ISSN (print): 2421-6798
ISSN (on line): 2421-7158

Consiglio Nazionale delle Ricerche

IRCrES

ISTITUTO DI RICERCA SULLA CRESCITA ECONOMICA SOSTENIBILE
RESEARCH INSTITUTE ON SUSTAINABLE ECONOMIC GROWTH

Working Paper

Numero 5/2017

General purpose technologies in dynamic systems: visual representation and analyses of complex drivers

Mario Coccia

WORKING PAPER CNR-IRCRES, anno 3, numero 5, Aprile 2017

General purpose technologies in dynamic systems: visual representation and analyses of complex drivers[1]

MARIO COCCIA[a,b]
ORCID ID: 0000-0003-1957-6731
Country: IT

[a] CNR-IRCRES, National Research Council, Research Institute on Sustainable Economic Growth, via Real Collegio 30, Moncalieri (TO) – Italy
[b] ARIZONA STATE UNIVERSITY, Center for Social Dynamics & Complexity, 550 East Orange St., Tempe, Arizona | 85287

Mail: mario.coccia@ircres.cnr.it, mario.coccia@cnr.it

ABSTRACT
The main aim of this study is to provide a new graphical representation of the potential root causes of General Purpose Technologies (GPTs) for the analysis and foresight of these path-breaking innovations that support the technological and economic change over the long run. *Firstly*, the study here shows that basic driving forces set the stage for the source of GPTs, such as higher democratization, high population and continuous demographic change, high investment in R&D, the purpose of global leadership between great powers, contestable socioeconomic environments with effective/potential threats of belligerent subjects, etc. *Secondly*, an appropriate graphical representation of these drivers of GPTs is given by a fishbone diagram, which is a visualization technique for a comprehensive theoretical framework to represent, systematize and analyse the source of GPTs. This technique of the fishbone diagram can provide fruitful information for the foresight of GPTs that support the economic change over time. Some examples are given by applying the Fishbone diagram to describe the determinants of specific GPTs over time: steam engine and ICTs. Overall, then, fishbone diagram seems to be an appropriate and general technique of graphical representation to systematize and analyse whenever possible, the complex root causes of GPTs for the foresight of these path-breaking innovation in society.

KEYWORDS
General Purpose Technology; Technological Foresight; Source of technical change; Technological Evolution; Evolution of Technology; Fishbone Diagram.

JEL CODES:
O31, O33

Reference to this paper should be made as follows:
Coccia M. (2017) "General purpose technologies in dynamic systems: visual representation and analyses of complex drivers", *Working Paper CNR-IRCRES*, vol. 3, n. 5, pp. 1-19, ISSN (on line): 2421-7158.

DOI: 10.23760/2421-7158.2017.005

[1] I gratefully acknowledge financial support from National Endowment for the Humanities / National Research Council of Italy–Direzione Generale Relazioni Internazionali Research (Grant 0072373-2014 and 0003005-2016) for my visiting at Arizona State University where this research started in 2015. I thank the Library of Arizona State University for scientific material provided on these topics. I am grateful to Trang T. Thai (GE Global Research) and an anonymous referee for fruitful suggestions concerning these topics. I also thank colleagues at ASU that provided many helpful suggestions. The author declares that he has no relevant or material financial interests that relate to the research discussed in this paper.

CONTENTS

General purpose technologies in dynamic systems: visual representation and analyses of complex drivers

MARIO COCCIA

1 INTRODUCTION

Technological progress has a great weight in supporting patterns of economic growth over the long run (Helpman, 1998, p. 1; Coccia, 2005b; 2005c; 2007; 2009a; 2010a; 2010b; 2010c. Ruttan, 2001; Rosenberg, 1982). A main element of the technical progress is the path-breaking innovations, which make prior technical knowledge obsolete and sustain industrial and corporate change of inter-related nations (Sahal, 1981; Colombo et al., 2015). A path-breaking innovation is the General Purpose Technology (GPT) that is one of the contributing factors of the long-run technological and economic change in society (Bresnahan, 2010). The GPTs are enabling technologies for a pervasive use in many sectors to support new products and processes (Helpman, 1998, p. 3). The GPTs generate changes of techno-economic paradigm ("Technological Revolutions"), which affect almost every branch of the economy (Freeman and Soete, 1987, pp. 56-57) and sustain the "secular process of growth" of human society (Bresnahan and Trajtenberg, 1995, p. 83; cf. Helpman, 1998; Lipsey et al., 1998). Ruttan (2006) argues that GPT is basic to sustain productivity and economic growth of nations over time. The driving forces of GPTs are different from those that support other innovations of less intensity (Helpman, 1998; Ruttan, 1997; Lipsey et al., 1998, Coccia, 2005, 2005a, 2006, 2010, 2014, 2014a, 2014c, 2015). Scholars have described several approaches to explain the source of technical change and technological evolution of radical innovations (cf. Wright, 1997; Hall and Rosenberg, 2010; Helpman, 1998, p. 2; Coccia, 2015; Li, 2015; Robinson et al., 2007; Schultz and Joutz, 2010). However, an appropriate visualization technique for systematizing and analysing the potential root causes of General Purpose Technologies (GPTs) is hardly known. In particular, a problem in economics of technical change is to find an appropriate graphical approach for representing and analysing the drivers of General Purpose Technologies (GPTs) that support the foresight of these path-breaking innovation in society (cf. Ruttan, 1997; 2006).

The study here confronts this scientific problem by applying the fishbone diagram, which seems to be an appropriate visualization technique for representing and analysing the determinants of GPTs over time. The main aim of this study is therefore to provide a novel graphical representation to explore whenever possible, the potential root causes of General Purpose Technologies (GPTs) that explain the long-run economic change in society.

2 CONCEPTUAL GROUNDING

New General Purpose Technologies (GPTs) are revolutionary changes from current technological paradigms and trajectories (Bresnahan, 2010, pp. 763-791). These path-breaking innovations are mainly of transformative nature and generate a "destructive creation" (Calvano, 2007), which makes prior products/processes and knowledge obsolete (cf. Colombo et al., 2015) . Aghion et al. (2015) argue, that Schumpeterian growth paradigm, based on models growth as resulting from major innovations involving creative destruction, sheds light on sev-eral aspects of the growth process that cannot be properly addressed by alternative theories. Three important aspects of this Schumpeterian growth theory are: (a) the role of competition and market structure, (b) firm dynamics, and (c) the relationship between growth and devel-opment.

Lipsey and colleagues (1998, p. 43) define the General Purpose Technology: "a technology that initially has much scope for improvement and eventually comes to be widely used, to have many users, and to have many Hicksian and technological complementarities". GPTs are enabling technologies that exert a pervasive impact across firms, industries and that permeate the overall structure of the economy (Coccia, 2005, 2010a). The diffusion of GPTs is by sev-eral ripples of effects that remove barriers and generate significant techno-economic change in society (Peirce, 1974). Coccia (2005) classifies the GPTs, in the scale of innovation intensity, with the highest degree of socio-economic impact. In particular, Coccia (2005, pp. 123-124) claims, referring to revolutionary innovations such as GPTs, that:

> The means of human communication are radically changed and a new means of communication, which heavily affects all the economic subjects and objects, is born, forcing all those who use it to change their habits. A new technoeconomic paradigm is born . . . . The propulsive capacity for development offered by seventh-degree innovation is so high that it hauls the entire economy. Thanks to the new methods of communication, there is also greater territorial, social, and human integration. Another characteristic of seventh-degree innovations is the ease of their spread. The mobility of people, goods, capital, and information increases and the time taken to travel and communicate is reduced.

Bresnahan and Trajtenberg (1995, pp. 86-87) show that GPTs have a treelike structure with basic new technology located at the top of the tree and all derived technologies radiating out towards every branch of the economy. In fact, the *General Purpose Technologies generate clusters of new technology in several industries because they are basic processes/components or general infrastructure for the architecture of various families of products/processes that are made quite differently*. The different applications of new GPTs are driven by firms to maximize the profit and/or to exploit the position of a (temporary) monopoly in different sec-tors and/or industries over time (Coccia, 2015).

