African Journal of Science, Technology, Innovation and Development

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rajs20

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To cite this article: María del Pilar Escott Mota, Xochitl Margarira Cruz Pérez & Rafael Palacios (2022): Digital transformation and new dynamics of the triple helix model, African Journal of Science, Technology, Innovation and Development, DOI: 10.1080/20421338.2021.1988418

To link to this article: https://doi.org/10.1080/20421338.2021.1988418

Published online: 16 Feb 2022.

African Journal of Science, Technology, Innovation and Development, 2022
https://doi.org/10.1080/20421338.2021.1988418

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Digital transformation and new dynamics of the triple helix model

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This paper is intended to be an extension of innovation studies on the complexity of technological change and its relationship with the dynamics of the triple helix actors. Therefore, the research question is how to reduce the complexity of digital transformation from the point of view of innovation actors for a faster and more effective adaptation of their strategies?

To answer that question, this paper conceives digitization as a 'new technological path'. The complexity of digitization is assumed as the clearest expression of current technological change. The speed, dynamics and strength developed give technological change a character of domination. These characteristics have a transforming power on the actors that form the triple helix. Specifically, the objective of this work is to characterize the dynamism of the theoretical approach to technological change by making a longitudinal analysis of the development of digitization. The theoretical analysis allowed the identification of a set of variables, which modifies the way the actors are organized in triple helix model and can generate new arrangements in the interaction process. Also, it was observed that the variables identified are distinctive from other innovation variables in the approaches of Schumpeterian and neo-Schumpeterian actors.

The results of this work were achieved using qualitative analysis through the MAGG methodological approach that made it possible to systematize and classify longitudinally different theoretical perspectives on the dynamics of technological change. A theoretical contrasting method was relevant because it allowed us to identify these variables.

Keywords: technological change, triple helix, innovation, digitalization, technological pattern

JEL Classification: O30, O33, O36

Introduction

The theoretical-practical aspects and results of this work correspond to the development of research related to digital transformation and its effect on the universities in Mexico. Aspects related to the process of interaction of innovation actors were analyzed: university, company and the government in the Bajio region, where the large poles of technological development of the country are concentrated. In this paper, we focus on the theoretical dimension of technological change and digitalization.

One of the first hypotheses that encouraged and motivated this research was that the theoretical treatment carried out on technological change has been oriented more towards the characterization of its dynamics than to its own contextual definition. Although it is not the intention of this work to formulate a definition of technological change driven by digitalization, it does try to achieve an approximation of a possible definition supported by the theoretical elements that show digitization as a highly complex dominant technological path. This certainly cannot be achieved without the prior characterization and in-depth analysis of the current dynamism that digitalization develops.

Actors such as Mulder, Reschke, and Kemp (1999) tried earlier to establish a definition of technological change. They affirmed that the technological change that was experienced at the end of the last century was the effect of the way in which the society actors, and social and natural contexts were related to the technologies. This brought about the emergence and resolution of certain problems related to the interaction and roles of innovation actors, due to the prevailing technological pattern (Information and Communication Technologies) that demanded a change in the national innovation model.

Another approach to understand the phenomenon was undertaken by Van Lente (1993). The author suggested that technological change could be structured starting from the following notions: (a) Trajectory: series of products with similar applications; (b) Paradigm: group of expectations and heuristic notions related to a specific technological pattern; and (c) Links: among institutions through a solid coalition between actors.

An understanding of the technological change phenomenon was highly legitimized by the contributions of Perez (2010, 2014). This author refers to the technological revolutions and described aspects related to their behaviour in the economy and society. Likewise, Perez (2010, 2014) defines this characterization as a techno-economic paradigm structured in two phases: (1) installation and (2) deployment. The installation of paradigm refers to the irruption followed by a sub-phase of technological change frenzy, which is understood as a phase of social, economic, political, and cultural adaptation. The deployment phase corresponds to the synergy and maturity of technology. A relevant aspect in the point of view of Perez (2010, 2014) is that she refers to the readjustment period of the paradigm, also known as the inflection point. According to the author, it allows inferring the appearance of a new technological pattern that can generate transformations in the set of actors in society.

Other actors, such as Zeppini (2011) state that technological change is a driver of the economy. Cantner and

Vannuccini (2018) share Zeppini's (2011) point of view and further affirm that technological change is stimulated by innovation and promoted by change actors. Fatás-Villafranca, Jarne, and Sánchez-Chóliz (2012) clarify that innovation causes a technological change that opens the way for a new technological era framed by a new capital assessment which consequently generates a new technological pattern, and even affirm that this technological pattern can eventually replace the old technological pattern. The authors use the term 'eventual' because the sequence does not occur automatically.

