at defending rights

4.1 The Nelson-Winter model

The pioneering work of evolutionary modeling was that of Nelson and Winter (1982), "*An Evolutionary Theory of Economic Change*". Nelson and Winter, from now on (NW, 1982) share the Schumpeterian idea that capitalism is the engine of change and since the neoclassical school does not explainhow real economics work, there is a need to develop an alternative approach. The model's philosophy is based on the fact that companies in order to compete in markets need to reinvest their profits into better and more productive equipment and technology. Successful firms accumulate their profits, reinvest and grow faster than others, those that are not successful are eliminated. NW, unlike Schumpeter, decide to take evolutionary theories from biology, something that displeased Schumpeter in the 1930s. NW (*cf.* 1982: 302 et seq.). Finally, the profitability of the company or the capital to be invested depends on a series of variables: price / cost ratio, investmenton technology and productivity of physical and human capital, innovation costs, imitation costs, capital depreciation. The impact of each variable is obtained through simulations. Further research led to the adaptation of NW to multisectoral models, with simultaneous equations for the public sector, financial sector, etc. So that the components of aggregate supply and aggregate demand are being integrated. All generally end with NW-style simulations (1982), for example, Possas *et al.* (2005).

5. Technology goes micro

Technology has gone from the macro and sectoral analyses to a micro issue; it deals with several approaches: engineering, financing, marketing, institutional, etc. The above implies that the study of technology has gone from the philosophical and speculative to the experimental given the use of quantum (econometrics) methods. To mention only the financial focus, it is worth noting that none of the previous economists was concerned about the financing of technology. It seems that the problem of technology financing was taken for granted when in fact it is not possible to massify a radical or incremental innovation without ensuring continuous and cheap financing. In practice, technology

financing is integrated with corporate finance, marketing and distribution, e.g. how to optimize technological innovation? What is the optimal combination of equity financing and / or debt?, cost of capital, etc.

One of the most important works is that of Wilson (*cf.* 2015: 3 et seq.) who shows how in the OECD member countries affected by the 2008 financial crisis, a variety of financing alternatives have been given to innovative companies; from tax incentives to increasing co-ownership of the government with the entrepreneur; government funds, private funds, mezzanine loans, increasing share of "Venture Capitals" attracted by high-risk technological innovation as well as "business angels". According to Wilson, equity financing for small technology companies has been reduced in the face of fears of another crisis coming back. Wilson emphasizes the inability to measure the effectiveness of each mechanism.

Others such as Allen & Douglas (1999), Bhagat, S. & Welch, I. (1995), Blass, A. & Yosha, O. (2001) have tried to define the optimal debt-equity structure to finance technological innovation although they work on it but on limited geographical areas; on the contrary, Gómez-Mejía (2017) tries to be conclusive about the optimal source of financing technology: debt or capital stock. After taking a sample of 40.906 firms that trade on world capital markets, and following the OECD technology classification, econometrics models are applied and equity financing is found to be more productive than debt financing.

Besides the financial, there are aspects that can determine the innovative momentum; Dodgson (*cf.* 2008: 272 et seq.) sums up several: protection of copyright; difficulty in obtaining patents, licenses and their durability; possibilities of third parties entering the competition; existence of distribution channels; provision of after-sales services; use of knowledge; skilled labor; involvement of R & D centers, etc.

Conclusions

Technological innovation was an underestimated subject for all schools of economic, social or political thought until Schumpeter. It has become a protagonist in the thought of the twentieth and twenty-first centuries as the causes of economic and social development are deepened, however, many questions remain unanswered because of limitations self-imposed by the same areas of thought: to think that economic problems are solved with the participation of economic variables without taking into account the interdisciplinarity that more effectively reflects reality. Given the inability of the social sciences to explain the backwardness of many countries in technological development, there was a reaction within the same thinking that seeks new opportunities through integration with managerial and natural sciences. Natural sciences apply biology and genetics leading to evolutionist approaches and mathematical models that describe the reproductive processes of animal species to be applied to the economy and explain the reproduction and survival of firms in what corresponds to the processes of technological innovation.

Conflict of interests

The authors declare that they have no conflict of interest.