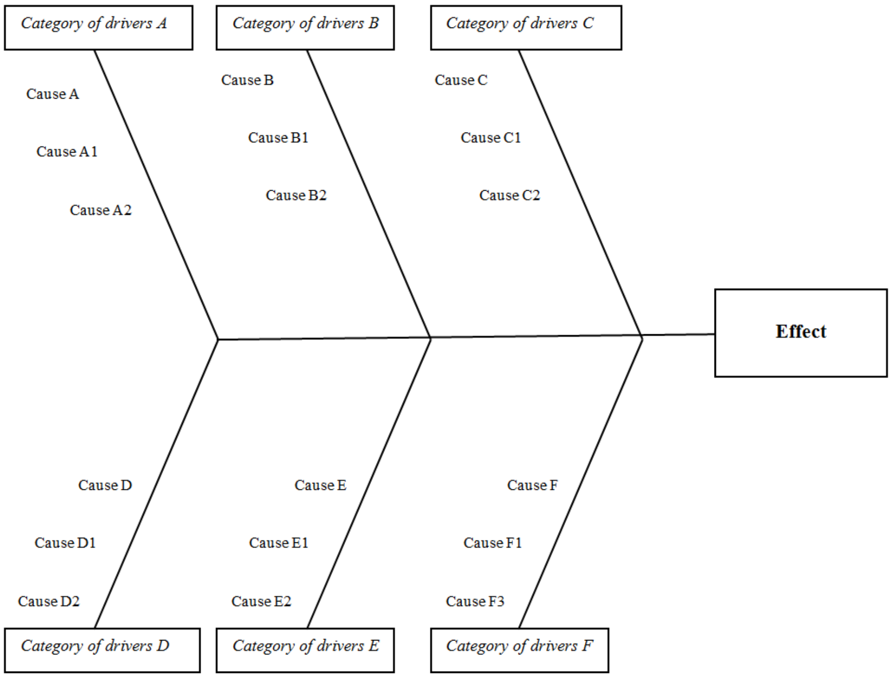
In general, GPTs are characterized by pervasiveness, inherent potential for technical improvements, and 'innovational complementarities', giving rise to increasing returns-to-scale, such as the steam engine, the electric motor, and semiconductors (Bresnahan and Trajtenberg, 1995, p. 83, original emphasis) . Jovanovic and Rousseau (2005, p. 1185) show that the distinguishing characteristics of a General Purpose Technology are: (1) Pervasiveness: "The GPT should spread to most sectors". It has an impact on technical change and productivity growth across a large number of industries; (2) Improvement: "The GPT should get better over time and, hence, should keep lowering the costs of its users". It should lead to sustained productivity growth and cost reductions in several industries; (3) Innovation spawning: "The GPT should make it easier to invent and produce new products and processes" (cf., Bresnahan and Trajtenberg, 1995). Lipsey et al. (1998, p. 38ff) describe other main characteristics of GPTs, such as: the scope for improvement, wide variety and range of uses during its techno-logical evolution and strong complementarities with existing or potential new technologies. Another main feature of GPTs is a long-run period between their initial emergence as inven-tion and final commercial introduction in new products/processes (Lipsey et al., 1998; 2005). Rosegger (1980, p. 198) showed that the estimated time interval between invention and major innovation can be about 50 years: e.g., electric motor is about 58 years, electric arc lights 50 years, telegraph about 44 years, synthetic resins 52 years, etc. Overall, then, GPTs are complex technologies (general platforms -e.g., satellites- or basic components- e.g., semiconductor-) that induce product/process innovations in several sectors for a vital corporate, industrial, economic and social change over time (Coccia, 2015). Electricity power, information and communications technology are regarded as the prototypic General Purpose Technologies (Jovanovic and Rousseau, 2005).

3 STUDY DESIGN

Firstly, to develop a visualization technique for graphical representation and technological analysis of the source of GPTs over the long run, this study describes some drivers of GPTs with a general overview of the socio-economic literature. Secondly, this study systematizes the plexus (interwoven combination) of these drivers of GPTs by using a fishbone diagram, which can provide an appropriate visual representation of inter-related determinants underlying the source of GPTs. Fishbone diagrams (also called Ishikawa diagrams or cause-and-effect diagrams) is a graphical technique to show the several causes of a specific event or phenomenon (fig. 1). In particular, a fishbone diagram (the shape is similar to a fish skeleton) is a common technique used for a cause and effect analysis to identify a complex interplay of causes for a specific problem or event in management science.

As a matter of fact, this Cause and Effect Analysis was originally developed by Ishikawa (1990) as a quality control tool of products to identify potential factors causing an overall ef-fect and prevent the quality defects of products. Each cause is a source of variation of the phenomena understudy. Causes are usually grouped into major categories to identify the overall sources of variation that lead to a main effect (Fig. 1). In general, the Fishbone dia-gram can be used as an appropriate visual representation of phenomena that involve the inves-tigation of multiple cause-and-effect factors of specific events/facts (cf. Ayverdia et al., 2014; Buyukdamgaci, 2003; Ishii and Lee, 1996). Ramakrishna and Brightman (1986) compared their own Fact-Net-Model with Fishbone Diagram, and Kepner and Tregoe Method to show perceived differences. Overall, then, fishbone diagram can provide an appropriate graphical representation of the inter-related drivers of complex technologies, such as GPTs.

Figure 1. A Fishbone Diagram



4 A GENERAL DESCRIPTION OF THE PLEXUS OF DETERMINANTS GENERATING MAJOR INNOVATIONS

The source of major innovations (e.g., GPTs) depends on complex drivers over time and space. Economic literature shows several determinants of major technologies (cf. Ruttan, 1997, 2006; Bresnahan and Trajtenberg, 1995; Coccia, 2010; 2014; 2014a; 2015; Schultz and Joutz, 2010). Some main driving forces of GPTs are discussed as follows.

- *Geographical factors: temperate climate and natural resources*

Technological innovation is a vital human activity that interacts with geographic factors and natural environment (Coccia, 2015a). Geographical characteristics of certain areas support the location of people and, as a consequence, the concentration of productive activities, inventions and technological innovations over the long run (Krugman, 1991). The new geography of innovation analyses several spatial factors relating to the origin and diffusion of technological innovation, e.g., spatial proximity of economic subjects and agglomeration of resources (Rosenberg Norman, 1992; Smithers and Blay-Palmer, 2001; Howells and Bessant, 2012). In particular, new economic geography argues that "all production depends on and is grounded in the natural environment" (Hudson, 2001, p.300). Feldman and Kogler (2010) claim that the natural advantages of resource endowments and climate in certain places can induce innova-tion and economic growth (cf., Moseley et al., 2014). Lichtenberg (1960) shows that geo-graphical factors, rather than proximity to raw materials or markets, influence the production of knowledge and the cumulative nature of several innovations. Audretsch and Feldman (1996) confirm that the agglomeration of firms and innovative activities is related to ad-vantages in the natural environment, such as available resources and other factors of the phys-ical geography. In general, the concentration of human and natural resources is in specific ge-ographical places, such as major cities, long known to be society's predominant engines of innovation and growth (Bettencourt et al., 2007). The climate is a main geographical factor that affects natural resources, natural environment and human activities. Long ago, Montes-quieu (1947 [1748]) argued that the climate shapes human attitude, culture and knowledge in society. Recent economic literature shows that warm temperate climates have an appropriate natural environment for humans that, by an evolutionary process of adaptation and learning, create complex societies, efficient institutions and communications systems. This socio-economic platform supports, in temperate latitude, the efficient use of human capital and as-sets that induce inventions, innovations and their diffusion over time and space (Coccia, 2015a).