There are many perspectives on the notion of technological change. This work does not pretend to be based on a particular point of view. Rather, different opinions that address elements that approximate a holistic view of technology and its effect on society as a whole were considered. In this sense, the vision of technological change of Mulder, Reschke, and Kemp (1999) has great value for the analysis in this work. They visualize technological change as: '[…]the interaction between human actors (it means, societies), their set of technologies and the natural and social environment, leading to the solution of some old problems and the appearance of new ones that require a change in the type and composition of technologies (and actors / human societies)' (8-9).

The perspective of actors such as Cantner and Vannuccini (2018), when they refer to the changes promoted by the innovation actors, has relevant value in this analysis. The authors characterize the dynamics of innovation actors and their direct effects on the economy, which implies the appearance of inflection points in the functionality of innovation actors. No less important are the contributions of Kurzweil (2005) based on the Law of Accelerated Returns. The author explains the exponential dynamics of technology. According to Kurzweil (2012) there is an exception in intelligent technology, since it expands at a double exponential rate; its growth rate is in itself exponential. From this approach emanates the notion of technological singularity, which consists of explaining the current technological change rate.

All these points of view cohere with the dynamics currently experienced by the digital economy. According to Valenduc (2018), the digital economy is a technological pattern. Valenduc and Vendramin (2016) make reference to the fact that some signs of technological patterns can also be found in Bell (1973) who mentions a postindustrial economy based on producing and consuming intangibles through storage, transmission and data processing as a way to carry out political and social exchanges. Valenduc and Vendramin (2016) identify four characteristics of this technological pattern: irrelevance of geographic location, role played by digital platforms, importance of network effects and the use and impact of 'big data'.

On the other hand, Orlikowski and Iacono (2000) affirm that the digital economy represents a rising and complex phenomenon. Carley (1999) suggests that the digital economy sets a novel economic, political, and social system distinguished by an intelligent environment shaped for information, tools to access and process information and the ability to communicate.

The notion of the digitalization of the economy used for this research draws on the contributions of Valenduc (2018), Valenduc and Vendramin (2016), Bell (1973), and Carley (1999), and defines it as an emergent technological pattern, complex and dynamic, that establishes a new economic, political, and social system characterized by producing and consuming intangibles, that involves a new relationship of innovation actors to configure the technological pattern. As such, this paper presents a characterization of technological change, the different theoretical approaches of technological change are analyzed and a set of variables that define the prevailing technological pattern (digitalization) are identified. Subsequently, these variables are classified temporarily through which the technological pattern is developed. Variables that influence the new dynamics of action, relationship, and functioning of innovation actors are then selected, mainly the university, the company and the government.

All this is achieved through the selected method of theoretical contrasting of variables (MAGG) (Marquina et al. 2013). These variables show the degree of complexity of digitization as an expression of technological change as well as its dominant character.

Technological change and digitalization as technological pattern and its relationship with the triple helix

Characterization of technological change: A descriptive approach to its composition

Schumpeter (1939, 1967) was the first to propose an approximation of the relationship between technological change and innovation. Schumpeter referred to the innovative process as an internal-endogenous modular unit that promotes capitalist development stimulated by the acting of an entrepreneurial agent (Cantner 2016; Schumpeter 1939, 1967). This approach focuses the role of the entrepreneur in the economy.

It is important to highlight two main aspects of Schumpeter's thought (1939): (a) the dynamic and unstable capitalist economy and (b) innovation as a component that promotes dynamism in the economy. According to Schumpeter (1939, 1967) the modification of ideas or search for new elements refers to the activity of innovating within a market economy where innovative technologies generate modifications and replace current technologies. From the Schumpeterian vision, to talk about innovation is to refer to the introduction of a new product or service to the market; a new method in the production processes for a certain sector, in which technological changes are able to show unprecedented ways to compete. In this sense, each innovation could represent the emergence of a new set of companies or technologies and the expiration of others (Schumpeter 1967).

Schumpeter (1939, 1967) also refers to the instability and the emergence of economic cycles, which are generated by innovation. Because of this, Schumpeter (1967) asserts that the technological changes can lead to a continuous revolution in the structure of the economy internally, demolishing the old to make way for the new, as an essential element of capitalism. Schumpeter (1967) calls

this 'creative destruction'. Technological changes refer a dynamic nature to the productive system and are put into practice through elements that can endogenously lead to industrial transformation.

Schumpeter (1939, 1967) affirmed that the beginning of the recession and the depression could have positive results, which is called 'gales of creative destruction' because it eliminates the old unproductive industries and, with it, he argued that the accelerations of the technological innovation during periods of depression were the main drivers of recovery. From these contributions by Schumpeter (1939, 1967) it can be inferred that innovation is one of the main drivers of adaptation in economies and, therefore, of technological change. According to Valenduc (2018), Schumpeter (1939, 1967) visualizes the existence of a cause–effect relationship around the technological changes and the long waves in which, through the productive fabric, important changes take place on the way that assessments are produced, in addition to services capable of propitiating an economic recovery.

