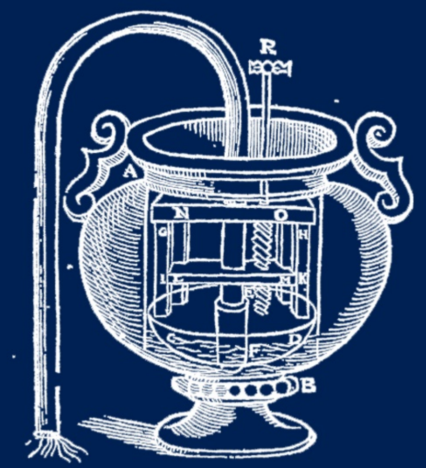
CNR-IRCrES Working Paper

A Simulation Model of Technology Innovation of a Territory



3/2022

Angelo Bonomi

Consiglio Nazionale delle Ricerche
IRCrES

ISSN (online) 2421-7158

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CNR-IRCrES Working Paper 3/2022

A Simulation Model of Technology Innovation of a Territory

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ABSTRACT
The technology innovation of a territory is considered as the result of R&D activity. This view represents the basis for statistical studies of innovation guidelines. However, studies on technology dynamics have shown that technology innovation is also the result of organizations, other than R&D, such as the startup-venture capital or the industrial platform systems, which differ in terms of financial strategies or generation of knowledge. In this paper, we develop a mathematical simulation model of a technology innovation of a territory in which all these three organizations are operating by calculating the number of developed successful technologies, which are considered as triggers of the economic growth. The results show that both startups and industrial platforms boost the formation of successful technologies compared to industrial R&D activity only. Due to the uncertainty of the parameters used, this model is just a rough representation of the reality. However, it presents a detailed description of the processes of generation, use of knowledge, and new technologies' development. Regardless of industrial or economic factors, this model is still valid for any industrial or economic situation. Its descriptions and results may be useful in R&D and technology management as well as in statistical studies for the innovation policies of a territory.

KEYWORDS: territorial innovation system, technology, technology innovation, R&D, startups, venture capital, industrial platforms.

JEL CODES: C63, O31, O32

DOI: 10.23760/2421-7158.2022.003

HOW TO CITE THIS WORKING PAPER
Bonomi, A. (2022). *A Simulation Model of Technology Innovation of a Territory*. (CNR-IRCrES Working Paper 3/2022). Torino: Istituto di Ricerca sulla Crescita Economica Sostenibile. Available at: http://dx.doi.org/10.23760/2421-7158.2022.003

The arguments of this article have been object of a presentation at the R&D 2022 Management Conference hold at the University of Trento, July 9-13.

CONTENTS

1. INTRODUCTION

This model, which derives from studies on technology dynamics (Bonomi, 2020), it does not actually represent a new model of technology innovation, but rather a new way to think about it. In economic studies there is no agreement on what the word “technology” actually means, no general theory on how technology arise, no deep understanding of what “innovation” consists of, and no theory of evolution of technology (Arthur, 2009). In technology dynamics, a clear scientific definition of technology is given as a set of physical, chemical and biological phenomena that produce an exploitable effect for human purposes, regardless of industrial, economic or social factors (Bonomi, 2021). This approach may be simplified by considering sets of physical phenomena as technological operations. Through the concepts and models of the science of complexity, this approach allows to develop a general mathematical model of technology, valid for a single technology, which was originally used to explain learning by doing activities (Auerswald & Lobo, 1996). It was later extended to the case of many technologies pursuing the same purpose to explain their potential competition and evolution (Bonomi, 2020). Furthermore, technology dynamics considers that a territory’s technology innovation system can be described in terms of structures that organize fluxes of knowledge and capitals that generate new technologies. These structures, all of which may be active in a territory, are:

- The industrial R&D projects system
- The startup-venture capital (SVC) system
- The industrial platform system

