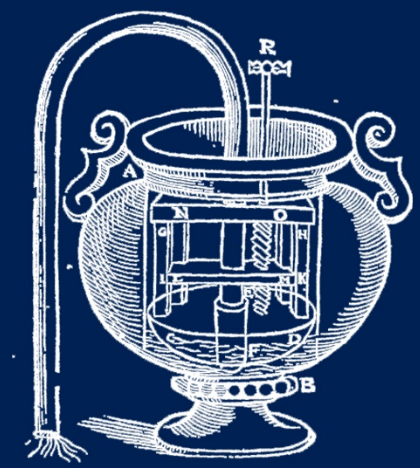
CNR-IRCrES Working Paper

On Search of a General Model of Technology Innovation



4/2021

Angelo Bonomi

Consiglio Nazionale delle Ricerche

ISSN (online) 2421-7158

Direttore Emanuela Reale

Direzione CNR-IRCrES
Istituto di Ricerca sulla Crescita Economica Sostenibile
Via Real Collegio 30, 10024 Moncalieri (Torino), Italy
Tel. +39 011 6824911 / Fax +39 011 6824966
segreteria@ircres.cnr.it
www.ircres.cnr.it

Sede di Roma Via dei Taurini 19, 00185 Roma, Italy
Tel. +39 06 49937809 / Fax +39 06 49937808

Sede di Milano Via Corti 12, 20121 Milano, Italy
Tel. +39 02 23699501 / Fax +39 02 23699530

Sede di Genova Corso Ferdinando Maria Perrone 24, 16152-Genova, Italy
Tel. +39 010 6598798

redazione@ircres.cnr.it
www.ircres.cnr.it/index.php/it/produzione-scientifica/pubblicazioni

CNR-IRCrES Working Paper 4/2021

On Search of a General Model of Technology Innovation

ANGELO BONOMI

CNR-IRCrES, Consiglio Nazionale delle Ricerche, Istituto di Ricerca sulla Crescita Economica Sostenibile, Italy

corresponding author: abonomi@bluewin.ch

ABSTRACT
This work has the objective to present a general model of technology innovation considering technology as a separated discipline from scientific research and economy. That is justified by the fact that many technologies have been developed without economic purposes but after generating technologies with a great economic importance, and that there are limits to the study of fundamentals of technology only from an economic point of view. The study defines some principles that are at the base of technology and of its innovation. These principles lead to a model considering technology as a time-oriented structure of technological operations, and allowing the definition of concepts such as technological space, technological landscape and space of technologies. From this model it is possible to explain various technological processes including the nature of knowhow and the transfer of technology. The model then defines three organizational structures for innovation concerning the industrial R&D project, the startup-venture capital and the industrial platform systems, and then the stages of the innovation process. It follows the development of a model of technology innovation of a territory, based on loops of fluxes of knowledge and capitals, and in which these three organizational structures are in action. Applications of the general model of technology innovation concern the relation between science and technology, the technological competitivity, the relation between R&D investments and growth, new possible statistical studies, the relation between technology and the environment and the importance of intermediate scientific and technical education. The work terminates giving a perspective of evolution of the organizational structures for innovation toward a system of industrial platforms network.

KEYWORDS: technology, technology innovation, model of technology, R&D, startup, venture capital, industrial platforms.

JEL CODES: D83, E17, M15, O31, O32, O33

DOI: 10.23760/2421-7158.2021.004

HOW TO CITE THIS ARTICLE
Bonomi, A. (2021). *On Search of a General Model of Technology Innovation* (CNR-IRCrES Working Paper 4/2021). Istituto di Ricerca sulla Crescita Economica Sostenibile. Disponibile da http://dx.doi.org/10.23760/2421-7158.2021.004

INDICE

1. Introduction

This study would try to answer to the question whether technology may be considered a discipline separated from economy and science owing its own principles, processes and structures in a similar way as biology is separated from chemistry and physics. In this case it is justified the search of a general model interpreting technology innovation and able to explain this activity independently from scientific research, economic factors or purposes. Actually, the process generating genuine, original technology innovations is not well understood, despite of the vast literature existing about the effects of technology on economy or how economy influence the technological change. In fact, it exists a gap between the study of technology from an economic point of view and studies concerning the development of specific technologies, intended as use of scientific results for this purpose. This gap may be covered by the study of technology as a separated discipline seen from a general and not only from an economical point of view. In fact, it may be easily shown in the evolution of technology the existence of many technologies that have been developed for other than economic purposes but triggering after technologies with a great economic importance. We may ask then whether the huge amount of literature, concerning the relation of technology and economy, is in measure to explain the real fundamental aspects of technology, valid for any purpose, and not necessarily only for economic purposes. Furthermore, we may ask whether the theoretical constructions, built from an economic point of view, are valid also in the contest of all the empirical increased knowledge in industry and across the countries (Di Maio, 2003). All that justify the search of a general model of technology innovation starting from studies on technology dynamics describing technological processes and organizational structures for innovation largely independent by economic factors (Bonomi, 2020). Studies that are based also on a direct experience of technology innovation, not biased by the huge literature on technology innovation seen only from an economic point of view. This fact is important considering that the knowledge of fundamentals of technology assumes today a great interest because of the present importance of technology to fulfill environmental and not only economic purposes.

In the search of a general model for technology innovation (GTI) it is essential to start with a suitable definition of what is technology. In fact, this term is object of different definitions that may be found in encyclopedias, books or articles. For a GTI it is necessary to choose a definition, valid for any purpose of the technology, not necessarily linked to the social or economic aspects of its impacts. Furthermore, it is necessary to give a definition of technology in such a way that it is assured its neutrality, considering its nature independent of the various types of purposes for its use. It is then useful to give also a general operative definition of innovation that explains the formation of the new technologies. For the search of a GTI it is also necessary to have a suitable general model of technology able to explain the various technological processes that are observed in technological activities (Bonomi, 2020). In order to satisfy the previously cited characteristics, it is useful to consider technology as a physical phenomenon, describable from a scientific point of view, and producing exploitable effects for the various purposes. This approach leads of course to consider technology as an enormous set of various specific technologies, each characterized by an enormous set of various physical, chemical and biological phenomena constituting what it may be defined a technological ecosystem. The study of a such complex system may be made by using concepts and models of transdisciplinary nature derived from the science of complexity. In this way it is possible to generalize the various sets of physical, chemical and biological phenomena composing a technology in term of technological operations, these operations constituting in fact the bricks of a general model of technology (Auerswald et al., 2000). The use of technological operations in the description of a technology implies to consider technology as a process, and not as an artefact composed by various components, this last approach in fact cannot represent all the possible technologies for its production. On the base of the previous considerations it is possible to define a certain number of principles that are at the base of the GTI and that will be presented in the section dedicated to its basic aspects.

After this introduction in a second section we discuss the importance of technologies without economic purposes, and in a third section the limits to the study of technology only from an economic point of view. In a fourth section we present the principles of a general model for technology innovation, and in a fifth section the general model of technology used in this study. In a sixth section we present the technological processes and in the seventh section the organizational structures for innovation. In the eighth section we present the process of technology innovation with its various stages of development. In the ninth section we describe the model of technology innovation of a territory in which all the three organizational structures for innovation are in action. In the tenth section we discuss the lessons that may be hold form the general model of technology innovation and after, in the eleventh section, we discuss the perspectives of evolution of the organizational structures for innovation. In the twelfth section are finally presented the conclusions.

2. THE IMPORTANCE OF TECHNOLOGIES WITHOUT ECONOMIC PURPOSES

The history of development of technologies shows many examples of this activity dedicated to purposes other than economic, for example for scientific purposes. That is the case of improvement of telescope by Galileo Galilei for astronomic investigations, and modern science is involved in the development of new technologies for large research equipment such as accelerators of particles in the study of matter or big interferometers for the detection of gravitational waves. However, the most important developments are those for military applications that have been of great importance in the XX century for their implication in the development of derived technologies of great economic importance. That was the case of synthesis of ammonia developed in Germany for the production of explosives during the 1st World War, because of unavailability of Chilean guano containing the necessary nitrates. Actually, nitrates are also natural fertilizers and, after the war, there was a great development of this industrial production destined to the agriculture. Another important example of technology developed for military purposes. finding after important economic applications, was the making, during the 2nd World War, of the atomic bomb with the Manhattan Project (Rhodes, 1986). Such project in fact developed a great number of technologies used after for civil applications, the most important being the nuclear production of energy. Probably the most important case of technologies developed for military purposes, finding after an enormous development with great economic and social implications, was the miniaturization of electronic circuits developed during the Cold and Korea Wars for military devices. In fact, this development was not of interest of industry at that time, considering these technologies having high costs and negligible markets (Giarini & Loubergé, 1978). It was Steve Jobs the first to understand the enormous potential of personal computers made by using miniaturized circuits, easy to use by normal people, and not only by professionals, opening enormous markets and further technology developments (Isaacson, 2011). Furthermore, it shall be considered that it is also well known that modern networking technologies, backbone of internet, emerged in early 70' from the US Department of Defense agencies ARPA and DARP (Feldman & Francis, 2002). We may consider that, without these early military technology developments, probably most of the present information and communication technologies (ICT) would not be available or much less developed. All these examples show well how the technological change cannot be exclusively ascribed to economic activities, and that technology activity has its own characteristics not necessarily only dependent on economic factors.