- *Cultural and religious factors*

Barro and McCleary (2003, p. 760) argue that: "successful explanations of economic performance must go beyond narrow measures of economic variables to encompass political and social forces". In fact, modern literature is also analysing social forces of economic develop-ment such as the culture (e.g. Guiso et al., 2006, pp. 23ff; Maridal, 2013; for factors of socio-economic systems cf. Coccia, 2009d; 2013). Weber (1956) discussed how the Protestant religious culture has affected the economic attitude of people and the entrepreneurship of capitalistic systems. Current socio-economic research analyses the religion and culture as basic drivers of economic growth and innovation (cf. Barro and McCleary, 2003; 2005; Guiso et al., 2006; Spolaore and Wacziarg, 2013; Coccia, 2014). Guiso et al. (2003) show the interplay between intensity of religious beliefs and people's attitudes that are conducive to economic growth (e.g., cooperation, trust, thriftiness, government, institutions, women's propensity to work, legal rules, and fairness of the market). In particular, Guiso et al. (2003, p. 225): "find that on average, religious beliefs are . . . conducive to higher per capita income and growth . . . . Christian religions are more positively associated with attitudes conducive to economic growth" (cf. Bettendorf and Dijkgraaf, 2010). In fact, religion shapes people's attitude of mind, education, culture and institutions of countries and likely is also a main socio-cultural determinant of the patterns of technological innovation (Coccia, 2014). A study displays that, on average, societies with a predominance of the Protestant, Jewish and Eastern religions have technological performance higher than societies with other predominant religious cultures (Coccia, 2014). These results may be due to fruitful relation between specific religions, culture and higher education institutions of countries that support high human capital. In addition, a higher religious/ethnic fractionalization in advanced society, ceteris paribus, has a positive effect on technological outputs. This appears to be particularly true among richer and more democratic countries with competitive markets, which are mainly located in the European and North-American geo-economic areas (Coccia, 2014). However, these findings are tentative and there is need for much more detailed research into the relations between religion, culture and innovation patterns of nations.

- *Democratization*

Democracy can be seen as a set of practices and principles that institutionalize and protect freedom (Modelski and Perry, 2002; Norris, 2008). Barro (1999, p. 160) points out that "increases in various measures of the standard of living forecast a gradual rise in democracy". Acemouglu et al. (2008) analyse the relationship between income per capita and democracy and argue that political and economic development paths are interwoven. Coccia (2010) shows that democratization is an antecedent process to technological and economic change. In particular, democratization seems to be a main driving force for technological change: most free countries, measured with liberal, participatory, and constitutional democracy indices, have a level of technological outputs higher than less free and more autocratic countries. As a matter of fact, it seems that "democracy richness" generates a higher circulation of infor-mation and appropriate higher education systems that, in advanced countries, support high human capital for fruitful patterns of technological innovation, wellbeing and wealth of na-tions over the long run (Coccia, 2010).

- *High population and demographic change*

Population growth plays a main role for patterns of technological innovation (Coccia, 2014a). Kuznets (1960) claims that: "high population spurs technological change because it increases the number of potential inventors" (as quoted by Kremer, 1993, p. 685). In particular, Kuznets (1960, p. 328) states: "Population growth . . .produces an absolutely larger number of genius-es, talented men, and generally gifted contributors to new knowledge whose native ability would be permitted to mature to effective levels when they join the labor force". Jones states that: " 'More people means more Isaac Newtons and therefore more ideas' " (as quoted by Strulik, 2005, p. 130). Kuznets (1960) and Simon (1977) also argue that high populations have a higher probability to create potential inventors because larger populations have propor-tionally more individuals with new ideas. Moreover, many inventions and innovations are demand-driven by large population, and as a consequence high population and an active de-mographic change can play a vital role for supporting patterns of technological innovation in advanced national systems of innovation (cf. Boserup, 1981, p. 5ff; Coccia, 2014a). Some studies also show that an optimal level of technological performance in advanced nations is due to positive growth rates of population that are lower than 1% (percentage of annual popu-lation growth rates), whereas innovative performances are negatively affected both by nega-tive and/or very high growth rates of population because of quadratic effects of the inverted-U shape curve of the relation innovative outputs/population growth (cf. Coccia, 2014a, pp. 57-59). This result confirms the study by Strulik (2005, p. 129) that: "long-run growth is compat-ible with a stable population".

- *Relevant problem*

GPTs are naturally directed to solve critical problems to achieve competitive advantages of leading nations (Coccia, 2015) or organizations in certain environments (Atuahene-Gima and Wei, 2011). Usher (1954) explained the evolution of new technology by using the theoretical framework of the Gestalt psychology. Usher's theory of cumulative synthesis is based on four concepts (see Basalla, 1988, p. 23): 1) Perception of the problem: an incomplete pattern in need of resolution is recognized; 2) Setting stage: assimilation of data related to the problem; 3) Act of insight: a mental act finds a solution to the problem; 4) Critical revision: overall ex-ploration and revision of the problem and improvements by means of new acts of insight. This theory fo-cuses on acts of insight that are basic to solve problems and generate vital innova-tions. The main implications of Usher's theory are the psychological aspects of invention and the evolution of new technology with a vital cumulative change (Basalla, 1988, p. 24). Coccia (2016) shows, through an inductive study in medicine, that consequential problems support the evolution of several radical innovations, such as path-breaking technologies for new target therapies in on-cology (cf., Coccia and Wang, 2015; Coccia, 2012a, 2012b, 2012c, 2012d, 2014b, 2014d, 2014e, 2015b, 2016a; 2016b; Coccia et al., 2012).

- *Major wars and environmental threats*

Ruttan (2006) argues that the war may be one of contributing factors that generates GPTs. In general, the high mobilization of scientific, technical, and financial resources during major con-flicts might support the origin of GPTs. In particular, a major war, or threat of a major war, may be a vital condition to induce political and economic institutions of great powers to commit the huge resources necessary to generate and/or sustain the development of new path-breaking technologies directed to solve strategic problems and provide a competitive ad-vantage in con-testable environments with potential threats (Ruttan, 2006). Hence, Ruttan (2006, p. 184ff) ar-gues that a *war* and/or a *threat of a major war* can support the development of GPTs that subse-quently generate clusters of commercial innovations for the economic growth in society.

- *Purpose of global leadership in contestable environments*

Coccia (2015) shows that the source of GPTs seems to be, *de facto*, purposeful systems (e.g. leading countries) with high economic potential and purposeful institutions having the purpose of achieving/sustaining a global leadership to cope with consequential environmental threats and/or to take advantage of important environmental opportunities. Coccia's (2015) theory gen-eralizes the Ruttan's approach, developing the theoretical framework of global leadership-driven innovation: GPTs are originated by the purpose of the global leadership of great powers, rather than wars *per se*.

In short, this theory by Coccia (2015) stresses the thesis that the source of GPTs is due to the purpose of global leadership of great powers which generates a main impetus for solving rele-vant and strategic problems with new technology during military and political tensions, such as the struggle to prove scientific and technological superiority, and military strength in space be-tween U.S. and Soviet Union in the 1960s (a contestable environment). This struggle for global leadership has generated major advances in ICTs and satellite technology, which are main GPTs supporting different product/process innovations in society. Another main example is given by U.S. Navy's Mobile User Objective System, a ground-breaking constellation of satellites, which can be a GPT for several new product/process to support U.S. global leader-ship in contestable environments with potential/effective threats of irrational multi-actors, e.g., the Islamic State of Iraq and Syria (Coccia, 2017).