The processes derived from these structures are valid for all industrial, economic or social situations. Technology dynamics considers that technology innovation is generated in a territory by the existing structures organizing fluxes of knowledge and capitals, and not by institutional organizations such as universities, research centres, industrial R&D laboratories, and so on. This means that all the institutional organizations, for example when conducting R&D activities, organize knowledge and capitals fluxes in the same way, following the model of the R&D structure. This also means that the technological innovation of a territory does not simply depend on the presence of various institutional organizations, but rather on the number of R&D projects and active startups, and on the presence of industrial platforms in the territory. This view of a technology innovation system is a novelty from that used in statistical studies concerning technology innovation, following guidelines such as the Frascati (OECD, 2015) or Oslo (OECD Eurostat, 2018) manuals. These manuals see technology innovation as a result of R&D activities in industry and in institutional organizations, but do not consider how it actually occurs. The new view of technology innovation described above can also give insight into possible statistical studies, taking in account a detailed description of the innovation process based on a scientific view of technology (Bonomi, 2020). After this introductory part, in the second section we describe the adopted model of technology innovation of a territory, including its mathematical description, and calculation example. In the third section, we discuss the model and its results and we also provide conclusions.

2. THE MODEL OF TECHNOLOGY INNOVATION OF A TERRITORY

In a previous study (Bonomi, 2017a), the model of the industrial R&D projects system has been developed and it is schematically presented in Figure 1. The activity consists of a cyclic process of knowledge and capitals fluxes that generate new technologies and knowledge from successful or abandoned projects. The new formed technologies may be seen also in terms of capitals that were required for the development of both successful and abandoned R&D projects. The generated knowledge, added to existent knowledge generated in past cycles, but reduced by a fading effect, is increased by external knowledge coming from scientific, technical or other origin, thus forming the total available knowledge for the generation of innovative ideas for the proposals of new R&D projects. This generation of new ideas depends on a combinatorial process of the available knowledge elements according to idea that new technologies are formed from the combination of previous existing technologies (Arthur, 2009). The formation of R&D project proposals depends also on the territory efficiency to take advantage of the available knowledge. The R&D project proposals will be selected leading to a number of funded R&D projects that will constitute the R&D activity of the cycle. These new technologies need industrial capitals to be employed, possibly generating returns of investment (ROI). The industrial capital system, possibly combined with public funding, makes R&D investment available to finance new selected R&D projects that close both capital and knowledge cycle. This schematic view was that existing before the 1970s when startups and venture capital activities were negligible, and the industrial platforms system not existing until the beginning of the 21st century.

In the current situation, a territory's technology innovation system cannot be represented only by industrial R&D activities, but it is necessary to consider the existence of the SVC system and to some extent the activity of industrial platforms (Bonomi, 2020). These organizational structures differ from R&D projects' activity. Specifically, the SVC system has a different capital strategy as it develops new technologies for their sale and not for their exploitation, like in the case of industrial capital, reinvesting part of these returns in new startups (Bonomi, 2019). Moreover, industrial platforms supply additional knowledge to the technology innovation system of a territory. This is achieved through a continuous exchange of information on the use of a technology, thus increasing the generation of innovative ideas for new technologies (Bonomi, 2020). Therefore, it is necessary to adjust the schematic view of knowledge and capitals fluxes of the R&D system, reported in Figure 1, to take in account the existence of the SVC and the industrial platform systems contributing to the technology innovation system of a territory. This new representation of knowledge and capitals fluxes is reported in Figure 2. We may notice that the technology innovation activity is not only represented by R&D projects, but also by startups with an activity that, may include R&D projects, but also the development of business models suitable for the new technologies. Furthermore, industrial platforms do not directly generate new technologies but they do it through the R&D projects and startups active in their structures. In this model the flux of capitals does not only concern industrial capital financing R&D projects, but also venture capital which finances new startups. In conclusion, this technology innovation model considers that there is a distributed innovation activity in the territory, not only consisting in industrial R&D, but also in contract research, startups, corporate venture funding, industrial co-operations, technology trade, and so on (Haour, 2004), this happening in the frame of a system of open innovation (Chesbrough, 2003).

Taking in account the existing differences from a territorial innovation system based on R&D projects only, it is possible to develop a mathematical model simulating the innovation activity by considering suitable modifications of the previous mathematical model of R&D activities (Bonomi, 2017b). Similarly to the previous simulation model, the mathematical model of a technological innovation system of a territory is based on the following assumptions:

- The generation of new technologies is based on both activities of R&D projects and startups.
- Some of these new technologies become successful with a high ROI, contributing to the economic growth of the territory.