3. THE LIMITS OF STUDIES OF TECHNOLOGY FROM AN ECONOMIC POINT OF VIEW

The study of technology from an economic point of view is covered by a huge literature including also reviews of the various theories developed in order to explain how economy influence the technological change. For this purpose, we have chosen, for a discussion about the limits of economy in studying technology, a synthetic review describing these theories and their capacity to account for technological and institutional co-evolution and change (Di Maio, 2003). This author, discussing further research on technological change, converges, in a certain measure, to the approach used in the study of technology dynamics (Bonomi, 2020). In fact, this author considers that most of the actual progress done on technological change concerns the findings of the empirical studies within and across industries and countries. The main issue ahead should now be the filling of the gap between such empirical increased knowledge and the theoretical constructions. In this respect, the understanding of the whole process, and in particular of the sources of technological change, is hindered by the received theoretical framework. Indeed, theoretical constructions should, at least, not to be in open conflict with the empirical regularities. In fact, it may be observed that empirical knowledge has created a gap with theoretical constructions. About the work that should be done to clarify the source of the process of technological change, the author of the survey suggests that the complex interaction between economic social and institutional elements, that characterizes such a process, could be modelled and rigorously understood by using a complex approach and the help of simulation, for examples by application of a methodology based on modelling technology (Auerswald et al., 2000) and search in technological landscapes (Lobo & Macready,1999). These studies, cited by the author, are in fact at the base of the descriptions of technology and technology innovation processes in technology dynamics (Bonomi, 2020). Concluding, the limits of the study of technological change, from an economic point of view, may be ascribed also to the fact that technological change or technology innovation in economic studies are based on a concept of technology not clearly defined, carrying out a whole range of meanings not necessarily coherent. In fact, following Brian Arthur thought about the nature of technology (Arthur, 2009), there is no agreement on what the word “technology” means, no overall theory on how technology comes into being, no deep understanding of what “innovation” consists of, and no theory of evolution of technology. In technology dynamics there is, in the elaboration of a GTI, the advantage consisting in a clear definition of technology, based on a scientific point of view, as a set of physical. chemical and biological phenomena producing an effect exploitable for human purposes. That makes possible also the separation of the basic physical nature of technology from the purposes of its use, and the development of a rigorous coherent general model of technology, using concepts of the science of complexity, that may have a mathematical description, and that are useful to explain technological processes and the activity of the organizational structures for innovation (Bonomi, 2020).

4. THE PRINCIPLES FOR A GENERAL MODEL OF TECHNOLOGY INNOVATION

Following the previous discussion on exigences necessary to develop a GTI it is possible to define three principles that can be at the base of a GTI as follows:

1. *Technology is an activity fulfilling a human purpose*

This definition of technology has been advanced by Brian Arthur (2009) and it is fundamental in the description of technology and technology innovation.

2. *Technology may be considered composed by a set of phenomena of physical, chemical and biological nature producing an effect exploitable for the fulfilling of various purposes*

This further definition of technology, seen from a scientific point of view as a physical phenomenon, has been derived from studies in technology dynamics, in order to show the neutrality of technology, separating the purposes from the phenomenal aspects of its activity, and opening the study of the basic aspects of technology valid for any purpose of its use. (Bonomi, 2020).

3. *New technologies are formed by new combinations of previous technologies exploiting or not exploiting new phenomena discovered by science*

This description of the formation of new technologies by combinations and exploiting new discovered phenomena has been also advanced by Brian Arthur (2009) and completed in technology dynamics because of the existence of new technologies based only on combination of previous technologies without a direct exploiting of new or never used phenomena discovered by science (Bonomi, 2020).

Considering these three principles, it is possible the definition of a general model of technology and of technology innovation, the description of some fundamental characteristics of the technology and of the innovation process as follows:

Technology may be described in form of a model based on a time-oriented structure of technological operations

This definition is at the base of a general model of technology and it takes origin from a previous model of technology innovation (Auerswald et al., 2000), while its time-oriented structure takes origin from studies on technology dynamics (Bonomi, 2020).

Technology innovation may be seen as a change of a defined technology structure

This general definition of technology innovation is derived from the model of technology and it is fundamental in the elaboration of a model of a GTI (Bonomi, 2020).

Technological operations have the nature of a technology and may be considered also a set of physical, chemical and biological phenomena contributing to the formation of a technology

This definition of technological operation is derived from the model of technology (Auerswald et al., 2000) in accord with technology dynamics studies (Bonomi, 2020).

As operations of a technology have also a technological nature, a technology may be described with a gross or fine structure depending on the detail with which are represented the operations

The possibility to describe a technology at various levels of detail derives from the previous definition of technological operations.

The use of a technology requires a knowledge, called knowhow, that is not transferable completely in a spoken or written form

Knowhow represents an indispensable knowledge for the use and the transfer of a technology accompanying the process of technology innovation. Its nature may be described by the model of technology (Bonomi, 2020).

Any technology is characterized by a degree of radicality that measures its difference with another technology pursuing the same purpose

The degree of radicality is a fundamental characteristic of a technology and of its innovation. It may influence the competitivity of a technology and its impact in the socio-economic system. It may be measured through the model of technology and it is a quantitative substitution of the used terms of incremental or radical technology (Bonomi, 2020).

The technology innovation activity may be considered composed by technological processes, explained by the general model of technology, and organizational structures, based on fluxes of knowledge and capitals, in which are made the technological innovations

This view of the activity of technology in term of technological processes and organizational structures for innovation is also the results of studies on technology dynamics (Bonomi, 2020).

Following the definitions and the characteristics of technology described previously, it shall be noted that the presented physical model of technology and technology innovation, does not enter in discussion on the complex relations between technology and economy, in particular it does not enter in considerations about the amount of available investments, and in financing or not financing a technology innovation. Neither it enters in discussion about the economical impact of new technologies, nor how new technologies influence economy, but it is limited to consider that new technologies may have different economic impacts, and that a high degree of radicality of a new technology entering in use may be normally associated to a high economic return. Nevertheless, the knowledge of the fundamental aspects of technology, that are independent of economic factors, may be useful in technology management and establishment of policies for technological innovation. This knowledge may be also useful for the development of new methods and strategies necessary to conserve the efficiency of innovation activities faced to future expected radical changes of technological activities.

5. THE MODEL OF TECHNOLOGY

The model of technology used for the GTI considers a technology as a set of operations each characterized by a set of parameters that may assume various discrete values or choices within a determined range (Auerswald et al., 2000). This set assumes the form of a time-oriented structure representable as a graph (Bonomi, 2020). An example of such structure is given in Fig. 1. representing a technology of heat treatment. Another example is the production of faucets that it is represented simplified in Fig. 2. As operations have themselves the nature of a technology, an operation may be described as a set of sub-operations as in the case of the chroming operation reported in Fig. 2. This model of technology, through its mathematical description, defines further concepts such as the technological space, the technological landscape and the space of technologies (Bonomi, 2020).

5.1. Technological space

Considering a technology with its parameters and respective values or choices, it is possible to obtain, by a combinatory calculation, all the possible configurations or recipes that characterize a technology. These recipes may be represented by points in a discrete multidimensional space called technological space (Auerswald et al., 2000). The Hamming distance between two points in this space represents a measure of the difference between two recipes of the technology.

5.2. Technological landscape

Associating a scalar value of efficiency to each recipe represented in a technological space, we transform this space in what it is called a technological landscape of a technology (Auerswald et al., 2000). The form of the technological landscape depends on the nature of the considered efficiency (energetic, environmental, economic, etc.) depending then on the purpose of use of the technology. The search of an optimal recipe for the use of a technology may be seen as an exploration of its technological landscape looking for a "peak" of efficiency. Such landscape has been the object of further studies concerning the optimal conditions of efficiency (Kauffman, Lobo & Macready, 2000), in term of adaptive explorative walk (Lobo & Macready, 1999), in a study on recombinant search in the invention process (Fleming & Sorenson, 2001) and in technological search in landscapes mapped by scientific knowledge (Fleming & Sorenson, 2004).

5.3. Space of technologies

The technological space is useful to describe a single technology, however, when discussing of competition or evolution of various technologies, it may be useful to have a space representing all technologies satisfying the same purpose. The structure of a technology may be represented by a graph that may be described as a matrix, and it is then possible to represent all technologies as points corresponding to the different matrices in a discrete multidimensional space called space of technologies (Bonomi & Marchisio, 2016). The Hamming distance between two points in the space of technologies represents the difference or the degree of radicality of a new technology in respect to a preexistent technology. Innovations may be considered radical if the Hamming distance between the two technologies is great, or incremental if it is small. In this way the space of technology defined by the model offers a special view of what it has been defined as natural trajectories of technical progress (Nelson & Winter, 1977) in the frame of technological paradigms (Dosi, 1982).

6. THE TECHNOLOGICAL PROCESSES

Following the previous definitions, the technology innovation activity may be considered composed by a certain number of technological processes that may be explained by the general model of technology. These processes are a characteristic of a single technology or by a set of technologies pursuing the same purpose and are detailed as follows.

6.1. Externality effect

This important effect occurring during the use of a technology is the result of externalities such as: changes of raw materials, variation of costs, new regulations to be complied, etc. These externalities may modify the technological landscape reducing possibly the efficiency of the used recipe (Auerswald et al., 2000). It is then necessary to search a new optimal recipe exploring the new landscape through an activity of learning by doing (LbyD), or even to change the structure of the technology realizing an innovation normally of incremental type with a low degree of radicality.

6.2. Intranality effect

The intranality effect consists in the fact that changing the conditions of an operation in order to improve its efficiency, that may influence the efficiency of other operations of the technology (Auerswald et al., 2000). Consequently, the optimization of the entire technology shall be obtained by a process of tuning, changing the various parameter values or choices of the operations of a technology. The intranality effect exists also in the change of an operation in the structure of a technology that may influence the efficiency of other operations of the structure. In this case the operative conditions of other operations of the structure shall be changed in order to introduce modifications of the structure of the technology necessary for an efficient use of the innovation (Bonomi, 2020). The intranality effect has been observed for example in the Italian industrial district of production of ceramic tiles in which a new product or process developed by a firm, necessitating complementary innovations in subcontracting firms, would be adoptable only if it generates an important demand for the subcontracting firms that should introduce the complementary innovations (Russo, 2003).

6.3. Ramification of technologies

This important technological process occurs when a new technology with an important radical degree appears in the space of technologies and triggers the formation of other technologies that represent improvements, diversifications or alternatives to the initial radical technology (Bonomi, 2020). Technology ramification is characterized normally by a decrease with time of the radical degree of the formed technologies and by an increase of their number. An indirect demonstration of existence of technology ramification may be found by studying the formation of patents from an initial patent of a radical innovation. That is the case for example of the topological evolution of patents from an initial patent covering computerized tomography from 1975 to 2005 (Valverde et al., 2006).

6.4. Spandrel effect

This effect explains the formation of new radical technologies, in the space of technologies, and their further ramification impacting in this way the evolution of technologies. That is due to the existence of an outer or spandrel space, in respect to the space of technologies occupied by the ramification, and available for the generation of new radical technologies. The spandrel effect has been recognized originally in the biological evolution (Gould, 1996) considering the formation of species, not directly linked to the Darwinian selection, in fact occupying free niches in the space of biological evolution.