The theoretical proposal of Schumpeter (1939, 1967) focuses on innovation and creative destruction. Innovation causes an alteration of the normal course of the economy creating a process of industrial mutation that incessantly revolutionizes the economic structure from within, incessantly destroying the old to make way for the new. In this sense, it is understood that technological changes are implemented as far as entrepreneurs show innovative attitudes.

Creative destruction under the evolutionary approach

Along with Nelson and Winter (1982), other important scientific contributions were produced by authors such as Dosi (1982), Rosenberg and Nathan (1982), Soete and Turner (1984), Pavitt (1984), Freeman (1987), Lundvall (1992), Archibugi and Planta (1996), Perez (2003) and Mazzucato (2013). In general, they have continued to analyze Schumpeter's creative destruction approaches and have made important contributions to the new dynamics that innovation develops.

There are also other contributions that refer to the identification of a set of variables that generate the economic system product of innovation. According to Hanusch and Pyka (2006), one of the fundamentals of the innovation economy relates to study of dynamic phenomena caused endogenously by the economic system from the meso-level of the economy. This is so because, since according to Dopfer, Foster, and Potts (2004), the meso-level of an economic system is where the most decisive structural and qualitative changes take place.

In this sense, and starting from the contributions of Knight (1921), Shackle (1949), Dopfer, Foster, and Potts (2004), Hanusch and Pyka (2006), and Valenduc (2018), it is not surprising that nowadays the neo-Schumpeterian school is known for excelling in studies on innovation and learning behaviour at the micro level of an economy, on industry dynamics driven by innovation at the meso-level, on determined innovation and on technological change.

Evolutionists like Dosi (1982), Rosenberg and Nathan (1982), Soete and Turner (1984), Pavitt (1984), Freeman (1987), Lundvall (1992), Archibugi and Planta (1996), Perez (2010), and Mazzucato (2013), and students of this approach such as Dopfer, Foster, and Potts (2004), Hanusch and Pyka (2006) and Valenduc (2018) agree that the evolutionary economy deals with the following three aspects. The first is that technological change is reflected in all the levels of the economy; therefore, attention should not only be paid to structural changes; it is also necessary to take into account ways to suppress the restrictions that affect economic development to open up the way for new scenarios. The second aspect refers to the observation that those qualitative changes do not occur continuously over time but belong to the idea of marked equilibria which comprise phases with uniform and regular developments, as well as radical changes. The third is about the notion of the aforementioned processes, denoting non-linear positive externalities, which are the authors of forming patterns and other emerging forms of structure; in other words, these patterns are not unpredictable, even though uncertainty is inherent in innovation.

Digitization as technological pattern

Industry 4.0 according to Gerbert et al. (2015) transforms the process in which products and services are designed, manufactured, and operated. The way in which people and machinery connect and interact enables production systems to be 30% faster and 25% more efficient, which will take mass customization to new horizons (Gerbert et al. 2015). This new way of connectivity and interaction brought about by digitization and industry 4.0, according to Gerbert et al. (2015), is being promoted by essential technological advances such as: big data and analytics, autonomous robots, simulation, horizontal and vertical integration systems, the internet of things, industry, cyber security, the cloud, additive manufacturing, and augmented reality.

Forschungsunion Wirtschaft–Wissenschaft (2013), Pomeranz (2009), Gerbert et al. (2015), and Baldwin (2016, 2019) highlight that the pattern of digitalization is becoming increasingly evident in the social and economic interweaving of a more daily way through the digital coding of various technological advances. These technological advances have become such a common element in the current era that, although they refer to intangible production, they generate consumption based on data processing and dissemination (Gerbert et al. 2015; Pooja 2017).

It could be inferred from the contributions of Estrada, Álvarez, and Palacios (2016), 'Forschungsunion Wirtschaft-Wissenschaft' (2013), Pomeranz (2009), Valenduc and Vendramin (2017), Valenduc (2018), Gerbert et al. (2015), and Baldwin (2016, 2019) that the current dynamics of technological change are transforming the form of both the performance and the interaction of the innovation actors. According to the contributions of Estrada, Álvarez, and Palacios (2016), this process of transformation is oriented to analyze the actors in three areas or subsystems: productive, financial, and institutional. The composition of these three subsystems allows us to identify the endogenous and exogenous elements that are energized by the appearance of a new technological pattern. The composition of these three

subsystems transforms the dynamics of the triple helix. This means that the actors in the triple helix are joined by new actors, who require to be included as subsystems themselves to be able to face the complexity of digitization. The organization of actors in subsystems is a relevant element of digitization.