References

1. Allen, F. & Douglas, G. (1999). "Diversity of opinion and financing of new technologies". *European Economic Review*, 39, 179-209.
2. Allen, F. & Yago, G. (2010). *Financing the Future. Market-based innovations for growth*. New Jersey: Prentice Hall. Milken Institute.
3. Andersen, E. S. (1994). *Evolutionary Economics, Post-Schumpeterian Contributions*. London: Pinter
4. _(2001, June 12-15). *Towards a Multiactivity Generalisation of the Nelson-Winter Model*. Conference presented at the 2001 Nelson-Winter Conference, organized by DRUID, Aalborg, Denmark.
5. _(2004). "Population thinking, Price's equation and the analysis of economic evolution". *Evolutionary and Institutional Economics Review*, 1, 127–148.
6. _(2004, June). *From Schumpeter´s failed econometrics to modern evometric analysis: Creative destruction as a tale of two effects*. Conference presented at the International Schumpeter Society. Bocconi University, Milán. Retrieved from http://www.business.aau.dk/~esa/evolution/esapapers/esa04/schumpconf04.pdf
7. Bhagat, S. & Welch, I. (1995). "Corporate Research and Development Investments: International Comparisons," *Journal of Accounting and Economics*. 19, 443-470. Retrieved from http://dx.doi.org/10.1016/0165-4101(94)00391-H.
8. Blass, A. & Yosha, O. (2001). "Financing R&D in Mature Companies: An Empirical Analysis", Working Paper Series STE-WP-10. Bank of Israel, Tel Aviv University, and CEPR. Dodgson, M., Gann, D., & Salter, A. (2008). *The Management of technological innovation*. Oxford: Oxford University Press.
9. Elliot, J. S. (1980). "Marx and Schumpeter on Capitalism's Creative Destruction". *Quarterly Journal of Economics*, 94, 45-68.
10. Fagerberg, J. (2002). "A Layman's Guide to Evolutionary Economics". Retrieved from Jan.fagerberg@tik.uio.no
11. Fagerberg, J. & Verspagen, B. (2007)."Innovation, growth and economic development: have the conditions for catch-up changed?". *International Journal of Technological Learning, Innovation and Development*, 1, 13-33.
12. Freeman, C. (1974). *The Economics of Industrial Innovation*. London: Pinter.
13. Freeman, C. & Pérez, C. (1988). Structural Crises of Adjustment: business Cycles and Investment Behavior, pp. 38-66. In G. Dosi, C. Freeman, R. Nelson, G. Silverberg y l. Soete (eds), *Technical Change and Economic Theory*. London: Pinter
14. Freeman, C. & Louca, F. (2001). As Time goes by. *From the Industrial Revolutions to the Information revolution*. Oxford: Oxford University Press.
15. Freeman, C. (2005). *"The National System of Innovation in historical perspective"*. Cambridge Journal of Economics, 19, 5-24.
16. Gómez-Mejía A. (2017). *"Financing Technological Innovation in Global Capital Markets*. 2009-2016".To be published by Revista Libre Empresa, Universidad Libre, Cali, Colombia.