- *Research policy and national system of innovation*

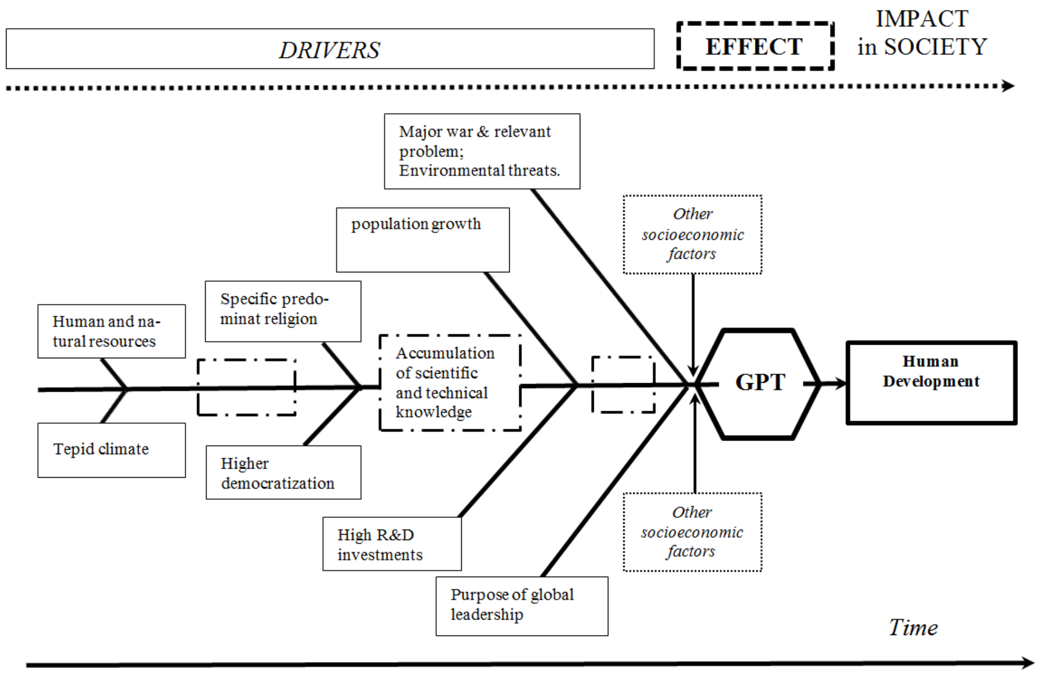
Governments in advanced economies devote much policy attention to enhancing investment in R&D to support the technical progress and productivity (Coccia, 2008a; 2008b; 2009; 2010d; 2012; Coccia and Rolfo, 2000; Rolfo and Coccia, 2005). In fact, R&D plays a key role for sup-porting technical innovation of economies, and includes expenditures by the in-dustry, govern-ment, higher education and private non-profit sectors (cf. Jones and Williams, 1998, pp. 1133ff; Coccia, 2012).

Griffith et al. (2004) display that R&D has a direct effect on the growth of the Total Factor Productivity (TFP) across several OECD countries. Instead, Mamuneas and Nadiri (1996, p.57) claim that: 'The optimal mix of . . . [incremental R&D tax credit and immediate deduct-ibility provision of R&D expenditures] is an important element for sustaining a balanced growth in output and productivity in the manufacturing sector''. Zachariadis (2004) investigates the rela-tionship between TFP and R&D investment and finds a positive relation between these variables (cf. Goel *et al*., 2008). Instead, Coccia (2012) shows that when R&D spending of business enterprise sector exceeds R&D spending of government sector, the labor productivity and GDP tend to growth, *ceteris paribus*. Moreover, a range of R&D investment as per-centage of GDP between 2.3 per cent and 2.6 per cent seems to maximize the long-run impact on productivity growth of advanced countries (Coccia, 2009; cf. Coccia, 2011). This finding is the key to explain the political economy of R&D for sustained productivity, accumulation of scientific and technical knowledge, as well as technology improvements in industries of advanced countries.

5 A COMPREHENSIVE GRAPHICAL REPRESENTATION OF THE DRIVERS OF GPTS TO SUPPORT THE FORE-SIGHT AND INNOVATION POLICY: THE FISHBONE DIAGRAM

This study shows a visualization technique for systematizing and analysing the drivers of GPTs, just discussed, that explain the social and economic change over time. In particular, an appropriate visual representation of the complex drivers of major innovations can be the fishbone diagram. Figure 2 shows this comprehensive theoretical framework (Fishbone diagram) to represent and explore the source of GPTs. In particular, the fishbone diagram in Figure 2 shows that the source of GPTs is due to a com-plex interplay of causes represented at left, which support emerging GPTs (hexagon at right). The major categories of the potential root causes of GPTs are described as follows. Firstly, the presence of natural and human resources in temperate climate for societies with economic potential is the base for laying the foundations for a GPT. This condition is a necessary, but not a sufficient factor because GPTs thrive in specific socioeconomic and cultural background with high level of democratization and specific predominant religions, such as Protestant reli-gion that can fruitful affect the higher education system and culture of human resources in so-ciety. However, an appropriate socioeconomic background is an important base for the source of major innovations but GPTs thrive mainly when great powers have to achieve and/or sup-port the purpose of global leadership to cope with consequential environmental threats and/or take advantage of important opportunities in contestable circumstances (e.g., during major conflicts/threats and/or struggle to prove scientific superiority and military strength among great powers).

Figure 2. Determinants of the source of GPTs in advanced nations represented with the fishbone diagram. Note: GPT = General Purpose Technology.



These factors are supported by an efficient national system of innovation that invests in economic and human resources to solve relevant problems by creating new tech-nology and, as a consequence, strategic competitive advantages in contestable environments and sustaining patterns of economic growth over the long run. In this context, high growth rates of population play a vital role to support the evolution of leading societies and the long-term development of GPT and major technologies in society with problem- and demand-driven mechanisms (Coccia, 2014, 2016).

These sequential and complex factors are basic for the source of GPTs that support long-run human development in society (Fig., 2).

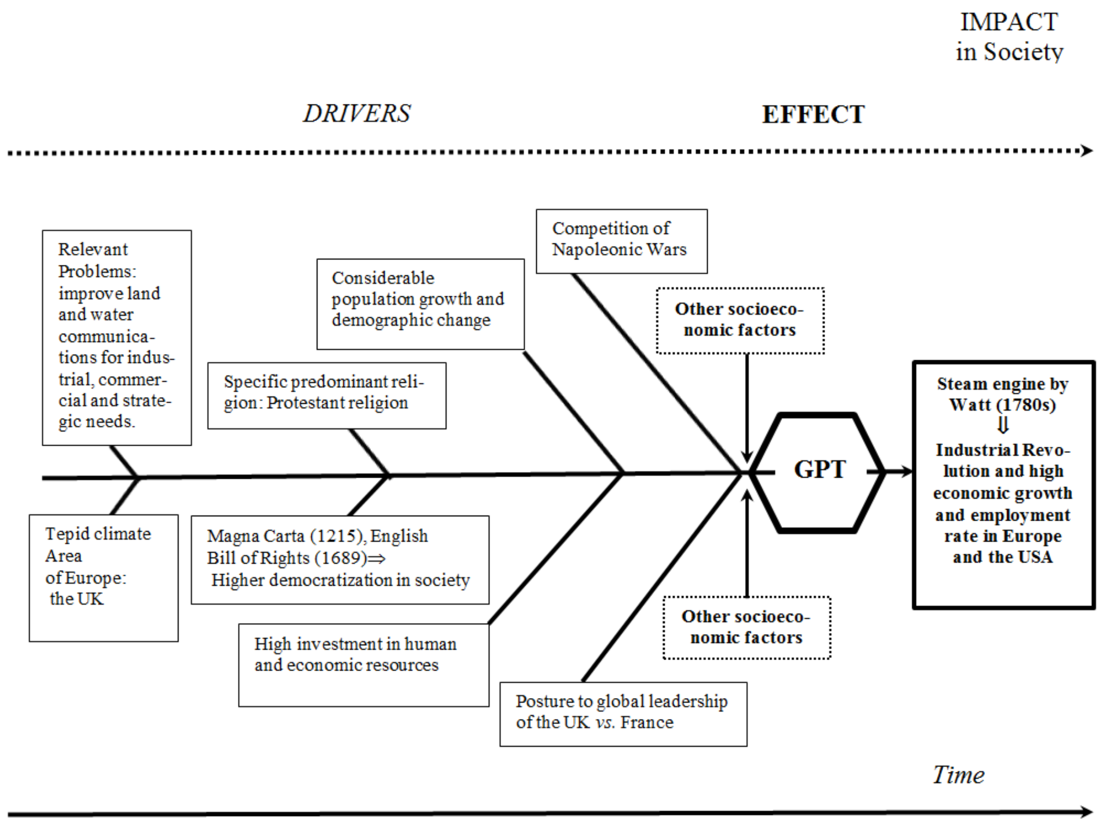
A final and important implication of this theoretical framework is that some of the features and determinants that cause GPTs, in the graphical representation of the Fishbone diagram here (Fig. 2), seem to be enduring and invariant properties of human societies, rather than ac-cidental shocks/events (cf. also Wright, 2005). Hence, driving forces of GPTs seem to have regularity in their long-run historical developmental paths in the presence of contestable envi-ronments in which great powers endeavour to achieve and/or sustain the purpose of global leadership on specific geo-economic areas.