Singularity on approach to address technological change and digitization

Kurzweil (2005) in the 1990s proposed a reason why technology and evolutionary processes generally prosper exponentially. However, Kurzweil (2012) suggests that there is an exception in intelligent technology, since it expands at a double exponential rate, which means, that its growth rate is in itself exponential. The author mentions that the first two decades of the twentieth century saw more progress than in the entire nineteenth century (Kurzweil 2012). In this approach lies the notion of technological singularity, which consists in the explanation of the pace of technological change. According to (Kurzweil 2012), technological change is constantly accelerating and its capabilities are expanding at a rate that is also increasing more quickly, preventing technological projections from being made. One of the aspects referred to by Kurzweil (2005) is that technological changes and with them the highest performance of computing have been around for at least one hundred years. Therefore, Kurzweil (2005, 2012) insists that the rate of exponential growth will be maintained, and that singularity is close as technology continues to accelerates at such an exponential rate that progress will eventually become virtually instantaneous, a singularity.

Table 1: Components of technological change.

Author	Components of technological change	Approach
Cantner and Vannuccini (2018)	-Heterogeneity of actors as homo agents. -Interaction of the actors through competition and cooperation.	-Schumpeterian
Zeppini (2011)	-Technological competence -Endogenous interaction of heterogeneous actors. -Technological diversity -Network externalities -Social interactions -Market dynamics -Environmental policy	-Schumpeterian
Fatás-Villafranca, Jarne, and Sánchez-Chóliz (2012)	-Endogenous inversion -Knowledge threshold	-Schumpeterian
Valenduc (2018)	-Technological transition -Inflection point -Digital economy -Ecological sustainability	-Schumpeterian -Theory of technological change -Evolutive economy
Schot and Steinmueller (2016)	-Sustainable development	-Theory of science, technology and innovation policy
Choi, Jeong, and Jung (2018)	-Technological convergence	-Co-classification of technological patent domains
Mulder, Reschke, and Kemp (1999)	-Technological niches as semi protected spaces for a new technology. -Environmental sustainability	-Evolutionary theorization on technological change for technological policies -The strategic management of niches
Coccia (2018)	-Change in quality	-Innovation economy
Van Lente (1993)	-Technological trajectory -Technological paradigm -Links between institutions	-Evolutive economy
Perez (2018a)	-Technological assimilation -Technological direction -Environmental sustainability	-Evolutive economy
Perez (2018b)	-Technological assimilation -Technological direction -Technological diffusion -Technological patterns -Government action	-Evolutive economy
Perez (2018c)	-Inflection point	-Evolutive economy
Luján and Moreno (1996)	-Scientific policy	-Evolutive economy
Kurzweil (2012)	-Technological expositional behaviour	-Law of Accelerated Returns

Source: Created by the authors

Table 2: Integrated components of technological change.

Components	Definition	Characteristics that identify the component	Innovation contextualized
Heterogeneity of actors - homo agents -	By Cantner and Vannuccini (2018), homo agents are a micro unit that induces – as an inventor and innovator of new ideas – and / or propagates change – as an imitator and adopter of novelty. Zeppini (2011) and Cantner and Vannuccini (2018) mention that currently larger entities have been suggested where different actors – heterogeneity – work together, as in networks and cooperative R & D projects and in value chains.	-Invention -Innovation -Adoption of technology -Heterogeneous networks	Endogenous
Interaction of actors	Cantner and Vannuccini (2018) refers to the interaction of actors as the mechanisms of interaction between individuals and a group of individuals that lead to creative destruction in the sense of Schumpeter (1967) and beyond when dealing with long-term dynamics. Competition, as well as cooperation, market exchange, as well as non-market transactions and relationships, comprise important modes of interaction between these change actors that provide structures in markets and industries (Cantner and Vannuccini 2018).	-Transactions and external relations to the market	Endogenous
Technological competence	Zeppini (2011) considers technological competence as an emerging phenomenon of decision making by economic agents.	-Emerging variable of economic actors	Endogenous
Technological diversity	Zeppini (2011) addresses technological diversification in the presence of recombinant technological innovation.	-Recombinant technological innovation -Innovation through technological fusion	Endogenous
Network externalities	According to Zeppini (2011) an endogenous mechanism leads to decision feedback cycles. This mechanism is present when the value of a technology increases as the number of users that use it, that is, a technology becomes more attractive as more companies implement it, reducing costs – economies of scale -, as more agents use it, due to technology standards and infrastructures - network externalities –, and as it becomes more efficient (Zeppini 2011).	-Decision feedback cycles -Technological value measured by users	Endogenous
Social interactions	For Zeppini (2011) they represent an endogenous mechanism that leads to decision feedback cycles such as network externality. Social interactions according to Zeppini (2011) could have positive feedback whenever the decision to adopt technology is also driven by 'word of mouth' through a contagion effect or by a recruitment process or as effects of conformity and habit formation.	-Decision feedback -Technological adoption for the formation of new social habits	Endogenous
Market dynamics	Zeppini (2011) refers to the market conditions and behavioural characteristics of the agents that cause a prevalence of innovation or imitation, and in particular, what factors are important that there is greater or lesser innovation in an industry	-Behaviour of actors determined by market conditions. -Innovation oriented by the behaviour of its actors	Endogenous
Environmental policy	Zeppini (2011) suggests that, in order to address the environmental problem of polluting technologies, a government policy must operate at different levels, combining an environmental policy, an innovation policy and alleviating the externalities of the network, for example, with technology standards more flexible and infrastructure.	-Flexible technological standards	Exogenous