6.5. Velocity of innovation

The velocity of innovation depends on many factors including technological factors dues to the possible velocity of the changes of operations during the development of a new structure of a technology. For example, changes of operations of electronic or informatic type in ICT may be physically more rapid than in the case of new chemical or biological technologies with their higher materiality, speeding the development of new technologies. In fact, the rapidity of development of ICT has been observed to make obsolete the chosen technologies during implementation of projects of their applications, and leading to formation of new types of project management to face such problem (Girard & Stark, 2001).

6.6. Technology transfer and knowhow

With the term technology transfer are commonly intended two different technological processes, the first one concerns the bringing in use a new technology after its development, the second one the transfer of a used technology to another location or in more general way the transfer of technology from an expert to a newcomer. These two processes present similarities but also differences and both need a knowledge named knowhow necessary to operate the transferred technology. The knowhow, defined previously as corollary of the principles of the GTI, may be explained by the model of technology (Bonomi, 2020) as follows: a technology is normally influenced by externalities, often with limited effects, that however change the technological landscape. The operator in most cases changes simply the parameters values in order to restore optimal conditions using his knowledge of technological or scientific nature as well accumulated experience. As the effects of externality may be of different types and appear and disappear many times, the necessary changes to maintain optimal conditions of operation for the technology are memorized by the operator and constitute his knowhow of the technology. Such complex knowledge cannot be transferred simply by oral or written instructions but needs imitation and LbyD activity for the operator willing to acquire the knowhow. In the case of transfer of technology by bringing in use a new technology it is necessary to solve further problems of knowhow associated to the scale up of production of pilot plants or of prototypes (Bonomi, 2020).

7. THE ORGANIZATIONAL STRUCTURES FOR TECHNOLOGY INNOVATION

Technology innovation was made in the past centuries essentially only by inventors pursuing a single invention. In the second half of the XIX century technology innovation became organized as continuous activity appeared first about 1870 in the German dye industrial laboratories, and called later research and development (R&D). This system diffused after in USA and Europe since the end of the XIX and the beginning of the XX century (Basalla, 1988). In the second half of the XX century it appeared a second type of organizational structure for innovation called startup-venture capital (SVC) system, and at the beginning of the XXI century another new organizational structure, called industrial platform system, finding a first use in ICT. It shall be noted that all these organizational structures, formed with time, shall not be considered as fully alternative organizations for technology innovations. In fact, in their formation there was also the embedding of activities of the previous organizations. In this way the SVC system may contain R&D projects, and in the industrial platform structure may be present startups and R&D projects activity. It should be noted that these organizational structures are independent from the institutional organizations in which it is made the innovation. For example, an R&D project activity is considered by the GTI the same independently it is carried out in an industrial R&D laboratory, in a university laboratory or in a contract research organization, although it might be some differences in the conditions and efficiency with which it is carried out the R&D activity. In fact, for example, the exploitation of generated R&D knowledge for further R&D projects, is limited in industrial laboratories by the strategies of the firms (Bonomi, 2020). These three types of organizational structures for innovation may be briefly described in term of flows of knowledge and capitals as follows.

7.1. The R&D system

The R&D activity may be considered occurring in a structure making innovations by organizing two fluxes respectively of knowledge and capitals (Bonomi, 2017a), and a model of the R&D process is reported schematically on Fig. 3. It consists in an input of financed projects, partly abandoned and other successful in producing new used technologies. Knowledge generated by both successful or abandoned projects, combined with technical, scientific or other knowledge, generates innovative ideas that may be transformed in R&D project proposals submitted and then selected for financing. New technologies enter in use with availability of industrial capitals and producing returns of investments. Industrial capitals, combined possibly with public funds, make available investments for financing selected R&D projects proposals closing the knowledge and capital cycles. The knowledge generated by the R&D activity by both successful or abandoned projects is for the model the driving force for the generation of innovative ideas for new R&D projects (Bonomi, 2020). A mathematical simulation of the R&D model shows that it is necessary a critical minimum number of R&D projects (i.e. investments), in fact a threshold, to obtain statistically at least one new usable technology and even more for a successful technology generating economic growth (Bonomi, 2017b). Consequently, the economic growth of a territory does not depend actually simply on R&D investments in general, but rather on the intensity of generation of innovative ideas, on the efficiency of exploitation of available knowledge, and on adopted strategies, availability of capitals and a suitable industrial organization (Bonomi, 2020).

7.2. The startup-venture capital system

This system is composed by companies called startups financed by venture capital (VC). Startups differ from R&D projects because they do not make only R&D but also business model developments suitable for the developed technology. Startups have as objective the selling of the developed technology with its business or in collecting capitals to become an industrial company. VC has strategies completely different from those of industrial capital financing R&D projects as it develops technologies for their selling and not for their exploitation, that in an operation called exit (Bonomi, 2019). The SVC system includes a financial cycle, reported in Fig. 4, starting with startup projects proposals to VC, selection of financed startups that in part reach an exit, and in part are abandoned. The return of investment (ROI) to VC obtained by selling startups may be used to refinance new startups. A mathematical simulation of the cycle shows that, if ROI is enough high, covering not only the made investments, there is the formation of an autocatalytic development of financing capabilities for new startups boosting technological and economic growth (Bonomi, 2019). The necessity of a high ROI, in order to close positively the financial cycle of VC, makes this system particularly suitable for the development of radical innovations, potentially able to give high returns, in respect to the R&D industrial system. This last system may be used on the contrary for the development of incremental innovations with lower risks of failure and necessitating a lower ROI to cover the made investments. In fact, the experience shows that a successful VC strategy is based on selection of startups with high ROI potential and excellent experienced teams instead of a selection based on the probability of success of the startup project, and that needs a suitable knowhow in financing and monitoring startups activities (Bonomi, 2020). Finally, it shall be considered that, beside its financial cycle, there is for the SVC system also a knowledge cycle, similar to that of R&D, consisting in knowledge formed in either successful or abandoned startups useful for the creation of new startup projects, but consisting not only of technical but also of business model knowledge. It shall be noted that both knowledge and capital of the SVC system may trigger an autocatalytic growth of innovations when certain critical levels of knowledge and capital availability are overcome.

7.3. The industrial platform system

The industrial platform system realizes a new form of technology development based on continuous relations between offer and demand of new technologies, and it may include R&D projects and startups activities (Bonomi, 2020). In fact, industrial platforms derive from a general platform system largely applied in social and economic activities (Cicero, 2017), and its industrial version is diffusing in the implementation of ICT and enabling technologies for the digitalization of the manufacturing industry (Bonomi, 2018). The basic actors of an industrial platform are: the owners that represent the proprietors assuring the vision of the platform, the partners i.e. companies with a continuous relation with the platforms for various services, the peer producers that may be companies, startups, research laboratories with discontinuous relations with the platforms supplying complementary services, new technologies and R&D projects, the peer consumers i.e. companies or customers interested to buy, in a continuous relation, products or services of the platforms. Externally there are the stakeholders of the platforms making controls and regulations for the platforms and interested possibly to their growth and prosperity. An industrial platform is characterized by a strong exchange of knowledge, in particular between the developers and the users of a new technology, and by monetary transactions among the various actors of the platform in which there are payments for products or services by peer consumers to the platform, and the payments by the platform to partners and peer producers for services, new technologies or for their development. The structure of the platform is reported schematically in Fig. 5.

7.4. A comparison among the various organizational structures

As previously noted the three described organizational structures shall be considered inclusive and not alternative and, for example, R&D activities may be present in the SVC system and startups present in the industrial platform system. In fact, these three types of organizational structures represent an evolution of the technology innovation system following the various ways to exploit knowledge, to finance technology developments in relation with the various degrees of radicality of the innovation. There is in particular a difference between the investment strategies of the industrial financing of R&D and the VC financing of startups. In fact, as we have previously noted, while industrial financing is oriented vs. the use of the developed technology, the VC financing is oriented vs. the selling of the developed technology. Furthermore, while the industrial capital decides the amount of financing of new R&D projects following various factors not necessarily linked to the results of financed technologies, the VC exploits the positive results of its investments to finance further startups generating an autocatalytic increase of availability of further capitals for startups. Following the aspects of these two organizational structures previously discussed, it appears, as previously cited, that the industrial R&D projects system is more suitable for innovations of incremental type while the SVC system is more suitable for radical innovations in which the high potential of ROI would compensate largely the higher probability of investment failure (Bonomi, 2020). The industrial platform system is completely different from the two other organizational systems as its strategy is based principally on the increase of knowledge and not on financing. That is obtained in particular by the exchange of knowledge between the platform and the peer consumers, and its efficiency derives from the great availability of knowledge favoring the combinatory nature of innovation, in accord with the previous defined principle for the development of new technologies. The diffusion of the industrial platform system could modify radically the technology innovation system by shifting partly technological competition among firms to competition among platforms, while the offer of technology developments by research entities shifts offer toward firms to offer toward platforms becoming peer producers (Bonomi, 2020).

8. THE STAGES OF TECHNOLOGY INNOVATION

Considering the organizational structures with the technological processes described previously, we may give now an articulated view of technology innovation stages taking account of the various possible paths and conditions followed by an innovative idea from its generation to its transformation into a new technology that finally enters in use. From the point of view of the GTI technology innovation may occurs through one of the three organizational structures for innovation, i.e. the industrial R&D system, the SVC system and the industrial platform system. The choice of the system depends on various factors described previously in comparing the various organizational structures, and including the degree of radicality of the innovation, the financing strategies and the importance given to knowledge in improving or generating new technologies. The temporal sequence of a technology innovation may be divided in three stages: the generation of innovative ideas, the development of the innovative ideas until the formation of new technologies and the generation of innovations during the use of the technologies. These stages are represented schematically in Fig. 6 in which the development stage is split further in a first step concerning feasibility, a second step concerning the determination of performances and economy of the innovation, followed by a last step concerning industrialization. The phases of innovation are described as follows.

Generation of innovative idea for the technological innovation process

The generation of an innovative idea is fundamentally a combinatory process involving preexisting technologies with exploitation or not of new or never exploited phenomena discovered by science. This generative process may be the result of individual creativity (Dumbleton, 1986), or may emerge by generative relations among various actors interested in the innovation (Lane & Maxfield, 1995). The combinatory process includes normally also general scientific and technical knowledge as well as other types of knowledge. Important exploitable sources of knowledge are coming from the activity of the organizational structures and concerning successful or abandoned projects or startups, and by LbyD activities occurring during the use of a technology.