6 APPLICATIONS OF FISHBONE DIAGRAMS FOR SPECIFIC GPTS

The source of some GPTs visualized with the Fishbone diagram is represented as follows.

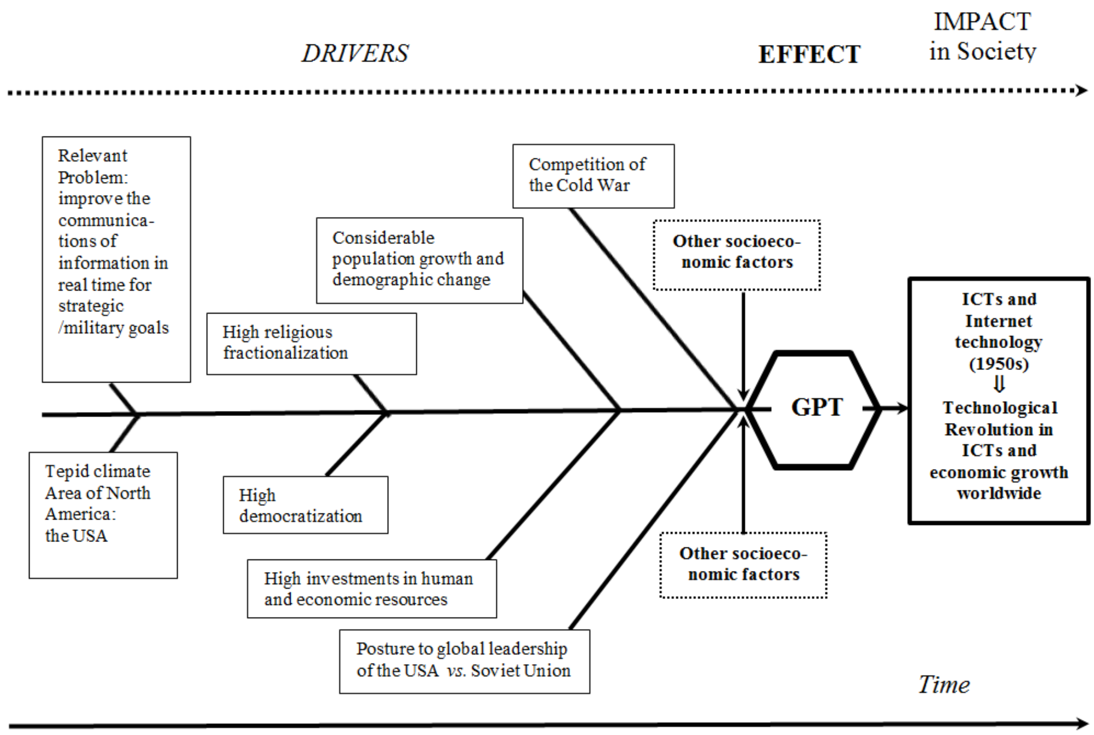
- ☐ The case of the GPT of the Steam Engine in England

Figure 3. Fishbone diagram for visual representation of determinants of the steam engine from 1700s



☐ The source of the GPT of Information and Communications Technologies (ICTs) in the U.S. A.

Figure 4. Fishbone diagram for graphical representation of the source of ICTs from 1950s



7 CONCLUDING OBSERVATIONS

History of technology shows that GPTs create basic elements and strategic platforms for several products/processes in different industries (cf. Singer et al., 1956). In general, GPTs are driven by manifold factors and it is important a simple visual representation for systematizing and analysing their source over time. What can be learned from fishbone diagram designed here to represent and explore the determinants of GPTs?

A main finding of this study is that the fishbone diagram offers an appropriate visual representation of complex drivers of GPTs for technological analysis. In short, this technique shows clearly and simply the sequential determinants of the source of GPTs over time and space.

In particular, results of this study are:

(1) The conceptual framework here shows a visual representation of complex and inter-related factors driving GPTs with a cause-effect approach over the long run;

(2) The visual representation here is able to identify similar drivers for several GPTs to detect regularity of general source over time and space;

(3) The visual representation here is able to explain how and why GPTs thrive in specific geo-economic areas and time period.

The theoretical framework of this study satisfies main concepts of the philosophy of science, such as *consilience, simplicity and analogy* (Thagard, 1988, Chp. 5). In particular,

- This graphical representation seems to be consilient, since it shows similar sources for dif-ferent GPTs in the history of technology.
- The simple elements of the study here are well known in economic and managerial literature. The idea that GPTs is associated to different factors is not new, however, the idea

that a fishbone diagram can provide an appropriate visual representation of sequential and inter-related drivers of GPTs has not been used in current literature to display and explore the complex source of major innovations.

- The characteristic of *analogy* of results here is well-established by using the Fishbone dia-gram for representing and explaining the source of different major technologies at micro- and macro-level of analysis (*e.g.*, at firm and country level). In short, the fishbone diagram seems to be a general technique for visual representation and technological analyses of sources of GPTs and other new technologies over time and space.

While economic literature has made considerable progress explaining the sources of innovations across firms, many pressing issues remain at national level. Some of the most important questions that the scholars in economics of new technology should address going forward are:

Do such technologies only originate from powerful, major nations?

How does the theory account for these?

How GPTs support the economic growth?

This study endeavours to provide a starting point to these vital questions that can form the ground work to be further developed in several interesting directions.

In response to the first question, it seems that global leadership of powerful society tends to generate high technological performances and, in specific circumstances, revolutionary innovations (Coccia, 2015, 2017). New General Purpose Technologies tend to be originated by strategic investments of powerful nations for solving overriding problems, in the presence of effective/potential environmental threats, to achieve/sustain the global leadership (cf. Basalla, 1988, p. 23ff). Afterwards, GPTs in stable environment have a long-run diffusion on wide geo-economic systems (Coccia, 2015, 2017).

In short, the main driver of GPTs is de facto the goal to achieve/sustain the powerful, major nations, rather than effective/potential conflicts per se. In other words, the international con-flict is not the cause of GPTs but one context in which country-leading systems engender GPTs to cope with environmental threats and/or to take advantage of important opportunities. However, many important technologies result from the convergence of developments from a wide range of sources and nations such as during WWII.

With respect to the second question how the theory account for this convergence of efforts for developing major technologies, International Theories of Cooperation among nations is an appropriate theoretical framework to explain the cooperation of nations to cope with environmental threats, such as during conflicts, and support new technology for achieving a competitive advantage (cf., Grieco, 1990; Milner, 1992). In fact, the role of cooperation across systems is also important for developing big science and technologies during peacetime be-cause of the huge costs of some new technologies. Main examples in this context of interna-tional cooperation focused to develop new science and technologies are the space exploration, ITER (International Thermonuclear Experimental Reactor), etc. (cf. Ruttan, 2006).

The third question how GPTs support the economic growth can be explained with three different perspectives. The 'demand pull' tradition, initially associated with the work of Griliches and Schmookler, emphasized the importance of change in market demand on the supply of knowledge and technology. A second growth theory version emerged from debates in the ear-ly I960s about the reason for the apparent stability in factor shares in the presence of rapidly rising wage rates. A third, microeconomic model was built directly on an early observation by Hicks. 'A change in the relative prices of factors of production is itself a spur to innovation and to inventions of a particular kind - directed at economising the use of a factor which has become relatively expensive’ (as quoted by Ruttan, 1997, p. 1520-21; cf., Ruttan, 2001). Agh-ion et al. (2015, p. 572ff) demonstrate how Schumpeterian growth theory generates predic-tions that make use of the fact that innovations involve creative destruction (i.e., with current innovators driving out previous technologies). Schumpeterian growth theory can also explain the relationship between growth and product market competition. This framework can be used to link growth with firm dynamics, thereby generating predictions on the dynamic patterns of markets and firms (e.g., entry, exit, reallocation) and on the ways in which these patterns shape the overall growth process. Schumpeterian growth theory can reconcile growth with development. Firstly, it shows how institutional development shapes the relationship among firm size distribution, reallocation, and growth. Secondly, it brings out the notion of appropri-ate growth institutions and policies, that is, the idea that what drives growth in a sector or country far below the world technology frontier is not necessarily what drives growth in a sector or country at the technological frontier, at which creative destruction plays a more im-portant role.