- The innovation activity is seen as a number of cycles, each fed by some R&D projects and startups, and generating some new technologies. This means that the model considers that each R&D project or startup either develops a new technology or it is abandoned within the time of a cycle.
- We consider that the flux of knowledge within the system is formed by some information packages, generated by each successful or abandoned R&D project or startup, and by additional knowledge coming from platforms and from external sources.
- Proposals for new R&D projects and startups result from a combination of these packages, and are followed by a selection for financing.

As in the previous model (Bonomi,2017b) the mathematical model considers knowledge as composed by a certain number of information packages, as previously quoted in the assumptions of the model. That means that each R&D project or startup, successful or abandoned, generates an average number of information packages. The number of packages generated by startups is considered higher than that of R&D projects accounting the generation of knowledge also concerning business models. The total knowledge generated in a cycle by R&D projects and startups is increased by knowledge from past cycles, although reduced by a fading effect. Furthermore, this knowledge is increased by a fraction of knowledge originated from the activities of industrial platforms, and by a fraction concerning external knowledge of scientific, technical or other nature. The number of potentially innovative ideas can be obtained by a combinatorial calculation that considers that of available information packages. This usually yields many potentially innovative ideas, many of which are valid or even absurd, and it is the task of the innovation system of the territory to select valid ideas for R&D projects or startups proposals. The rate of formation of proposals will depend on the innovative efficiency of the territory. In order to calculate the number of successful technologies obtained, we consider below different selection rates related to;

- the actual number of R&D projects and startups that are financed for a development;
- the number of R&D projects and startups generating new technologies;
- the number of successful technologies resulting from new technologies developed by R&D projects or startups.

It shall be noted that the various rates concerning the selection for financing, the rate of generation of new technologies and the rate of development of successful technologies may be different in the case of R&D projects or startups. This is a consequence of the fact that radical innovations, typically developed by startups, have a lower probability to be fully developed and, moreover, in case of success, they have a higher probability to have great returns of investments than incremental innovations, typically developed by industrial R&D projects (Bonomi, 2020). Consequently, the rate of development of new technologies from startups will be lower than from R&D projects. On the contrary, the rate of formation of successful technologies from startups will be higher than from R&D projects.

2.1. Description of the mathematical model

The mathematical model considers the innovation activity of a territory formed by N_p number of R&D projects and N_s number of startups. Each cycle activity will be characterized by a total number N resulting by the sum of N_P of R&D projects and N_s of startups following the equations:

$$N = N_s + N_p \qquad N_s = bN \qquad N_p = (1 - b)N \quad (1)$$

in which b represents the fraction of startups participating in the activity. At the beginning, the model calculates the amount of knowledge available for the generation of R&D projects and startups. It is considered on the average that each R&D project generates p information packages, and each startup q information packages. The total number I_T of information packages generated by either successful or abandoned R&D projects and startups, and by additional knowledge, may be calculated by the following equation:

$$I_T = [(pN_{p(L)} + qN_{s(L)}) + \sum_{i=1}^{n} I_i(1-f)](1 + k + e) \quad (2)$$

in which we have:

I_T: total number of information packages available for new innovative ideas after the last cycle
$N_{p(L)}$: number of R&D projects in the last considered cycle
$N_{s(L)}$: number of startups in the last considered cycle
p: average number of information packages accompanying each R&D project
q: average number of information packages accompanying each startup
n: number of past cycles
I_i: number of available information packages of the past cycles from i = 1 to i = n
f: rate of fading effect (*)
k: fraction of added information packages by industrial platforms
e: fraction of added information packages by external knowledge

(*) It shall be noted that for remaining information packages of past cycles we intend that the initial number of information packages of a cycle is reduced by a fading effect f at each successive cycle before the last one. With $f = 0$ the fading effect is not present and with $f = 1$ there is a complete loss of past information packages.