(*Continued*)

Table 2: Continued.

Components	Definition	Characteristics that identify the component	Innovation contextualized
Technological Convergence / Technological Niche	Mulder, Reschke, and Kemp (1999) define it as the field of application of one or more interrelated technologies that create semi protected spaces for a new technology. Choi, Jeong, and Jung (2018) follow it as the join of different areas of technology allows the focalization of the key convergence technological fields that can be used as a guide to prioritize investment.	-Business investment generated by key technologies produced by fusion of technologies.	Exogenous
Internal investment in R & D	For Fatás-Villafranca, Jarne, and Sánchez-Chóliz (2012) within each technological era, we assume that companies in our economy allocate their resources according to certain operating routines.	-Operational routines determine investment in R & D	Exogenous
Knowledge threshold	Fatás-Villafranca, Jarne, and Sánchez-Chóliz (2012) refer to the new accumulative knowledge. When it reaches a threshold value H *, there is a jump in the technological potential of the economy and a new technological era begins (Fatás-Villafranca, Jarne, and Sánchez-Chóliz 2012).	-Accumulated knowledge -Technological potential generated by accumulative knowledge -New technological paradigm driven by accumulative knowledge	Endogenous
Technological Transition	According to Valenduc (2018), it is a period in which technologies are becoming obsolete due to the arrival of new programmes and innovative technological resources.	-Technological maturation by input of technologies	Endogenous
Inflection point	Period of readjustment, it is a transitional period, very represents the turning point between the installation and deployment phase, it can also be seen as a fictitious bonanza scenario based on financial bubbles or the way to a stable bonanza model (Perez 2010, 2003; Valenduc 2018).	-Technological transition (Installation and deployment of technology) -New economic takeoff.	Endogenous
Digital economy	Valenduc (2018) mentions that the current era is immersed in a process of technological transition framed by a technological pattern in transition, it is about the digitalization of the economy.	-Digitalization as a technological pattern in transition	Exogenous
Sustainable development	Mulder, Reschke, and Kemp (1999), Perez (2018a) and Schot and Steinmueller (2016) argue that fundamental changes are required in production processes and consumption patterns supported by alternative technological trajectories to achieve environmental sustainability (Mulder, Reschke, and Kemp 1999). These changes, which go beyond the control of particular pollutants and improvements in ecological efficiency, are known as changes in technological regime.	-Alternative technological trajectories determine patterns of production and consumption -Technological regime	Exogenous
Change in quality	Coccia (2018) mentions that technological progress or the technological evolution of the product is due to the change in quality over a period of time. Positive increases in the levels of technical characteristics should lead to an increase in quality (Coccia 2018).	-Temporary quality of the product defines its own technological evolution	Endogenous
Technological trajectory	Van Lente (1993) defines it as the series of products with similar applications. On the other hand, Dosi (1982) mentions that the technological trajectory represents a group of activities executed to solve a problem defined within the prevailing digital pattern.	-Products with similar applications -Mix and collaborative actions to respond to digitalization	Endogenous
Technological paradigm	For Van Lente (1993) this consists in the grouping of expectations and heuristic notions related to a specific technological pattern.	-Paradigm as a technological pattern	Endogenous

(*Continued*)

Table 2: Continued.