Development and formation of a new technology

This development may occur generally in one of the three different organizational structures constituted by the R&D project system, the SVC system and the industrial platform system and concerns the verification of the feasibility of the innovative idea, important specially in the case of exploitation of new phenomena discovered by science, followed by the determination of the performances of the technology and estimation of its economy, through studies on prototypes or pilot plants in order to verify the validity of the technology, and finally by the industrialization step making the technology ready for its use (Bonomi, 2020).

Generation of innovations during the use of a technology

During the use of a technology there are externalities and intranalities that influence the efficiency of the technology leading to the search of new better conditions of operation or even making some changes in its structure and then generating a new technology normally of incremental type. In less frequent cases there is the birth a of a new idea leading to the development of a more efficient alternative radical technology (Bonomi, 2020).

9. Model of technology innovation of a territory

The various schematic representations of the three organizational structures of innovation may be combined forming a structure that describes in fact both the fluxes of knowledge and capitals occurring in the activity of the technology innovation system in a territory. Taking account that the R&D activity is present in the SVC system, that at the same time may be included in the structure of the industrial platform, it is possible to describe a structure, starting from the schematic view of the R&D system activity reported in Fig. 3, by including the activity of the other two organizational systems. That may lead to a model of the technology innovation activities of a territory as reported in Fig. 7. In this case the central activity of R&D may be indicated in a more general way as innovation development, taking account that new technologies may be formed by R&D projects or startups, and indirectly by industrial platforms that include in fact R&D projects and startups activities. The development generates, as in the case of the R&D system, a flux of knowledge coming from either successful or abandoned R&D projects or startups, these last generating in addition also knowledge in business model developments. This knowledge is useful for the generation of innovative ideas. However, in this case, it shall be considered also an important new source of knowledge coming from the industrial platform system, and represented by the exchange of knowledge among the actors of this system, and in particular between the suppliers and the users of a new technology. All this knowledge, combined with external scientific, technical or other knowledge, contributes to the formation of innovative ideas and proposals of new R&D projects for the industry or startups for the VC. The amount of generated proposals, in respect to the amount of available knowledge, will depend on the innovation system efficiency of the territory. The proposals will be then selected for the financing of R&D projects or startups closing in this way the knowledge flux cycle. The activity of development generates also new technologies. These ones may be seen as represented by the costs of successful or abandoned R&D projects, or investments in successful or abandoned startups, starting in this way the flux of capitals. The new technologies enter in use through availability of industrial capitals and then generating returns of investments. However, it is necessary to take account that new technologies developed by startups are sold by VC directly to industry or in the transformation of a startup in an industrial company. The obtained returns of capitals from these exits are partly retained by VC and the rest reinvested in new startups. The total capital for investment in new R&D projects or startups is then formed by: industrial investments for R&D projects, VC reinvestments for startups and possibly public investments of various nature, closing in this way the capital flux cycle. As noted previously, the generation of new technologies is a specific activity of R&D projects or startups, and the industrial platforms generates new technologies through the activity of these two systems present in the platform structure. Consequently, the specific contribution of a platform to the innovation system of a territory consists essentially in the increase of available knowledge through exchanges among the various actors of the platform boosting the generation of innovative ideas. Considering the described innovation system for a territory, there are two main factors that boost technology development, and then its economic growth. The first factor consists in the amount of available knowledge and the innovation efficiency of the territory in the generation of innovative ideas for new R&D projects or startups. The second factor consists in the amount of generated new technologies, and in particular in their degree of radicality with a high ROI potential, and that depends on the rate of success of R&D projects or startups in the activity of innovation development. The knowledge factor is maximized in the case of presence of the platform system, while the degree of radicality of new technologies with their high ROI potential is maximized in the presence of the SVC system. Another aspect favorizing the development of a territory consists in the possibility to start autocatalytic processes through the cumulation of knowledge for innovative ideas in the R&D and startup activity, and then the formation of new technologies, but also the increasing of available capitals for technology developments through the VC financial cycle as described in Fig. 4. From this schematic view of the technological innovation system of a territory, it appears clear that the territorial development potentially depends on the existence and diffusion of the various types of organizational structures for innovation. In fact, a territorial innovation system based only on industrial R&D projects will not have the same potential of the SVC system in generating technologies with a high degree of radicality and then high ROI, while it cannot have a large diffusion of knowledge, and then a great generation of innovative ideas, possible in the case of presence of the industrial platform system. Concluding the reaching of a great technology development and growth of a territory is surely favorized by the diffusion of SVC and industrial platform systems, substituting partly the industrial R&D projects system in the generation of successful new technologies.

10. LESSONS FROM THE GENERAL MODEL OF TECHNOLOGY INNOVATION

The described GTI may hold some important lessons that concern various aspects of the innovation process such as: the relation between science and technology, the technological competitivity in industrial districts or sectors, relation between technologic and economic growth, limits and suggestions for statistical studies on technology innovation, relation between technology and the environment, and scientific and technical education. Such lessons may lead to conclusions in accord, but also in certain cases in disagreement, with commonly diffused views about technology and its innovation.

10.1. Relation between science and technology

Technology is considered commonly derived from science and often seen just as a byproduct coming from the scientific activity in which scientific results of interest may be transformed automatically, after a certain time, in technologies. The position of GTI in the relation of technology with science is different because it considers a new technology as the result of a combination of preexisting technologies exploiting or not exploiting new phenomena discovered by science for a certain purpose. On the other side the experience in R&D has shown that often this activity needs for its purposes results of scientific research forming in this way an intertwining process between R&D and scientific research (Bonomi, 2020). Against the common view of technology derived from science there is also a surprising opposite view sustained by Heidegger, a well-known German philosopher, that made this statement in his essay entitled “The Question concerning Technology” (Kemp, 2003). He affirmed in fact that it is science originated by technology. Actually, this radical position finds a certain justification if we consider the history of science from another point of view. In fact, astronomic scientific discoveries of Galileo Galilei have depended essentially on the available technology for the construction of the telescope, chemistry as science would not be born without existence of efficient vacuum pumps and precision balances for the study of gas reactions and then the development of the atomic-molecular model for matter. Furthermore, research in modern physics would not be possible without accelerators of nuclear particles or big interferometers intercepting gravitational waves with their complex technologies. Of course, the limits to this view are in the fact that science uses also important ideas for its discoveries, for example the atomic structure of matter resulted from philosophical thought in ancient Greece. Nevertheless, the relation between science and technology appears as a complex intertwining process in which technology makes possible scientific discoveries and scientific discoveries makes possible new technologies. The consequence of this intertwining process is that the division between fundamental, basic, oriented and applied research is of minor interest in the relation between science and technology because these types of research are all included in the same intertwining process, and natural phenomena and ideas, exploitable for new technologies, may be originated by all these types of research. This position was sustained for example by Frederick Terman of the Stanford University, considered the godfather of the Silicon Valley, refusing the separation between applied and basic research (Stuart, Leslie & Kargon, 1994). By consequence also fundamental research may be considered of high interest as potential source of radical competitive innovations, and a certain diffused view about fundamental research seen as only a cultural activity represents a narrow view of the reality.

10.2. Technological competitivity among firms

The GTI may explain certain regimes of technological innovation existing in industrial districts or sectors making the same product and that have been called the Red Queen regime and the Pulcinella's secret regime (Bonomi, 2020). Such regimes are characterized by a technological evolution based on only incremental innovations with a low potential for economic growth. These regimes may be disrupted by the appearing of new radical technologies or radical changes in the externality of the used technologies, putting in danger the existence of the district or sector firms. The description of these regimes is the following.

The Red Queen regime

This regime, has the name derived by a character of Alice in Wonderland that told to Alice "in this place it takes all the running you can do, to keep in the same place", and used previously to name a regime of genetic competition between preys and predators (Van Valen, 1973). It represents a situation diffused in industrial districts or sectors making the same product in which a firm develops a new incremental technology obtaining an advantage, but that it is rapidly easily eliminated by the other firms with the same competences through similar or alternative incremental technologies. This situation leads to a continuous technological development but without important growth or emerging of dominating firms. This regime may be disrupted by arrival of a new radical technology. An example was the case of appearance of digital watches of Japanese industry against the conventional Swiss mechanical watch industries in the seventies of the past century (Bonomi, 2020).

The Pulcinella's secret regime

Pulcinella is a Neapolitan theater mask that believes to have an advantageous secret knowledge but in fact this knowledge is also available to other people that also may believe to be their secret advantage. Such behavior is diffused in the technological practice of various industrial sectors and districts. The consequence is a system with a poor exchange of knowledge, technological stagnation and even decline (Bonomi, 2020). This regime was present for example in the European ferroalloys industry unable to develop a suitable technological diversification against the competition of developing countries. These ones were able to offer the possibility to build greater plants with a low cost of electrical energy from their big hydroelectric plants, sometimes offering energy based on a flat and not on consumption rate. In this way the European production of ferroalloys disappeared completely after the eighties of the past century with the exception in Norway with its hydroelectric plants at the sea level.