Considering that a potentially innovative idea may be obtained by the combination of m available information packages, the number of potentially innovative generated ideas G is obtained by a combinatory calculation based on the number of available information packages I_T through the following equation:

$$G = I_T (I_T - 1)/m \quad (3)$$

The number P of obtained R&D projects and startups proposals is actually a small fraction of G, and it depends on the innovative efficiency of the territory in exploiting the available knowledge and is represented by the rate s. This rate might be different following the case of R&D projects or startups proposals. Likewise, it is possible to calculate the number N of financed startups and R&D projects considering a rate t for financing proposals, a rate that also might be different for R&D projects or startups. To simplify the calculations, we have assumed that all R&D projects and startups proposals, calculated with the same rate s, were financed, and then adopting $t = 1$ in every case. The development of new technologies can be calculated from these numbers of financed N_p R&D projects and N_s startups, following equation (1), which considers a rate v for R&D projects and a rate w for startups. In this way, it is possible to calculate the total number T of new technologies:

$$T = vN_p + wN_s \quad (4)$$

In addition, the formation of new successful technologies S can be calculated considering a rate r for new technologies from R&D and a rate z for new technologies from startups by:

$$S = rvN_p + zwN_s \quad (5)$$

Thus, it is possible to calculate the total number S of successful technologies formed in a cycle, and of values formed in the following cycles. All variables and parameters used by the model are reported in Table 1.

2.2. Example of calculation with the model

The model has been used to calculate the number of formed successful new technologies as a function of a sequence of cycles for three scenarios. The first one, considered as a reference, with only industrial R&D activity (*b* and *k* = 0); the second one, with R&D and startup activity but without any industrial platform (*k* = 0); the third one, with R&D activity and industrial platforms but without any startup activity (*b* = 0). In this way, it is possible to observe separately the variation of number of new successful technologies, compared with industrial R&D activity only, in case of presence of startups or industrial platforms. As previously noted, for these calculations, we have adopted a drastic simplification considering all proposals of R&D projects or startups as financed (*t* = 1), and the total number N of R&D projects and startups proposals as obtained from the amount of potentially innovative ideas by using a unique rate for parameter *s* = 0.0025. The parametric values used for running the model are reported in Table 2. Most of the values of these parameters are indicative and they are based on R&D and startup activities' experience. Some of them derive from studies on the success rate of startups (Bonomi, 2019) or from successful patents derived from R&D projects (Scherer & Haroff, 2000) in forming successful technologies. We discuss the justification for the choice of the values of the parameters concerning the various types of selection rates and generation of proposals in the next section. The model calculations have been made by using an Excel® sheet derived from the model represented in Figure 2, and by introducing the mathematical equations in the suitable case position. The calculations have been made starting from the initial number N of R&D projects and startups equal to 100, and recording the results of each cycle. The results are presented in Figure 3 reporting the number of successful technologies obtained after three cycles for the three adopted scenarios:

- *b* = 0   *k* = 0: presence of R&D projects activity only
- *b* = 0.2   *k* = 0: presence of R&D projects, startups but no industrial platform
- *b* = 0   *k* = 0.2: presence of R&D projects, industrial platforms but no startups

It is possible to observe that both the presence of startups and industrial platforms increases the number of formed successful technologies compared with the presence of industrial R&D projects activity only. Apparently, the impact of startups is higher than that of industrial platforms. However, it shall be noted that industrial platforms are only at the beginning of their diffusion and a detailed knowledge of their impact on the technology innovation system, represented by parameter *k*, is not well known. Continuing the calculation for the fourth cycle, the number of successful technologies formed becomes unreasonably high, with more than a hundred of successful technologies, and this result will be discussed in the next section.