Components	Definition	Characteristics that identify the component	Innovation contextualized
Links between institutions	Van Lente (1993) suggests them as the solid coalition between the actors that provide variation and the context of selection.	-Coalition and coordination among actors -Information of actors to define ways of acting	Endogenous
Technological assimilation	Perez (2018b) mentions that it is crucial to understand that every great wave of development does not stop there, with the set of new technologies and infrastructures brought by each revolution. The assimilation of each of these sets of interrelated changes produces and also requires a change in the socio-economic context and the socio-institutional framework, to allow the full deployment of the wealth creation potential of the new industries, the modernization of the industries deployed in the previous wave and the flowering of new services and activities that arise in response to changes in lifestyles: in other words, the changes that new technologies and infrastructures bring to the way we live our daily lives.	-Deployment of industries based on the socioeconomic and institutional context. -Social effects product of the new technological deployment	Endogenous
Technological direction	For Perez (2018b) the profitable propagation of each new technological paradigm has always required appropriate direction at the appropriate time.	-Profitable propagation of the technological paradigm	Exogenous
Technological diffusion	Perez (2018b) suggests it as the process by which a technology is propagated in a group of users. The gradual diffusion requires profound organizational and technical changes (Perez 2018b).	-Technological spread in groups of users. -Gradual technological diffusion as a result of organizational and technical changes	Endogenous
Technological pattern	Negraes Brisolla (1995) refers to the social, historical and cultural condition through which technology is integrated. According to Perez (2018b), recognizing these recurrent patterns makes us go from broad periods to the identification of very different technological revolutions.	-Differentiated technological revolutions	Endogenous
Government action	For Perez (2018b), the development of each techno-economic paradigm depends on the society and governments capacities to realize the enormous transformative potential that each technological revolution in particular install, and to generate a specific context and type of dynamic demand that can generate innovations and investment that must be released.	-Transformative potential of the paradigm for the socio-institutional context. -Innovations generated by dynamic type demands.	Endogenous
Scientific Policy	Luján and Moreno (1996) consider technology as a vital element in the action of public power, given that studying the process of evolution between technologies and institutions is an essential factor to analyze scientific policy.	-Technology as an instrument of political power. -Institutions -Scientific policy generated by the parallel evolution of technologies and institutions	Exogenous
Technological exponential behaviour	Kurzweil (2012) suggests that technology and evolutionary processes generally prosper exponentially	-Exponential acceleration of technology	Exogenous

Source: Created by the authors based on the literature review

Towards the determination of new variables of technological *change*

Methodological description and towards the identification of variables

To achieve a characterization of technological change, a literature review was carried out by applying the MAGG methodological approach of Marquina et al. (2013), which proposes four blocks: literature search, exploration of the literature, development of the argument and criticism of the literature, and building a solid review. This will establish the bases for the methodological design of the research and serve as a basis for the analysis of the results, allowing the development of conclusions and valuable contributions.

Towards the identification of variables

The last stage of the MAGG approach (2013) called literature review aims at this research theoretical contrast, where the key concepts of different authors who have developed the issue of technological change from different approaches are compared, revealing common concepts.

Once these similarities were identified through theoretical tests, they were unified to eliminate conceptual redundancies. This procedure generated a new set of components on technological change, which are shown in Table 1.

Once the similarities between the authors and the components of technological change were identified, we proceeded to unify conceptual perspectives. This procedure generated a new set of variables defined as 'integrated components of technological change', which are shown in Table 2.

Conclusions

The variables identified in this work are called 'integrated components'. These are the result of the qualitative analysis of multiple theoretical perspectives and the restructuring process on the variables that characterize technological change. The digitalization seen as a dominant technological pattern brings with it the periodic accumulation of the theoretical variables on technological change and also presents a greater heterogeneity of variables linked to innovation contextualized in two dimensions: endogenous and exogenous. This composition of various elements that characterizes the digitalization on the one hand continues with greater force, sustaining Schumpeter's creative destruction approach. On the other hand, the elements generate new implications – not yet sufficiently identified – in the forms of action of the actors that make up the triple helix.

The endogenous and exogenous notion of integrated components are defined as areas in which the variables identified predominate and their existence is generated by the predominant technological pattern. The exogenous variables exhibit the new and diverse characteristics generated by the technological pattern and that influence the dynamics of the endogenous variables of the innovation actors. The results show how new endogenous variables are generated and how others cease to influence the functionality of innovation actors. Also, these exogenous variables enhance the meaning of other existing endogenous variables and further enhance the innovation strategies of the actors.

A structured characterization of qualitative character on the theory of technological change shows, unlike other types of analysis dimensions, as the different theoretical visions that have existed over time, for periods, revolutions or technological paradigms do not necessarily reach their obsolescence; rather, these with the components that identified them continue to shape the spectrum of innovation among the actors of the triple helix. The interaction of the government, the university, the company and society cannot be understood in the absence of the set of cumulative variables of technological change. This allows us to infer that the efficient use of the triple helix as a strategic dimension of innovation must be approached in the context of complexity and not in the field of selectivity and particularity. Certainly, in this context of innovation, it is not clear the limitations that arise in the process of interaction of innovation actors, do not allow a type of functionality regulated by the actors of the triple helix.

The results obtained infer a common element in the set of actors analyzed, and that technological change is not only progressive, but also highly complex. This refers very directly to Kurzweil's vision of technological uniqueness. Two problematic aspects related to creative destruction in the Schumpeterian vision are evident: (a) the complexity of innovation and (b) the type of knowledge required to innovate in the midst of the dynamics of digitalization and industry 4.0.