10.3. Relation between technology and economic growth

The GTI, through a mathematical simulation model of R&D (Bonomi, 2017b), shows that the formation of new technologies as a function of investments in technology innovation is not a linear or continuous process. In fact, the mathematical model of R&D takes account of the existence of selection rates concerning the choice of R&D proposals to be financed, the rate of formation of new technologies from the total number of R&D projects carried out, and the selection of new technologies that become successful technologies impacting the economic growth. The existence of these selection rates determinates statistically the necessity of a minimum number of R&D projects to obtain at least one new technology, and a minimum number of new technologies to obtain at least one successful technology. The existence of these thresholds, in the generation of new and successful technologies affects the existence of analogous thresholds between the investments in R&D and the economic growth, considering that the number of financed R&D projects is related to R&D investments, and the number of formed successful technologies to economic growth. On the other side, above these thresholds, there is the effect of the combinatory nature of formation of innovative ideas from available knowledge that cumulates with time by effect of the R&D activity. That may trigger an autocatalytic growth of formation of new and successful technologies. Following the model, the thresholds and the autocatalytic growths depend also on the efficiency of a territory to exploit the available knowledge for the generation of innovative ideas. That has been shown through the mathematical simulation model of the R&D activity, considering a starting number of R&D projects, simulating the R&D investments, and the formation of successful technologies, i.e. simulating the economic growth, and finally considering the value of efficiency of exploitation of available knowledge in the territory in which are made the R&D investments. The results show that, below a certain number of initial R&D projects, the formation of new technologies is absent. New technologies are formed only above this threshold and successful technologies are formed even at a higher level. Such behavior is reported schematically in Fig. 8 that presents the various situations. In the case of low investments in R&D the formation of new technologies is absent, or they are formed in a very little number, transforming R&D investments in a financial loss in a regime of technology decline. Above a certain threshold of investments there is formation of new technologies, however mostly of incremental type without a great influence on economic growth, typical situation of a Red Queen regime. At a higher level of number of projects or investments there is the formation of successful technologies assuring technology development and economic growth. The model shows also that the cumulation of knowledge generated by successful or abandoned R&D projects may form an autocatalytic exponential growth of generation of innovative ideas, and consequently of new and successful technologies. A similar type of autocatalytic effect exists, as discussed previously, also in the case of financing strategies in the SVC system in which, in the case of a successful activity, there is an autocatalytic exponential growth of available capitals for the reinvestment in a growing number of new startups following the cycle reported in Fig. 4. Of course, these autocatalytic processes cannot continue indefinitely and find generally a limit due to the generation of innovative ideas or available financing necessary to sustain the exponential growth and, less frequently, by limited availability of human resources or facilities for the R&D activity. Autocatalytic technological growth may become a reality in certain technological sectors with a high innovative potential such as artificial intelligence, synthetic biology, quantum physics applications and probably in the development of green technologies. Exponential growths have been already observed for example in nanotechnologies having an exponential evolution of number of patents from 1981 to 1992, and of scientific publications from 1981 to 1998 (Hullman & Meyer, 2003). An autocatalytic growth has been observed also in the case of the Silicon Valley (Saxenian, 1994) and in the case of South Korea. In this last country in the sixties the rate of R&D investments on GDP was only around 0.5%, becoming around 3% at the beginning of the nineties, that accompanied by a great economic development. This increase was attributed to an important loan obtained in 1965 from USA used for the creation of two research institutes the KAIS and the KITS, after merged forming the KAIST. The economic success of South Korea may be attributed to the contribution of these research institutes for development of science and new technologies, and by adopting the Japanese industrial organization (Stuart, Leslie & Kargon, 1996).

10.4. Statistical studies on technology innovation

Statistical studies are an important activity in the description of many aspects of the situation of technology innovation in a country. These studies follow essentially standardized rules reported in manuals published by the OECD, using basic definitions of R&D reported in the Frascati manual (OECD, 2015), and of general innovation activities in the more recent Oslo manual (OECD, 2018). However, these manuals define technology innovation in term of R&D activity existing at the beginning of the sixties of the past century (OECD, 1963), before the diffusion of new organizational structures for innovation such as the SVC and the industrial platform that have changed the system of formation of new technologies as described in the GTI. Actually, the OECD manuals consider technological innovation simply as the result of activities of basic research, applied research and experimental development. That is not erroneous but it does not take account of the real complexity of the present innovation processes and existence of the various organizational structures for innovation limiting to consider economic growth as a simple direct consequence of the investments in R&D. The idea that technology innovation is simply the result of basic, applied research and development activities is probably the result of the fact that the complexity of technology has not been studied at the same extent as the complexity of economy. The actual more complex situation of the technology innovation system has been previously described in Fig. 7 showing the fluxes of capitals and knowledge existing in a territory in which all the three types of organizational structures for innovation are present. These structures have a different diffusion in the various countries resulting in a different efficiency in exploiting the available innovation investments in the various territories, making doubtful the existence of a simple direct relation between R&D investments and economic growth. This view leading in fact to consider erroneously that the use of the R&D investments for growth have practically the same efficiency in all the countries. Furthermore, in the more recent Oslo manual, R&D is considered simply one of the various identified innovation activities forgetting that some of the other considered innovations are derived in fact directly from R&D activities. This simplified approach to the technological innovation activity in statistical studies is certainly in measure to describe the general situation of innovation in the various countries, but not in measure to explain in detail the processes and innovation structures that are at the origin of the collected data used in the statistics. Consequently, they are only able to give a general but not a specific knowledge useful for the establishment of effective policies of promotion of innovation. Policies that should take account of the various organizational structures making innovations with the existing differences in exploiting knowledge and in financing strategies. Differences that in fact influence the efficiency of the innovation system in generating an economic growth. On the other side, the knowledge of technology dynamics might suggest possible new statistical studies on detailed processes for innovation never considered before. Considering the schematic view of a territorial innovation system represented in Fig. 7 there is a certain number of statistical studies of interest in addition to the typical relation between R&D investments and growth. For example, the ratio of investments between those for industrial R&D projects and those by VC for startups, and the rate of success of R&D projects or startups in generating new technologies and possibly new successful technologies. An example of statistic of this type has been made for example considering patents (Scherer & Haroff, 2000), and showing in fact a skew distribution of the success of the formed new technologies.

10.5. Technology innovation and the environment

The combinatory nature of technology innovation, and the continuous progress of scientific research supplying new phenomena exploitable for new technologies, may give an important contribute to solve environmental problems such as pollution, depletion of resources and global warming, arguments discussed in a previous study (Bonomi, 2021). In fact, technology innovations could make possible the realization of a sustainable technologic growth, that by forming an ecosystem in which economy and technology do not look for compromises with environmental needs, but for integrated solutions that unify these activities at all levels. That is the objective for example of an environmental model called Natural Capitalism (Hawken et al., 1999). On the other side technology dynamics considers doubtful the realization of the objective of another environmental model called Circular Economy (Stahel, 2019). Although the increase of the circularity of the economy has certainly a benefic effect on the environment, and this strategy is in fact considered also in the natural capitalism model, the objective of the realization of a mature circular industrial economy, able to recycle completely wastes, producing virgin materials in their highest utility, valid for industrial productions in a closed cycle of production and use may be questioned about its feasibility. In fact, a full recycling would necessitate, for thermodynamics reasons, independently of the technological feasibility of recycling, an enormous amount of energy that would make doubtful its realization. Furthermore, the circular economy model renounces to consider certain bio-technologies, that are on the contrary an important part of the natural capitalism technological ecosystem, but considered not integrable in a mature circular model (Stahel, 2019). Finally, the circular economy model does not supply any real valid solutions facing radical technological innovations making rapidly obsolete used products as well as their recycling processes and repairing tools. That might lead implicitly to the paradox to neglect radical innovations with their benefits in order to conserve an improbable full circularity of the economy.

10.6. Technical and scientific education

Technical and scientific education are implied in an important process of the GTI that concerns the ramification of the technologies. It is well known that an initial radical technology may trigger further new technologies constituting improvements and diversification of the initial technology, and forming a ramification in the space of technologies. Normally it is observed the formation of more and more technologies with degrees of radicality that decrease as these technologies are far in the space of technologies from the initial radical technology. It may be observed also that, as the new technologies become more incremental, they are not obtained by researchers carrying out R&D, but through LbyD of technicians that use the technology. In fact, it is this inventive activity of technicians that realizes most of the great number of secondary patentable technologies of the ramification, and constituting the bulk of the impact of a new original technology in the socio-economic system. That means that intermediate scientific and technical education is also of a great importance in technology growth, fact that it is not always considered in supporting this level of scientific and technical education. Actually, the importance of scientific and technical education has been found in fact superior to the contribution of industrial property for an economic growth (Wang, 2010).

11. Perspective of evolution of the organizational structures

The evolution of the technological innovation system observed since the second half of the XIX century, in term of formation of the various organizational structures for innovation, might continue generating a further organizational structure for innovation. This new structure should be considered probably also inclusive, as the previous organizations, in the sense that it would also include the activities of the previous organizational structures. The main factor generator of technology innovation, beside the availability of exploitable scientific results, is the combinatory process forming new technologies that is favorized by the increase of amount and availability of knowledge. Among the three organizational structures for innovation it is the industrial platform system that is in measure to generate the major increases of knowledge for technological innovations. That is obtained by a continuous exchange of experience on the use and development of new technologies among the actors of the system. It is then possible to imagine a future scenario in which there is the formation of a network of platforms supplying specific types of technologies to a firm. This firm makes a product with its own technology, but combining also the use of basic technologies of the platforms with which it is in relation. For example, a future firm producing electric vehicles, with its own concept and technology, may exploit basic technologies of various platforms for example supplying technologies concerning electric motors, batteries and artificial driving systems. In this case it would be possible to form a platform network constituted by peer consumer firms using basic technologies and exchanging knowledge with the platforms. At the same time there are peer producers supplying discontinuously new technologies, R&D projects and startups activities to the various platforms. A schematic view of this industrial platform network is presented in Fig. 9 composed by two firms with similar productions in relation with three platforms that at the same time are in contact with various peer producers. It may be noted that a peer consumer firm might become also a secondary platform by supplying technologies and exchanging knowledge with its final consumers, especially in the case its products are in internet of things. In this case the innovation system would enjoy of an enormous exchange of knowledge from final consumers to producers of basic technologies boosting the generation of innovative ideas and new technologies. It should be noted that the realization of such scenario would depend on the evolution of business strategies. In fact, an industrial platform network system reduces the freedom in the realization of patents by a firm as the development of some basic innovation technologies for its products would be delegated to the platforms. The diffusion of the industrial platform network would then depend on whether business strategies will favorize technology innovation or industrial property exploitation.

12. Conclusions

This work has shown that technology may be considered a discipline separated from economic science although having important relations. That makes possible the identification of basic aspects of technology, valid for any purpose of use of a technology, and leading to principles that may allow the description of a GTI. Such model may be useful to describe various technological processes and organizational structures for innovation. The developed GTI may hold important lessons about the intertwining process between science and technology, the existence of specific regimes in the technological competition in industrial districts or sectors, the existence of critical thresholds and autocatalytic processes in the development of technologies, the possibility to make new statistical studies taking account of the identified processes and structures of technology innovation, and the importance of intermediate scientific and technical education for the development of applications of a new technology. Finally, discussing the perspectives of evolution of the organizational structures for innovation, it is possible to describe a future scenario consisting in a network of industrial platforms supplying basic technologies to firms, enjoying of a huge exchange of knowledge useful for the development of new technologies. The realization of such scenario would depend on whether business strategies will favorize technology innovation or industrial property exploitation.