The findings of the study here in this context show that some determinants of new technology can be contest-dependent, whereas other ones can be invariant factors for the origin of GPTs over time and space. Future research on these topics should (1) focus on and represent additional and intervening factors affecting the source of GPTs; (2) measure the evolution of GPTs and derived technological trajectories by using phylogenetic approaches and (3) measure and analyse how GPTs pervade multiple sectors of the economy by metrics of generality.

Overall, then, the study here seems to establish a general comprehensive theoretical framework (the fishbone diagram) for an appropriate graphical representation and technological analysis of the complex drivers of major innovations (e.g., GPTs) over the long run. However, we know that other things are often not equal over time and place in the history of technology. In fact, Wright (1997, p. 1562) properly claims that: "In the world of technological change, bounded rationality is the rule". Hence, more fine-grained studies will be useful in future to improve this approach for explaining complex predictors of emerging GPTs.

8 References

Acemoglu D., Johnson S., Robinson J.A., Yared P., 2008. "Income and Democracy", *American Economic Review*, vol. 98, n. 3 pp. 808-842.

Aghion P., Akcigit U., Howitt P., 2015. "The Schumpeterian Growth Paradigm", *Annual Review of Economics*, n. 7, pp. 557-575, doi: 10.1146/annurev-economics-080614-115412.

Atuahene-Gima K., Wei Y., 2011. "The Vital Role of Problem-Solving Competence in New Product Success", *Journal of Product Innovation Management*, vol. 28, n. 1, pp. 81-98.

Audretsch D. B., Feldman M. P., 1996. "R&D Spillovers and the Geography of Innovation and Production", *The American Economic Review*, vol. 86, n. 3, pp. 630-640.

Ayverdia L., Nakiboğlub C., Serap Ö. Z. Aydin, 2014. "Usage of Graphic Organizers in Science and Technology Lessons", *Procedia - Social and Behavioral Sciences*, vol. 116, 21 February, pp. 4264–4269, 5th World Conference on Educational Sciences.

Barro R. J., 1999. "Determinants of democracy", *Journal of Political Economy*, vol. 107, n. 6, pp. 158-183.

Barro R. J., McCleary R., 2003. "Religion and Economic Growth across Countries", *American Sociological Review*, vol. 68, n. 5, pp. 760-781.

Barro R. J., McCleary R., 2005. "Which Countries have State Religions", *Quarterly Journal of Economics*, vol. 120, n. 4, pp. 1331-1370.

Basalla G., 1988. The History of Technology, Cambridge, Cambridge University Press.

Bettencourt L. M. A, Lobo J., Helbing D., Kühnert C. and West G.B, 2007. "Growth, innovation, scaling, and the pace of life in cities", *PNAS*, vol. 104, n. 17, pp. 7301-7306.

Bettendorf L., Dijkgraaf E., 2010. "Religion and income: Heterogeneity between countries", *Journal of Economic Behavior & Organization*, vol. 74, n. 1-2, pp. 12-29.

Boserup E., 1981. Population and Technological change: A study of long-term trends, Chicago, University of Chicago Press.

Bresnahan T., 2010. "General Purpose Technologies" in Hall B.H., Rosenberg N. (Eds.) *Handbook of the Economics of Innovation*, Ch. 18, vol. 2, Elsevier.

Bresnahan T.F., Trajtenberg M., 1995. "General purpose technologies: 'engines of growth'?", *Journal of Econometrics, Annals of Econometrics*, vol. 65, n. 1, pp. 83-108.

Buyukdamgaci G., 2003. "Process of organizational problem definition: how to evaluate and how to improve", *Omega*, vol. 31, n. 4, pp. 327-338.

Calabrese G., Coccia M., Rolfo S., 2005. “Strategy and market management of new product development: evidence from Italian SMEs”, *International Journal of Product Development*, vol. 2, n. 1-2, pp. 170-189.

Calvano E., 2007. “Destructive Creation“, *Working Paper Series in Economics and Finance*, n. 653, December, Stockholm School of Economics.

Cariola M., Coccia M., 2004. “Technology transfer virtual network: analysis within the National System of Innovation”, *International Journal of Networking and Virtual organisation*, vol. 2, n. 2, pp. 162-172.

Cavallo E., Ferrari E., Bollani L., Coccia M., 2014. “Attitudes and behaviour of adopters of technological innovations in agricultural tractors: A case study in Italian agricultural system”, *Agricultural Systems*, vol. 130, pp. 44-54.

Cavallo E., Ferrari E., Bollani L., Coccia M., 2014a. “Strategic management implications for the adoption of technological innovations in agricultural tractor: the role of scale factors and environmental attitude”, *Technology Analysis & Strategic Management*, vol. 26, n. 7, pp. 765-779.

Cavallo E., Ferrari E., Coccia M., 2015. “Likely technological trajectories in agricultural tractors by analysing innovative attitudes of farmers”, *International Journal of Technology, Policy and Management*, vol. 15, n. 2, pp. 158-177.

Coccia M., 2001. “Satisfaction, work involvement and R&D performance”, *International Journal of Human Resources Development and Management*, vol. 1, n. 2/3/4, pp. 268-282.

Coccia M., 2004. “Spatial metrics of the technological transfer: analysis and strategic management”, *Technology Analysis & Strategic Management*, vol. 16, n. 1, pp. 31-51.

Coccia M., 2005. “Measuring intensity of technological change: the seismic approach”, *Technological Forecasting and Social Change*, vol. 72, n. 2, pp.117-144.

Coccia M., 2005a. “Technometrics: Origins, historical evolution and new direction”, *Technological Forecasting & Social Change*, vol. 72, n. 8, pp. 944-979.

Coccia M., 2005b. “Countrymetrics: valutazione della performance economica e tecnologica dei paesi e posizionamento dell’Italia”, *Rivista Internazionale di Scienze Sociali*, vol. 113, n. 3, pp. 377-412.

Coccia M., 2005c. “Economics of scientific research: origins, nature and structure”, *Proceedings of Economic Society of Australia*, ISBN: 07340 26080.

Coccia M., 2006. “Classifications of innovations: survey and future directions”, *Working Paper Ceris*, vol. 8, n. 2, pp. 1-19.

Coccia M., 2007. “A new taxonomy of country performance and risk based on economic and technological indicators”, *Journal of Applied Economics*, vol. 10, n. 1, pp. 29-42.

Coccia M., 2008. “New organizational behaviour of public research institutions: Lessons learned from Italian case study”, *International Journal of Business Innovation and Research*, vol. 2, n. 4, pp.402-419.

Coccia M., 2008a. “Investimento pubblico e privato in R&S: complementarietà ed interazione con la crescita della produttività”, *Economia e Politica Industriale*, vol. 34, n. 3, pp. 127-154.

Coccia M., 2008b. “Science, funding and economic growth: analysis and science policy implications”, *World Review of Science, Technology and Sustainable Development*, vol. 5, n. 1, pp.1-27.

Coccia M., 2008c. “Spatial mobility of knowledge transfer and absorptive capacity: analysis and measurement of the impact within the geoeconomic space”, *The Journal of Technology Transfer*, vol. 33, n. 1, pp. 105-122.

Coccia M., 2009. “What is the optimal rate of R&D investment to maximize productivity growth?”, *Technological Forecasting & Social Change*, vol. 76, n. 3, pp. 433-446.

Coccia M., 2009a. “Measuring the impact of sustainable technological innovation”, *International Journal of Technology Intelligence and Planning*, vol. 5, n. 3, pp. 276-288.

Coccia M., 2009b. “Bureaucratization in public research institutions”, *Minerva, A Review of Science, Learning and Policy*, vol.47, n. 1, pp. 31-50.