Finally, this work shows that the theoretical configuration of digitization is the base for understanding the complexity of digitization. Consequently, this encourages the generation of new theoretical perspectives in the field of innovation that will allow us to analyze the complexity of the triple helix actors and could also mean the impulse required for new concepts in the configuration of their dynamics.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

Archibugi, D., and M. Planta. 1996. "Measuring Technological Change Through Patents and Innovation Surveys." *Technovation* 16 (9): 451–519.

Baldwin, R. 2016. *The Great Convergence*. Cambridge, MA: Harvard University Press.

Baldwin, R. 2019. "Globalization 1.0 and 2.0 Helped the G7. Globalization 3.0 Helped India and China Instead. What will Globalization 4.0 do?" Retrieved from https://voxeu.org/content/globalisation-10-and-20-helped-g7-globalisation-30-helped-india-and-china-instead-what-will-globalisation-40-do#.XEbPABFbabc.twitter.

Bell, D. 1973. *The Coming of Post-Industrial Society: a Venture in Social Forecasting*. New York: Basic Books.

Cantner, U. 2016. "Foundations of Economic Change: An Extended Schumpeterian Approach." In *Foundations of Economic Change*, edited by Andreas Pyka and Uwe Cantner, 9–49. Cham: Springer.

Cantner, U., and S. Vannuccini. 2018. "Elements of a Schumpeterian Catalytic Research and Innovation Policy." *Industrial and Corporate Change* 27 (5): 833–850.

Carley, K. M. 1999. "Organizational Change and the Digital Economy: A Computational Organization Science Perspective." *Understanding the Digital Economy: Data, Tools, Research* 21: 325–351.

Choi, J. Y., S. Jeong, and J. K. Jung. 2018. "Evolution of Technology Convergence Networks in Korea: Characteristics of Temporal Changes in R&D According to Institution Type." *PloS one* 13 (2): e0192195.

Coccia, M. 2018. "Which Technological Characteristics Matter Most in Evolutionary Pathways of New Technology?

Hedonic Pricing Method for Detecting and Predicting Technological Trajectories in Smartphone." Working Paper CocciaLab n. 36, CNR. Turin: National Research Council of Italy.

Dopfer, K., J. Foster, and J. Potts. 2004. "Micro-meso-macro." *Journal of Evolutionary Economics* 14 (3): 263–279.

Dosi, G. 1982. "Technological Paradigms and Technological Trajectories: a Suggested Interpretation of the Determinants and Directions of Technical Change." *Research Policy* 11 (3): 147–162.

Estrada, Álvarez y Palacios. 2016. "Limitations of Latin America Innovation Systems: Analysis from the Creative Destruction Heuristics." Conference paper 16th ISS Conference on Evolutionary Economics and innovation, Montreal, Canadá.

Fatás-Villafranca, F., G. Jarne, and J. Sánchez-Chóliz. 2012. "Innovation, Cycles and Growth." *Journal of Evolutionary Economics* 22 (2): 207–233.

Forschungsunion Wirtschaft–Wissenschaft, P. K. Der. 2013. "Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0." *Abschlussbericht des Arbeitskreises Industrie* 4: 30–57.

Freeman, C. 1987. *Technology Policy and Economic Performance: Lessons from Japan*. London: Pinter Publishers.

Gerbert, P., M. Lorenz, M. Rüßmann, M. Waldner, J. Justus, P. Engel, and M. Harnisch. 2015. "Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries." BCG. URL: https://www. bcg. com/publications/2015/engineered_products_project_business_industry_4_future_productivity_growth_manufacturing_industries. aspx.

Hanusch, H., and A. Pyka. 2006. "Principles of neo-Schumpeterian Economics." *Cambridge Journal of Economics* 31 (2): 275–289.

Knight, F. H. 1921. "Cost of Production and Price Over Long and Short Periods." *Journal of Political Economy* 29 (4): 304–335.

Kurzweil, R. 2005. *The Singularity Is Near: When Humans Transcend Biology*. New York: Penguin Books.

Kurzweil, R. 2012. *La singularidad está cerca*. Berlín, Alemania: Lolabooks.

Luján, J. L., and L. Moreno. 1996. "El cambio tecnológico en las ciencias sociales: el estado de la cuestión." *Reis* 1: 127–161.

Lundvall, B. A., (ed). 1992. *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. London: Anthem Press.

Marquina, P., C. Alvarez, D. Guevara, and R. Guevara. 2013. "Revisión de literatura esquema Documento de trabajo con esquema para el desarrollo del Trabajo de Investigación Final." Doctoral dissertation, Tesis, modalidad Revisión de Literatura, en CENTRUM Católica. Lima, Perú.