13. References

Arthur, B. (2009). *The Nature of Technology*. New York: Free Press.

Auerswald, P., Kauffman, S., Lobo, J., & Shell, K. (2000). The Production Recipe Approach to Modeling Technology Innovation: An Application to Learning by Doing. *Journal of Economic Dynamics and Control*, 24(3), pp. 389-450. Available at https://doi.org/10.1016/s0165-1889(98)00091-8

Basalla, G. (1988). *The Evolution of Technology*. Cambridge: Cambridge University Press

Bonomi, A. (2017a). *A technological model of the R&D process and its implications with scientific research and socio-economic activities* (CNR-IRCrES Working Paper 2/2017). Istituto di Ricerca sulla Crescita Economica Sostenibile.
Available at http://dx.doi.org/10.23760/2421-7158.2017.002

Bonomi, A. (2017b). *A mathematical toy model of the R&D process, how this model may be useful in studying territorial development* (CNR-IRCrES Working Paper 6/2017). Istituto di Ricerca sulla Crescita Economica Sostenibile.
Available at http://dx.doi.org/10.23760/2421-7158.2017.006

Bonomi, A. (2018). *I canali innovativi di industria 4.0 e le PMI* (CNR-IRCrES Working Paper 7/2018). Istituto di Ricerca sulla Crescita Economica Sostenibile. Available at http://dx.doi.org/10.23760/2421-7158.2018.007

Bonomi, A. (2019). *The Start-up Venture Capital Innovation System, Comparison with industrially financed R&D projects system* (CNR-IRCrES Working Paper 2/2019). Istituto di Ricerca sulla Crescita Economica Sostenibile. Available at http://dx.doi.org/10.23760/2421-7158.2019.002

Bonomi, A. (2020). *Technology Dynamics: the generation of innovative ideas and their transformation into new technologies*. London: CRC Press, Taylor & Francis Editorial Group.

Bonomi, A. (2021). *Environment and a Sustainable Technologic Growth, how technology may be a solution and not necessarily a problem* (Working Document, section: Technology and Environment). Available at www.complexitec.org

Bonomi, A., & Marchisio, M. (2016). *Technology Modelling and Technology Innovation, how a technology model may be useful in studying the innovation process* (CNR-IRCrES Working Paper 3/2016). Istituto di Ricerca sulla Crescita Economica Sostenibile. Available at http://www.ircres.cnr.it/index.php/it/produzione-scientifica/pubblicazioni1?id=118

Cicero, S. (2017) *From Business Modeling to Platform Design* (PDT Platform Design Tookit White Paper). Available at https://platformdesigntoolkit.com/platform-design-whitepaper/

Di Maio, M. (2003). *Explaining Technological Change: A Comparative Survey*. (PhD preliminary study version). Siena, I: Dipartimento di Economia Politica, Università Degli Studi di Siena.

Dosi, G. (1982). Technical Paradigms and Technical Trajectories, the Determinants and Directions of Technical Change and the Transformation of the Economy. *Research Policy*, *11*(3), pp. 147-162. Available at https://doi.org/10.1016/0048-7333(82)90016-6

Dumbleton, J.H. (1986). *Management of High Technology Research and Development*. New York: Elsevier Science Publisher.

Feldman, P., & Francis, J. (2002). The Entrepreneurial Spark: Individuals Agent and the Formation of Innovative Clusters. In Curzio, A., & Fortis, M. *Complexity and Industrial Clusters*. Heidelberg: Physica Verlag.

Fleming, L., & Sorenson, O. (2001). Technology as a complex adaptive system: evidence from patent data. *Research Policy*, *30*(3), pp. 1019-1039. Available at https://doi.org/10.1016/S0048-7333(00)00135-9

Fleming, L., & Sorenson, O. (2004). Science as a map in technological search. *Strategic Management Journal*, 25(8-9), pp. 909-928. Available at https://doi.org/10.1002/smj.384

Giarini, O., & Loubergé, H. (1978). *The diminishing returns of technology: An essay on the crisis in economic growth*. Oxford, UK: Pergamon Press.

Girard, M., & Stark, D. (2001). *Distributing Intelligence and Organizing Diversity in New Media Projects* (Santa Fe Institute Working Paper 01-12-082). Available at https://www.santafe.edu/research/results/working-papers/distributing-intelligence-and-organizing-diversity

Gould, S.J. (1996). The Pattern of Life's History. In Brockman, J. *The Third Culture*. New York: Simon & Schuster.

Hawken, P., Lovins, A., & Lovins, H. (1999). *Natural Capitalism, creating the next industrial revolution*. Boston: Little, Brown and Company.

Hullmann, A., & Meyer, M. (2003). Publications and patents in nanotechnology. An overview of previous studies and the state of the art. *Scientometrics*, *58*(3), pp. 507-527. Available at https://link.springer.com/content/pdf/10.1023/B:SCIE.0000006877.45467.a7.pdf

Isaacson, W. (2011). *Steve Jobs*. New York: Simons & Schuster.

Kauffman, S., Lobo, J., & Macready, G.W. (2000). Optimal Search on a Technology Landscape. *Journal of Economic Behaviour and Organization*, *43*(2), pp. 141-166. Available at https://doi.org/10.1016/s0167-2681(00)00114-1

Kemp, P. (2003). La Question de la Technique selon Heidegger. In Chabot, P., & Hottois, G. *Les philosophes et la technique*. Paris: Librairie Philosophique J. Vrin.

Lane, D., & Maxfield, R. (1995). *Foresight, Complexity and Strategy* (Santa Fe Institute Working Paper, 95-12-106). Available at https://www.santafe.edu/research/results/working-papers/foresight-complexity-and-strategy

Lobo, J., & Macready, G.W. (1999). *Landscapes: A Natural Extension of Search Theory* (Santa Fe Institute Working Paper, 99-05-037). Available at https://www.santafe.edu/research/results/working-papers/landscapes-a-natural-extension-of-search-theory

Nelson, R., & Winter, S. (1977). In search of a Useful Theory of Innovation. *Research Policy*, *6*(1), pp. 36-76. Available at https://doi.org/10.1016/0048-7333(77)90029-4

OECD. (1963). *Proposed Standard Practice for Surveys of Research and Development*. Paris: Directorate for Scientific Affairs, DAS/PD/62.47.

OECD. (2015). *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development*. The Measurement of Scientific, Technological and Innovation Activities. Paris: OECD Publishing,

OECD/Eurostat. (2018). *Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation,4th Edition*. The Measurement of Scientific, Technological and Innovation Activities. Paris: OECD Publishing / Luxembourg: Eurostat.

Rhodes, R. (1986). *The Making of the Atomic Bomb*. New York: Simon & Schuster.

Russo, M. (2003). *Innovation processes in industrial districts* (ISCOM Project. Venice, November 8-10, 2002), revised version 07.02.2003.

Scherer, F.M., & Haroff, D. (2000). Technology Policy for a World of Skew-Distributed Outcomes. *Research Policy*, *29*(4-5), pp. 559-566.

Saxenian, A. (1994). *Regional Advantage, culture and competition in Silicon Valley and Route 128*. Cambride, MA - London: Harvard University Press.

Stahel, W. (2019). *The Circular Economy. A User's Guide*. London: Routledge, Taylor & Francis Editorial Group.

Stuart, W., Leslie, S.W., & Kargon, R. (1996, Winter). Selling Silicon Valley: Frederick Terman's Model for Regional Advantage. *The Business History Review*, *70*(4), pp. 435-472. Available at https://doi.org/10.2307/3117312

Valverde, S., Solé, R., Bedau, M., & Packard, N. (2007). *Topology and Evolution of Technology Innovation Networks* (Santa Fe Institute Working Paper 06-12-054). Available at https://doi.org/10.1103/physreve.76.056118

Van Valen, L. (1973). A New Evolutionary Law. *Evolutionary Theory* 1, pp. 1-30. Available in *Foundations of Macroecology*, edited by Smith, F.A., Gittleman, J.L., & Brown, J.H. (2014) Chicago: University of Chicago Press, pp. 284-314. https://doi.org/10.7208/9780226115504-022

Wang, E.C. (2010). Determinants of R&D investment: The Extreme Bound-Analysis approach applied to 26 OECD countries. *Research Policy 39*(1), pp. 103-116. Available at https://doi.org/10.1016/j.respol.2009.11.010

14. FIGURES

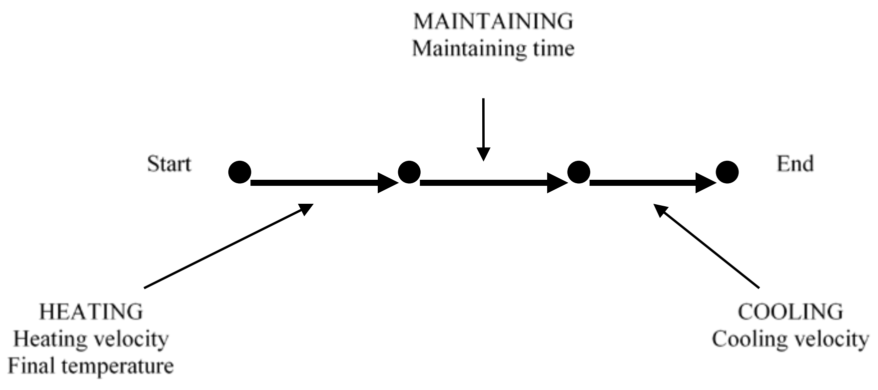


Figure 1. Structure of heating treatment technology with its operations and parameters.