Coccia M., 2009c. "Research performance and bureaucracy within public research labs", *Scientometrics,* vol. 79, n. 1, pp. 93-107.
Coccia M., 2009d. "A new approach for measuring and analyzing patterns of regional economic growth: empirical analysis in Italy", *Italian Journal of Regional Science- Scienze Regionali,* vol. 8, n. 2, pp. 71-95.
Coccia M., 2010. "Democratization is the Driving Force for Technological and Economic Change", *Technological Forecasting & Social Change,* vol. 77, n. 2, pp. 248-264.
Coccia M., 2010a. "The asymmetric path of economic long waves", *Technological Forecasting & Social Change,* vol. 77, n. 5, pp. 730-738.
Coccia M., 2010b. "Energy metrics for driving competitiveness of countries: Energy weakness magnitude, GDP per barrel and barrels per capita", *Energy Policy,* vol. 38, n. 3, pp. 1330-1339.
Coccia M., 2010c. "Foresight of technological determinants and primary energy resources of future economic long waves", *International Journal of Foresight and Innovation Policy,* vol. 6, n. 4, pp.225-232.
Coccia M., 2010d. "Public and private R&D investments as complementary inputs for productivity growth", *International Journal of Technology, Policy and Management,* vol. 10, n. 1/2, pp. 73-91.
Coccia M., 2010e. "Spatial patterns of technology transfer and measurement of its friction in the geo-economic space", *International Journal of Technology Transfer and Commercialisation,* vol. 9, n. 3, pp. 255-267.
Coccia M., 2011. "The interaction between public and private R&D expenditure and national productivity", *Prometheus-Critical Studies in Innovation*, vol. 29, n. 2, pp. 121-130.
Coccia M., 2012. "Political economy of R&D to support the modern competitiveness of nations and determinants of economic optimization and inertia", *Technovation,* vol. 32, n. 6, pp. 370-379.
Coccia M., 2012a. "Driving forces of technological change in medicine: Radical innovations induced by side effects and their impact on society and healthcare", *Technology in Society,* vol. 34, n.4, pp. 271-283.
Coccia M., 2012b. "Evolutionary growth of knowledge in path-breaking targeted therapies for lung cancer: radical innovations and structure of the new technological paradigm", *International Journal of Behavioural and Healthcare Research,* vol. 3, n. 3-4, pp. 273-290.
Coccia M., 2012c. "Evolutionary trajectories of the nanotechnology research across worldwide economic players", *Technology Analysis & Strategic Management*, vol. 24, n. 10, pp. 1029-1050.
Coccia M., 2012d. "Converging genetics, genomics and nanotechnologies for groundbreaking pathways in biomedicine and nanomedicine", *International Journal Healthcare Technology and Management,* vol. 13, n. 4, pp. 184-197.
Coccia M., 2013. "What are the likely interactions among innovation, government debt, and employment?", *Innovation: The European Journal of Social Science Research*, vol. 26, n. 4, pp. 456-471.
Coccia M., 2014. "Socio-cultural origins of the patterns of technological innovation: What is the likely interaction among religious culture, religious plurality and innovation? Towards a theory of socio-cultural drivers of the patterns of technological innovation", *Technology in Society*, vol. 36, n. 1, pp. 13-25.
Coccia M., 2014a. "Driving forces of technological change: The relation between population growth and technological innovation-Analysis of the optimal interaction across countries", *Technological Forecasting & Social Change,* vol. 82, n. 2, pp. 52-65.
Coccia M., 2014b. "Converging scientific fields and new technological paradigms as main drivers of the division of scientific labour in drug discovery process: the effects on strategic management of the R&D corporate change", *Technology Analysis & Strategic Management*, vol. 26, n. 7, pp. 733-749.
Coccia M., 2014c. "Religious culture, democratisation and patterns of technological innovation", *International Journal of sustainable society*, vol. 6, n.4, pp. 397-418.

Coccia M., 2014d. “Path-breaking target therapies for lung cancer and a far-sighted health policy to support clinical and cost effectiveness”. *Health Policy and Technology,* vol. 1, n. 3, pp. 74-82.

Coccia M., 2014e. “Emerging technological trajectories of tissue engineering and the critical directions in cartilage regenerative medicine”. *International Journal Healthcare Technology and Management,* vol. 14, n. 3, pp. 194-208.

Coccia M., 2015. “General sources of general purpose technologies in complex societies: Theory of global leadership-driven innovation, warfare and human development”, *Technology in Society*, vol. 42, August, pp. 199-226.

Coccia M., 2015a. “Patterns of innovative outputs across climate zones: the geography of innovation”, *Prometheus. Critical Studies in Innovation*, vol. 33, n. 2, pp. 165-186.

Coccia M., 2015b. “The Nexus between technological performances of countries and incidence of cancers in society”, *Technology in Society*, vol. 42, August, pp. 61-70.

Coccia M., 2016. “Problem-driven innovations in drug discovery: co-evolution of radical innovation with the evolution of problems”, *Health Policy and Technology*, vol. 5, n. 2, pp. 143-155.

Coccia M., 2016a. “Radical innovations as drivers of breakthroughs: characteristics and properties of the management of technology leading to superior organizational performance in the discovery process of R&D labs”, *Technology Analysis & Strategic Management*, vol. 28, n. 4, pp. 381-395.

Coccia M., 2016b. “Sources of technological innovation: Radical and incremental innovation problem-driven to support competitive advantage of firms”, *Technology Analysis & Strategic Management,* DOI: 10.1080/09537325.2016.1268682.

Coccia M., 2017. “The source and nature of general purpose technologies for supporting next K-waves: Global leadership and the case study of the U.S. Navy's Mobile User Objective System”, *Technological Forecasting and Social Change,* vol. 116, pp. 331-339, DOI: 10.1016/j.techfore.2016.05.019.

Coccia M., Bozeman B., 2016. “Allometric models to measure and analyze the evolution of international research collaboration”, *Scientometrics*, vol. 108, n. 3, pp. 1065-1084.

Coccia M., Cadario E., 2014. “Organisational (un)learning of public research labs in turbulent context”, *International Journal of Innovation and Learning*, vol. 15, n. 2, pp.115-129.

Coccia M., Falavigna G., Manello A., 2015. “The impact of hybrid public and market-oriented financing mechanisms on scientific portfolio and performances of public research labs: a scientometric analysis”, *Scientometrics*, vol. 102, n. 1, pp. 151-168.

Coccia M., Finardi U., Margon D., 2012. “Current trends in nanotechnology research across worldwide geo-economic players”, *The Journal of Technology Transfer*, vol. 37, n. 5, pp. 777-787.

Coccia M., Rolfo S. 2000. “Ricerca pubblica e trasferimento tecnologico: il caso della regione Piemonte” in Rolfo S. (Eds.) Innovazione e piccole imprese in Piemonte, Milano (Italy), Franco Angeli Editore, ISBN: 9788846418784.

Coccia M., Rolfo S., 2002. “Technology transfer analysis in the Italian national research council”, *Technovation - The international journal of technological innovation and entrepreneurship*, vol. 22, n. 5, pp. 291-299.

Coccia M., Rolfo S., 2007. “How research policy changes can affect the organization and productivity of public research institutes”, *Journal of Comparative Policy Analysis, Research and Practice,* vol. 9, n. 3, pp. 215-233.

Coccia M., Rolfo S., 2010. “New entrepreneurial behaviour of public research organizations: opportunities and threats of technological services supply”, *International Journal of Services Technology and Management*, vol. 13, n. 1/2, pp. 134-151.

Coccia M., Wang L., 2015. “Path-breaking directions of nanotechnology-based chemotherapy and molecular cancer therapy”, *Technological Forecasting and Social Change*, vol. 94, May, pp. 155-169.

Coccia M., Wang L., 2016. “Evolution and convergence of the patterns of international scientific collaboration”, *Proceedings of the National Academy of Sciences of the United States of America*, vol. 113, n. 8, pp. 2057-2061.

Colombo M. G., Franzoni C., Veugelers R., 2015. “Going radical: producing and transfering disruptive innovation”, *The Journal of Technology Transfer*, vol. 4, n. 4, pp. 663-669.

Feldman M. P., Kogler D. F., 2010. ‘Stylized Facts in the Geography of Innovation’ in Hall B. and Rosenberg N. (Eds.), Handbook of Economics of Technical Change, 1, pp. 381-410, Elsevier.