Mazzucato, M. 2013. *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*. London: Anthem Press.

Mulder, P., C. H. Reschke, and R. Kemp. 1999, June. "Evolutionary Theorising on Technological Change and Sustainable Development." 1st European meeting on Applied Evolutionary Economics, Grenoble, France, 7-9 June 1999.

Negraes Brisolla, S. N. 1995. "Capacitación tecnológica y patrones tecnológicos: Una visión a partir de los países en desarrollo." *Redes* 2 (5): 35–65.

Nelson, R. R., and S. G. Winter. 1982. *An Evolutionary Theory of Economic Change*, 929–964. Cambridge: Belknap Press/ Harvard University Press. 434 p.

Orlikowski, W. J., and C. S. Iacono. 2000. "The Truth Is Not Out There: An Enacted View of the Digital Economy." *Understanding the Digital Economy: Data, Tools, and Research* 1: 352–380.

Pavitt, K. 1984. "Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory." *Research Policy* 13 (6): 343–373.

Perez, C. 2003. *Technological Revolutions and Financial Capital*. Northampton, MA: Edward Elgar Publishing.

Perez, C. 2010. "Technological Revolutions and Techno-Economic Paradigms." *Cambridge Journal of Economics* 34 (1): 185–202.

Perez, C. 2014. "A new age of Technological Progress." In *Owning the Future*, edited by C. Umunna, 19–30. London: Edward Elgar Publishing.

Perez, C. 2018a. (11 de September de 2018). Second machine age or fifth technological revolution? (Part 1) [Message blog]. UCL Institute for Innovation and Public Purpose Blog, recuperated: https://medium.com/iipp-blog/second-machine-age-or-fifth-technological-revolution-part-1-ed66b81a9352.

Perez, C. 2018b. (20 de September de 2018). Second machine age or fifth technological revolution? (Part 2) [Message blog]. UCL Institute for Innovation and Public Purpose Blog, recuperated: https://medium.com/iipp-blog/second-machine-age-or-fifth-technological-revolution-part-2-db42863a8df8.

Perez, C. 2018c. (27 de September de 2018). Second machine age or fifth technological revolution? (Part 1) [Message blog]. UCL Institute for Innovation and Public Purpose Blog, recuperated: https://medium.com/iipp-blog/second-machine-age-or-fifth-technological-revolution-part-3-a268f91d5b34.

Pomeranz, K. 2009. *The Great Divergence: China, Europe, and the Making of the Modern World Economy*. Vol. 6. Princeton, NJ: Princeton University Press.

Pooja, D. 2017. *Digitalización: una tendencia emergente en prácticas de recursos humanos. Diario Imperial de Investigación Interdisciplinaria (IJIR)*. Vol.3. Bora: Instituto de Ciencias de la Administración. India.

Rosenberg, N., and R. Nathan. 1982. *Inside the Black box: Technology and Economics*. Cambridge, United Kingdom: Cambridge University Press.

Schot, J., and E. Steinmueller. 2016. *Framing Innovation Policy for Transformative Change: Innovation Policy 3.0. SPRU Science Policy Research Unit*. Brighton, UK: University of Sussex.

Schumpeter, J. 1939. *Business Cycles: A Theoretical, Historical and Statistical Analysis of the Capitalist Process*. Primera Edición. New York: McGrawHill.

Schumpeter, J. 1967. *Teoría del desenvolvimiento económico*. Cuarta Edición. México D.F: Fondo de Cultura Económica.

Shackle, G. L. 1949. "A non-Additive Measure of Uncertainty." *The Review of Economic Studies* 17 (1): 70–74.

Soete, L., and R. Turner. 1984. "Technology Diffusion and the Rate of Technical Change." *The Economic Journal* 94 (375): 612–623.

Valenduc, G. 2018. "Technological Revolutions and Societal Transitions. ETUI aisbl, Bruselas. Retrieved from https://www.etui.org/Publications2/Foresight-briefs/Technological-revolutions-and-societal-transitions.

Valenduc, G., and P. Vendramin. 2016. "Work in the Digital Economy: Sorting the Old from the New." European Trade Union Institute. Retrieved from http://ftu-namur.org/fichiers/Work_in_the_digital_economy-ETUI2016-3-EN.pdf.

Valenduc, G., and P. Vendramin. 2017. "Digitalisation, Between Disruption and Evolution." *Transfer: European Review of Labour and Research* 23 (2): 121–134.

Van Lente, H. 1993. "Promising Technology. The Dynamics of Expectations in Technological Developments." PhD Thesis, University of Twente, Delft, Netherlands.

Zeppini, P. 2011. "Behavioural Models of Technological Change." PhD Thesis, University of Amsterdam, Netherlands.