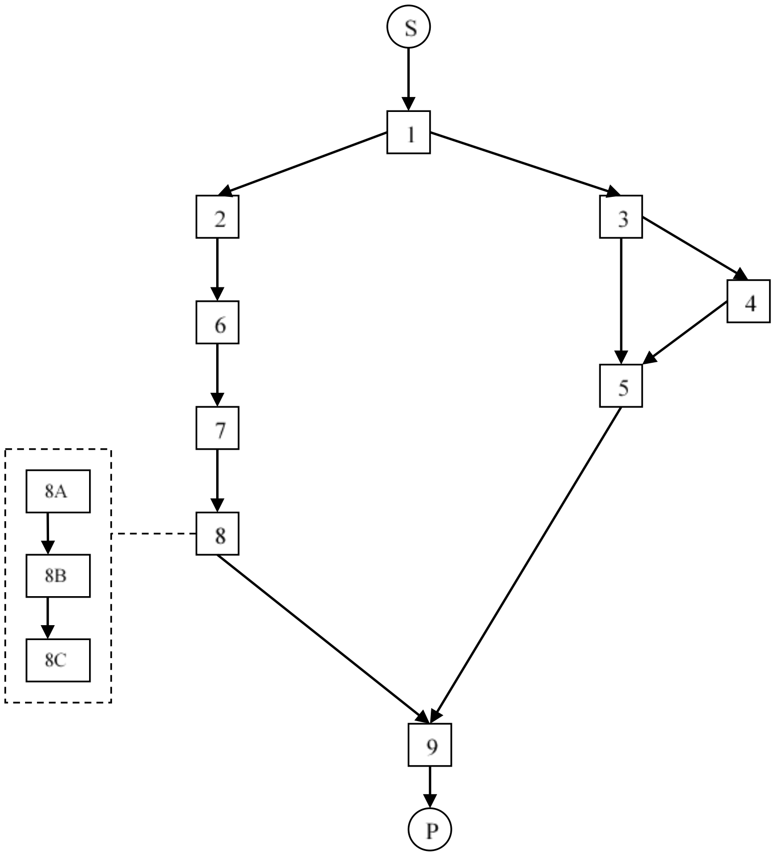


Figure 2. Simplified structure of faucets production technology.

Operations

S. Starting with copper and zinc ore
1. Production of molten brass
2. Production of brass ingots
3. Production of brass bars
4. Hot stamping
5. Machining
6. Casting
7. Finishing
8. Chromium plating
8A. Degreasing
8B. Nickeling
8C. Chroming
9. Assembling
P. Produced faucets

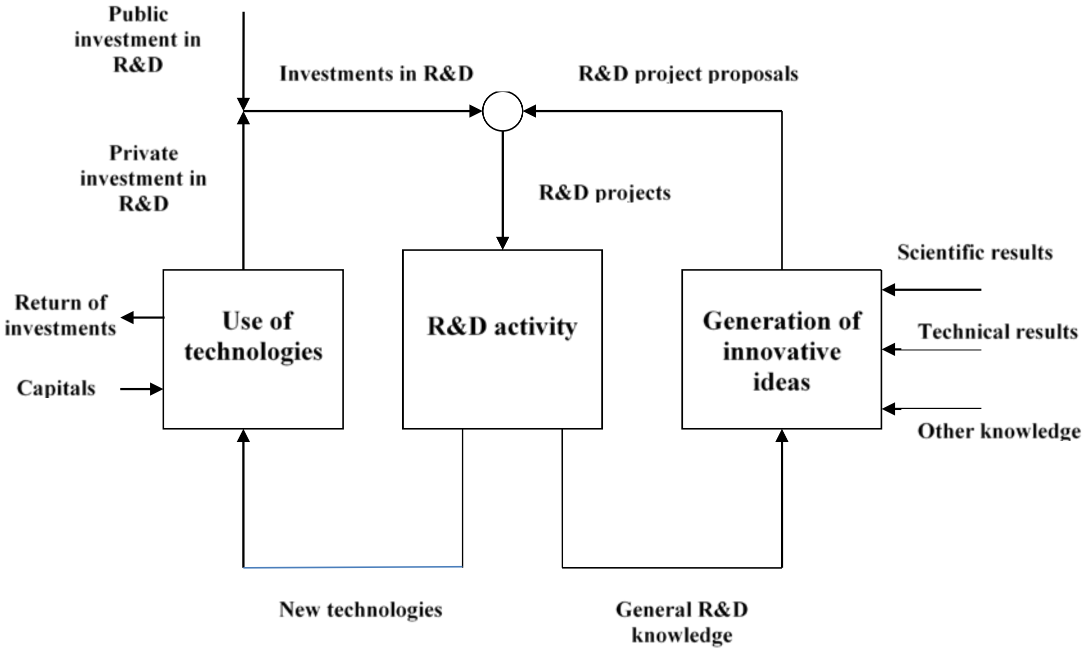


Figure 3. Schematic view of the industrial R&D projects system.

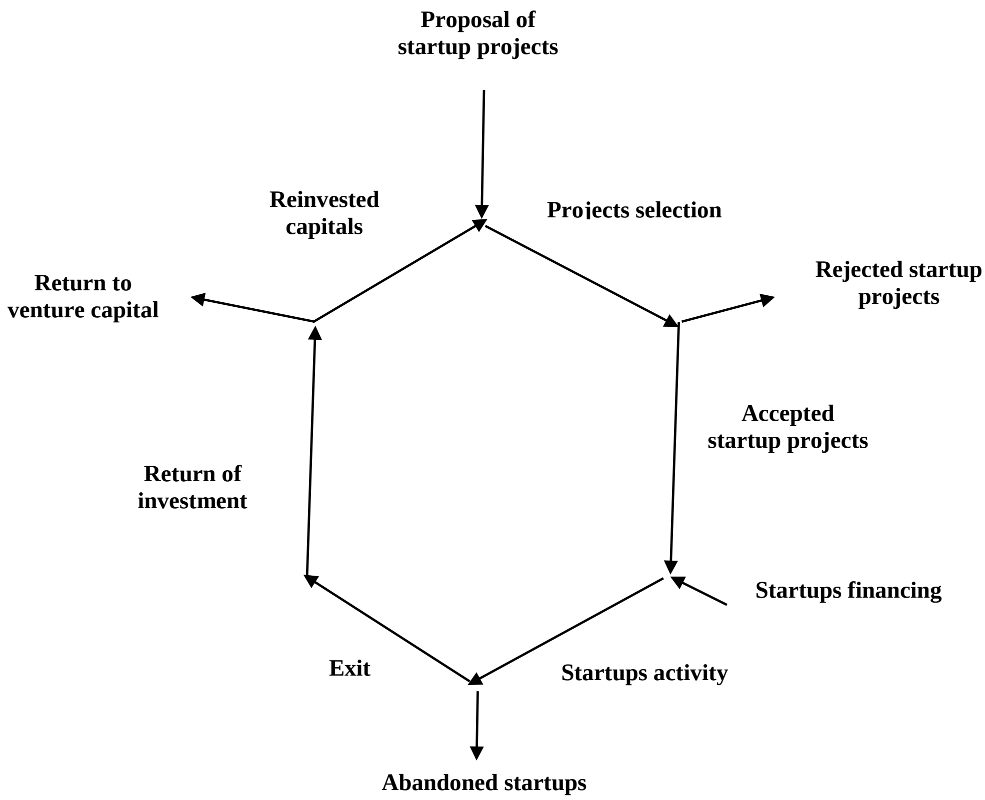


Figure 4. Schematic view of the SVC financial cycle system.

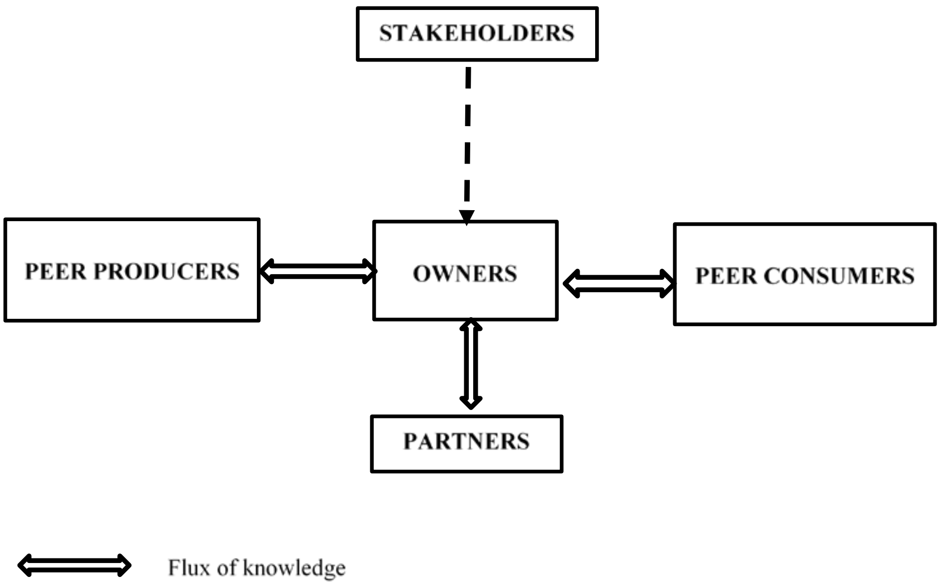


Figure 5. Schematic view of the industrial platform system.

Figure 6. The stages of technology innovation.