17. Hodgson, G. M. (1997). *Economics and Evolution*, pp. 9-40. In Jan Reijnders (ed.). Cheltenham: Elgar.
18. _(1998). On the evolution of Thornstein Veblen´s evolutionay economics. *Cambridge Journal of Economics*, 22, 415-431
19. _(2002).“Darwinism in Economics: From analogy to ontology”. *Journal of Evolutionary Economics*, 12, 259-281.
20. Keynes, J.M. (1936). *The General Theory of Employment, Interest, and Money.* Retrieved from http://etext.library.adelaide.edu.au/k/k44g/k44g.html
21. Landes, D. S. (1999). *The Wealth and Poverty of Nations: Why Some Are So Rich and Some So Poor.* New York: W.W.Norton and company.
22. Leontief, W. (1953). “Domestic Production and Foreign Trade: The American Capital Position Re-examine”, *Proceedings of the American Philosophical Society*. September, pp. 332-49.
23. Lucas, R. E, (1988). On the Mechanics of Economic Development, *Journal of Monetary Economics*, 22, 3-42.
24. Lundvall, B.A. & Johnson, B. (1994). “The learning economy”. *Journal of Industry Studies*, 1(2), 23–42.
25. Marshall, A. (1890, printed in 1920). *Principles of Economics*. Eigth edition. London: Macmillan and Company Ltd.
26. Marx, K. (2015, printed in 1887). *Capital A Critique of Political Economy. The Process of Production of Capital*. 1(1). Retrieved from https://www.marxists.org/archive/marx/works/download/pdf/Capital-Volume-I.pdf
27. Mumford, L. (1992). *Técnica y Civilización*. Quinta reimpresión. Madrid: Alianza Universidad.
28. Murmann, J, P. (2003). *Knowledge and competitive advantage. The coevolution of firms, technology and national institutions*. Cambridge: Cambridge University Press.
29. Nelson, R. R. & Winter, S. G. (1982). *An evolutionary theory of economic change*. Cambridge: Harvard University Press.
30. OECD. (2009). *Policy Responses to the Economic Crisis: Investing in Innovation for Long-Term Growth*.
31. _(2010), High-Growth Enterprises: What Governments Can Do to Make a Difference, OECD Studies on SMEs and Entrepreneurship, OECD Publishing. Retrieved from http://dx.doi.org/10.1787/9789264048782 en Agosto 21, 2015.
32. Pavitt, K. (1984).“Sectorial patterns of technical change: Towards a taxonomy and a theory”. *Research Policy*, 13(6), 343–373.
33. Pérez, C. (2002). *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages*. London: Edward Elgar Editorial.
34. _(2005). *Revoluciones Tecnológicas y Capital Financiero: La dinámica de las Grandes Burbujas Financieras y las Épocas de Bonanza*. México: Siglo XXI.
35. _(2010). “A view of technical change with the aid of History”. Technological University of Tallinn, Estonia. Retrieved from http://www.carlotaperez.org.
36. Porter, M. (1990). *The Competitive Advantage of Nations. New York*: Free Press.
37. Possas, M. L. (2005). “A Multisectoral Micro-Macrodynamic Model”. Universidade Federal do Paraná. Departamento de Economia. Retrieved from http://www.economiaetecnologia.ufpr.br/textos_discussao/texto_para_discussao_ano_2005_texto_08.pdf

38. Roll, E. (1994). *Historia de las doctrinas económicas.* Fondo de Cultura Económica. México.
39. Romer, Paul M. (1986). "Increasing Returns and Long-Run Growth". *The Journal of Political Economy*, 94(5), 1002-1037.
40. Ross, S., Westerfield, R. & Jordan, B. (2001). *Fundamentos de Finanzas Corporativas.* México: McGraw-Hill.
41. Ruttan, V. W. (2006). "Is War Necessary for Economic Growth? Military Procurement and Technology Development". University of Minnesota, Department of Applied Economics, *Staff Papers*, pp. 06-14. Retrieved from http://purl.umn.edu/13534
42. Smith, A. (1977) [1776]. *An Inquiry into the Nature and Causes of the Wealth of Nations.* University of Chicago Press.
43. Schumpeter, J. A. (1934). *The Theory of Economic Development.* Cambridge: Harvard University Press.
44. _(1939). *Business Cycle. A Theoretical, Historical and Statistical Analysis of the Capitalist Process.* New York : McGraw-Hill Book Company.
45. _(1943). *Capitalism, Socialism and Democracy.* New York: Harper Editorial
46. _(1947). *The creative response in economic history, Schumpeter (1989),* 221–231.
47. _(1954). *History of Economic Analysis* . London: Allen & Unwin (Publishers) Ltd
48. Veblen, T. B. (1898a), "Why is Economics Not an Evolutionary Science?", *Quarterly*, 24, 296-303. Reprinted in Veblen (1934).
49. Vernon, R. (1966). "International Investment and International Trade in the Product Cycle". *Quarterly Journal of Economics*, 80, 190-207.
50. Walras, L. (1877, printed in 1954). *Elements of Pure Economics.* Cambridge: Harvard University Press.
51. Wilson, K. E. (2015), "Policy Lessons from Financing Innovative Firms", OECD Science, Technology and Industry Policy Papers, 24, OECD Publishing, Paris. Retrieved from http://dx.doi.org/10.1787/5js03z8zrh9p-en