Freeman C., Soete L., 1987. Technical change and full employment, Oxford (UK), Basil Blackwell.

Goel R.J., Payne J.E., Ram R., 2008. “R&D expenditures and U.S. economic growth: A disaggregated approach”, *Journal of policy modeling*, vol. 30, n. 2, pp. 237-250.

Goldfarb B., 2005. “Diffusion of general purpose technologies: understanding patterns in the electrification of US Manufacturing 1880-1930”, *Industrial and Corporate Change*, vol. 14, pp. 745-73.

Grieco J., 1990. Cooperation among nations, Ithaca (NY), Cornell University Press.

Griffith R., Redding S., Van Reenen J., 2004. “Mapping the two Faces of R&D: Productivity growth in a Panel of OECD Industries”, *Review of Economics and Statistics*, vol. 86, n. 4, 883-895.

Guiso L., Sapienza P., Zingales L., 2003. “People’s Opium? Religion and Economic Attitudes”, *Journal of Monetary Economics*, vol. 50, n. 1, pp. 225-282.

Guiso L., Sapienza P., Zingales L., 2006. “Does Culture Affect Economic Outcomes?”, *The Journal of Economic Perspectives*, vol. 20, n. 2, pp. 23-48.

Hall B. H., Rosenberg N. (eds.), 2010. Handbook of the Economics of Innovation, vol. 1 and 2, Elsevier.

Helpman E. (ed.), 1998. General Purpose Technologies and Economic Growth, Cambridge (MA) MIT Press.

Howells, J., Bessant, J., 2012. “Innovation and economic geography: a review and analysis”, *Journal of Economic Geography*, vol. 12, n. 5, pp. 929-942.

Hudson R., 2001. Producing Places, New York, Guildford Press.

Ishii K., Lee B., 1996. Reverse fishbone diagram: a tool in aid of design for product retirement, *Proceedings ASME design engineering technical conferences and computers in engineering conference*, 96-DETC/DFM-1272.

Ishikawa, K.. 1990. Introduction to Quality Control, Abingdon (UK), Taylor & Francis.

Jones, C.I., Williams, J.C., 1998. “Measuring the Social Return to R&D”, *The Quarterly Journal of Economics*, 113 (4), 1119-1135.

Jovanovic, B., Rousseau P. L., 2005. “General Purpose Technologies” in Philippe Aghion and Steven N. Durlauf (eds), Handbook of Economic Growth, vol. 1B, Elsevier, Ch. 18.

Kremer M., 1993. “Population growth and technological change: one million B.C. to 1990”, *Quarterly Journal of Economics*, vol. 108, n. 3, pp. 681-716.

Krugman, P., 1991. Geography and Trade, Cambridge, MIT Press.

Kuznets S., 1960. “Population Change and Aggregate Output”, in Demographic and Economic Change in Developed Countries, Special conference series n. 11 Universities-National Bureau for Economic Research (Princeton University Press: Princeton), pp. 324-340. Reprinted in Economic Growth and Structure: Selected Essays. New York. W.W. Norton & Co., 1965.

Lichtenberg, R. M., 1960. One-tenth of a Nation: National Fortes in the Economic Growth of the New York Region, Cambridge (MA), Harvard University Press.

Lipsey R. G., Bekar C. T., Carlaw K. I., 1998. “What requires explanation?” in Helpman E. (ed.), General Purpose Technologies and long-term economic growth, Cambridge (MA), MIT Press, pp. 15-54.

Lipsey R. G., Carlaw K. I., Bekar C. T., 2005. Economic Transformations: General Purpose Technologies and Long Term Economic Growth, Oxford, Oxford University Press, pp. 131-218.

Mamuneas, T.P., Nadiri, M.I., 1996. “Public R&D policies and cost behavior of the US manufacturing industries”, *Journal of public policy* 63 (1), 57-81.
Maridal J. H., 2013. “Cultural impact on national economic growth“, *The Journal of Socio-Economics*, vol. 47, pp. 136-146.
Milner H., 1992. “International Theories of Cooperation Among Nations: Strengths and Weaknesses”, *World politics*, vol. 44, n. 3, pp. 466-496.
Modelski G., Perry G. III (2002) “Democratization in long perspective revisited”, *Technological Forecasting and Social Change*, vol. 69, n. 4 pp. 359-376.
Montesquieu, C., 1947. The Spirit of Laws, New York, Harper and Row.
Moseley, W. G., Perramond E., Hapke, H. M., Loris, P., 2014. An introduction to human-environment geography, Wiley-Blackwell.
Norris, P., 2008. Driving Democracy: do power-sharing regimes work?, Cambridge (UK), Cambridge University Press.
Peirce W. S., 1974. “The ripple effects of technological innovation: The case of iron ore pelletizing”, *Omega*, vol. 2, n. 1, pp. 43-51.
Ramakrishna H. V., Brightman H. J., 1986. “The fact-net model: a problem diagnosis procedure”, *Interfaces*, vol. 16, n. 6, pp. 86-94.
Ristuccia C. A., Solomou S., 2014. “Can general purpose technology theory explain economic growth? Electrical power as a case study”, *European Review of Economic History*, vol. 18, n. 3, pp. 227-247.
Robinson D. K. R., Ruivenkamp M., Rip A., 2007. “Tracking the evolution of new and emerging S&T via statement-linkages: Vision assessment in molecular machines”, *Scientometrics*, vol. 70, n. 3, pp. 831-858.
Rolfo S., Coccia M., 2005. “L’interazione tra ricerca pubblica e industria in Italia”, *l’Industria Rivista di Economia e Politica Industriale*, vol. 26, n. 4, pp. 657-674.
Rosegger G.,1980. The economics of production and innovation, New York, Pergamon Press.
Rosenberg N., 1982. Inside the black box: technology and economics, Cambridge University Press.
Rosenberg Norman J., 1992. ‘Adaptation of agriculture to climate change’, *Climatic Change*, 21, pp. 385-405.
Ruttan V. W., 1997. “Induced innovation, evolutionary theory and path dependence: sources of technical change”, *The Economic Journal*, vol. 107, September, pp. 1520-1529.
Ruttan V. W., 2001. Technology, Growth and Development, an induced innovation perspective, New York and Oxford, Oxford University Press.
Ruttan V. W. (2006) Is War Necessary for Economic Growth? Military Procurement and Technology Development, New York and Oxford, Oxford University Press.
Sahal D. (1981) *Patterns of Technological Innovation*, Addison-Wesley Publishing Company, Inc., Reading, Massachusetts.
Schultz L. I., Joutz F. L., 2010. “Methods for identifying emerging General Purpose Technologies: a case study of nanotechnologies”, *Scientometrics*, vol. 85, n. 1, pp. 155-170.
Simon J. L., 1977. The Economics of Population Growth, Princeton, Princeton University Press.
Singer C., Holmyard E. J., Hall A. R., Williams T. I., 1956. A History of Technology, vol. I and II, Oxford, Clarendon Press.
Smithers J. and Blay-Palmer A., 2001. “Technology innovation as a strategy for climate adaptation in agriculture”, *Applied Geography*, vol. 21, pp. 175-197.
Spolaore E., Wacziarg R., 2013. “How Deep Are the Roots of Economic Development?” *Journal of Economic Literature*, vol. 51, n.2, pp. 1-45.
Strulik H., 2005. “The role of human capital and population growth in R&D-based models of economic growth”, *Review of International Economics*, vol. 13, n. 1, pp. 129-145.
Thagard P., 1988. Computational Philosophy of Science, Cambridge (MA), The MIT Press.
Usher A. P., 1954. A history of mechanical inventions, Cambridge, Harvard University Press.
Weber M., 1956. The Protestant Ethnic and the Spirit of Capitalism, London, Unwin.
Wright G., 1997. “Towards A More Historical Approach to Technological Change”, *The Economic Journal*, vol. 107, September, pp. 1560-1566.

Wright I., 2005. “The social architecture of capitalism”, *Physica A*, vol. 346, pp. 589-620.
Zachariadis, M., 2004. “R&D-induced Growth in the OECD?”, *Review of Development Economics*, vol. 8, n. 3, pp. 423-439.