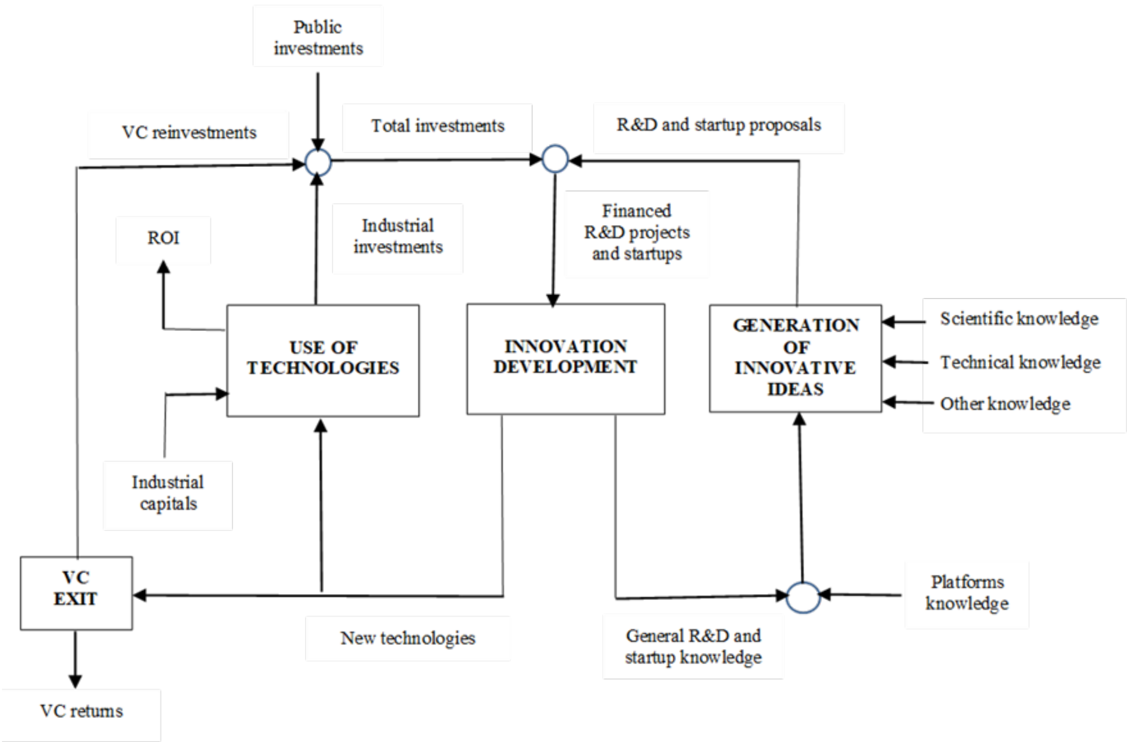


Figure 7. Fluxes of knowledge and capitals in the technological innovation system of a territory.

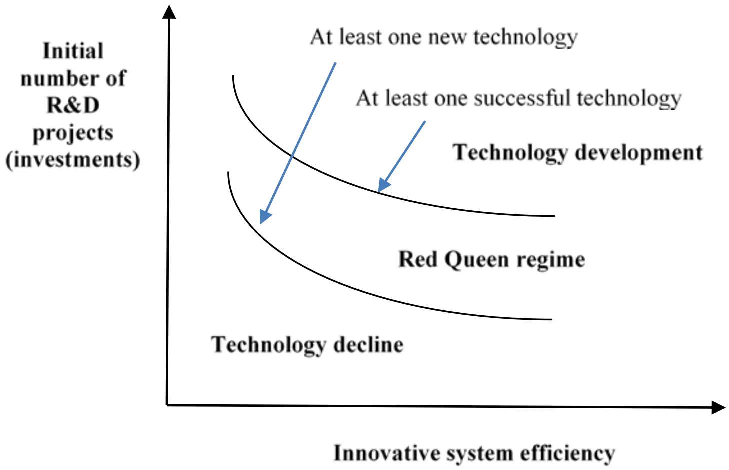


Figure 8. Technology innovation as a function of number of initial R&D projects and efficiency in exploiting knowledge.

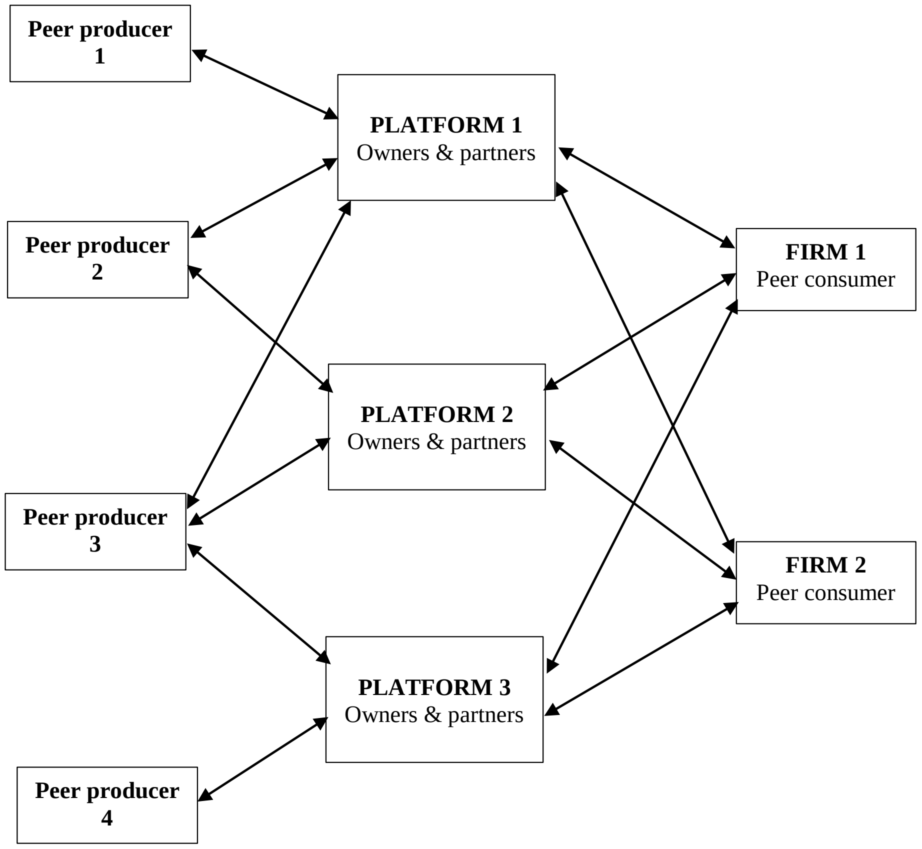


Figure 9. The industrial platform network system.

ISSN (online) 2421-7158

CNR-IRCrES Working Papers

2021

N.3/2021 Design and implementation of a web survey on the effects of evaluation on academic research. Andrea Orazio Spinello, Emanuela Reale, Antonio Zinilli.

N. 2/2021 An online survey on the effects of agile working in Italian Public Research Organisations. Serena Fabrizio, Valentina Lamonica, Andrea Orazio Spinello.

N. 1/2021 Technology Transfer Activities in Universities and Public Research Organizations: A Literature Overview. Ugo Finardi, Rolfo Secondo, Isabella Bianco.

2020

N. 12/2020 Unexpected loss multiperiodale e pricing del rischio di credito. Franco Varetto.

N. 11/2020 La ricerca in Nanotecnologie e Nanoscienze in Italia: spesa del settore pubblico e aree tematiche prevalenti. Ugo Finardi, Andrea Orazio Spinello.

N. 10/2020 Persistent fast growth and profitability. Lucio Morettini, Bianca Potì, Roberto Gabriele.

N.9/2020 Binomio *Burnout* e *Mindfulness* nelle organizzazioni. Alcuni studi e scenari di applicazione. Oriana Ippoliti, Riccardo Briotti, Bianca Crocamo, Antonio Minopoli.

N.8/2020 Innovation and communication of companies on Twitter before and during COVID-19 crisis. José N. Franco-Riquelme, Antonio Zinilli, Joaquín B. Ordieres-Meré and Emanuela Reale.

N. 7/2020 The proposal of a new hybrid methodology for the impact assessment of energy efficiency interventions. An exploratory study. Monica Cariola, Greta Falavigna.

N. 6/2020 The technology innovative system of the Silicon Valley. Angelo Bonomi.

N. 5/2020 Storia dell'industria delle macchine utensili in Piemonte dalle origini alla seconda guerra mondiale. Secondo Rolfo.

N. 4/2020 Blockchain e Internet of Things per la logistica Un caso di collaborazione tra ricerca e impresa. Edoardo Lorenzetti, Lucio Morettini, Franco Mazzenga, Alessandro Vizzarri, Romeo Giuliano, Paolo Peruzzi, Cristiano Di Giovanni.

N. 3/2020 L'impatto economico e fiscale di un evento culturale: misure e scala territoriale. Giovanna Segre, Andrea Morelli.

N. 2/2020 Mapping the tangible and intangible elements of the historical buildings and spaces. Edoardo Lorenzetti, Nicola Maiellaro.

N. 1/2020 Il lavoro agile negli enti pubblici di ricerca. Emanuela Reale, Serena Fabrizio, Andrea Orazio Spinello.

2019

N. 6/2019 Women's candidatures in local elections: does the context matter? Empirical evidence from Italian municipalities. Igor Benati, Greta Falavigna, Lisa Sella.

N. 5/2019 Research activities in Nanotechnologies and Nanosciences: an analysis of Piedmont's nanotech research system. Ugo Finardi.

N. 4/2019 Xylella fastidiosa: patogenesi, danni economici e lotta al disseccamento rapido dell'olivo. Maurizio Conti.

N. 3/2019 Flussi di traffico attraverso il tunnel automobilistico del Frejus: un semplice esercizio di *forecasting* e alcune considerazioni a margine. Ugo Finardi.

N. 2/2019 The Start-up Venture Capital Innovation System Comparison with industrially financed R&D projects system. Angelo Bonomi.

N. 1/2019 Complessità delle organizzazioni, complessità della formazione. Report di studio qualitativo ed analisi ermeneutica del Modello TRASE – IRCRES/CNR-IMO. Anna Chiara Scardicchio.

2018

N. 13/2018 Competenze di sviluppo sistemico evolutivo per la leadership e le organizzazioni orizzontali. Erica Rizziato, Erika Nemmo.

Numeri precedenti/Previous issues

ABSTRACT

This work has the objective to present a general model of technology innovation considering technology as a separated discipline from scientific research and economy. That is justified by the fact that many technologies have been developed without economic purposes but after generating technologies with a great economic importance, and that there are limits to the study of fundamentals of technology only from an economic point of view. The study defines some principles that are at the base of technology and of its innovation. These principles lead to a model considering technology as a time-oriented structure of technological operations, and allowing the definition of concepts such as technological space, technological landscape and space of technologies. From this model it is possible to explain various technological processes including the nature of knowhow and the transfer of technology. The model then defines three organizational structures for innovation concerning the industrial R&D project, the startup-venture capital and the industrial platform systems, and then the stages of the innovation process. It follows the development of a model of technology innovation of a territory, based on loops of fluxes of knowledge and capitals, and in which these three organizational structures are in action. Applications of the general model of technology innovation concern the relation between science and technology, the technological competitivity, the relation between R&D investments and growth, new possible statistical studies, the relation between technology and the environment and the importance of intermediate scientific and technical education. The work terminates giving a perspective of evolution of the organizational structures for innovation toward a system of industrial platforms network.

CNR - Consiglio Nazionale delle Ricerche

IRCrES - Istituto di Ricerca sulla Crescita Economica Sostenibile