3. DISCUSSION ON THE MODEL AND ITS RESULTS

It should be noted, before all, that a technology innovation system of a territory is highly complex and the simulation made by this model is only a rough representation. This combined with the possibility of only using indicative and uncertain parametric values for its functioning, makes the model more of a toy than a simulation model. However, we think that it may show some interesting aspects of the behaviour of technology innovation system of a territory owning the various structures, which organize knowledge and capitals fluxes when generating new technologies. As a consequence, we obtain an average generalization of the activities of the various institutional organizations operating in a territory with their different behaviour and efficiency. A critical key aspect of the model concerns the generation of R&D projects and startups proposals from available knowledge, with differences in efficiency according to the different territories, accompanied by uncertainty about the value that can be used for the calculations. Another critical key element of the model is the financing rate of selection of R&D projects and startups. This can vary with time depending on adopted financial strategies and capital availability of industrial and venture capital. The number of developed new technologies, and formed successful technologies depends, on one hand on the combinatory possibilities of the generation of innovative ideas and, on the other hand, on the availability of capitals. This makes the possibility of financing the enormous number of R&D projects and startups unrealistic. This number results from the combinatory calculation of innovative ideas, as observed by running the model with the increase in the number of cycles. This is a consequence of the adopted approximation that considers the existence of financing capitals for all presented R&D projects and startups proposals. Indeed, capitals availability has always a limit, and another limit can also be the availability of human resources and facilities for the R&D activity. Concerning the observed positive impact of startups and industrial platform in generating successful technologies in a territory, also observed from territorial experiences, the positive impact is evident in the case of industrial platforms, as they supply additional knowledge fostering the generation of innovative ideas, and subsequently of successful technologies. In the case of the startups, it is necessary to give an explanation. In fact, the formation on one hand of successful technologies by startups is favored by the high degree of radicality of the developed technologies, on the other hand, the high degree of radicality increases the rate of abandonment of startups development (Bonomi, 2020). Actually, it is the venture capital, together with the necessity to close positively its financial cycle, that makes necessarily the right selection and support to startups. The consequence is the development of a high number of successful technologies with good sale conditions to industry or the industrialization of the startups (Bonomi, 2019). This justifies the positive influence of startups in the technology innovation system of a territory.

Concluding, it is not the aim or ability of this model to simulate the real innovation activity of a territory with quantitative results in accord with empirical evidence. Its objective is to identify the processes in the technology innovation system of a territory, seen as an organizational system based on knowledge and capital fluxes. This means that the model is an attempt to show how the technology innovation activity works in a territory, regardless of the type of existing institutional R&D organizations, and industrial or economic factors, and thus the model valid for any institutional, industrial or economic situation in a territory. This view may be useful in technology and R&D management in determining the role of certain factors for innovation such as the conservation of past and external knowledge, the necessary combinatory creativity for innovative ideas and the possible financing strategies of selection of R&D projects or startups. Others activities that may be interested by the model are the case of statistical studies that would consider in depth the technology innovation process in the elaboration of territorial policies for innovation. Finally, differently from current views on the technology innovation systems, takes in account the presence of industrial platforms, supplying additional knowledge and then innovative ideas for the system. We consider that their possible future diffusion, with the development of platform networks, could modify deeply in future the functioning of the technology innovation systems (Bonomi, 2020).

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5. TABLES

Table 1. List of variables and parameters of the model

List of variables
N : total number of R&D projects and startups of a cycle
N_p : number of R&D projects
N_s : number of startups
$N_{p(L)}$: number of R&D projects in the last considered cycle
$N_{s(L)}$: number of startups in the last considered cycle
T : number of formed new technologies
S : number of formed successful technologies
I_T : total number of available information packages after the last cycle
G : number of potentially innovative ideas
P : number of innovative ideas for R&D projects and startups proposals
List of parameters
b : rate of startups on the total number N
v : rate of new technologies formed from R&D projects
w : rate of new technologies formed from startups
r : rate of formation of successful technology on number of technologies formed by R&D projects
z : rate of formation of successful technology on number of technologies formed by startups
p : average number of information packages of each R&D project
q : average number of information packages of each startup
n : number of past cycles
I_i : number of remaining information packages of past cycles from i = 1 to i = n
f : rate of fading effect
k : fraction of added information packages by industrial platforms
e : fraction of added information packages by external knowledge
s : rate of the innovative system efficiency
t : rate of selection of R&D projects and startup proposals
m: combinatory number for generation of potential innovations

Table 2. Parametric values used for the application of the model

b : rate of startups on the total number N	0 – 0.2
v : rate of new technologies formed from R&D projects	0.025
w : rate of new technologies formed from startups	0.015
r : rate of formation of successful technology from R&D projects	0.2
z : rate of formation of successful technology from startups	0.9
p : average number of information packages of each R&D project	3
q : average number of information packages of each startup	4
f : rate of fading effect	0.5
k : fraction of added information packages by industrial platforms	0 - 0.2
e : fraction of added information packages by external knowledge	0.1
s : rate of the innovative system efficiency	0.0025
t : rate of selection of R&D projects and startup proposals	1
m : combinatory number for generation of potential innovations	2

6. FIGURES

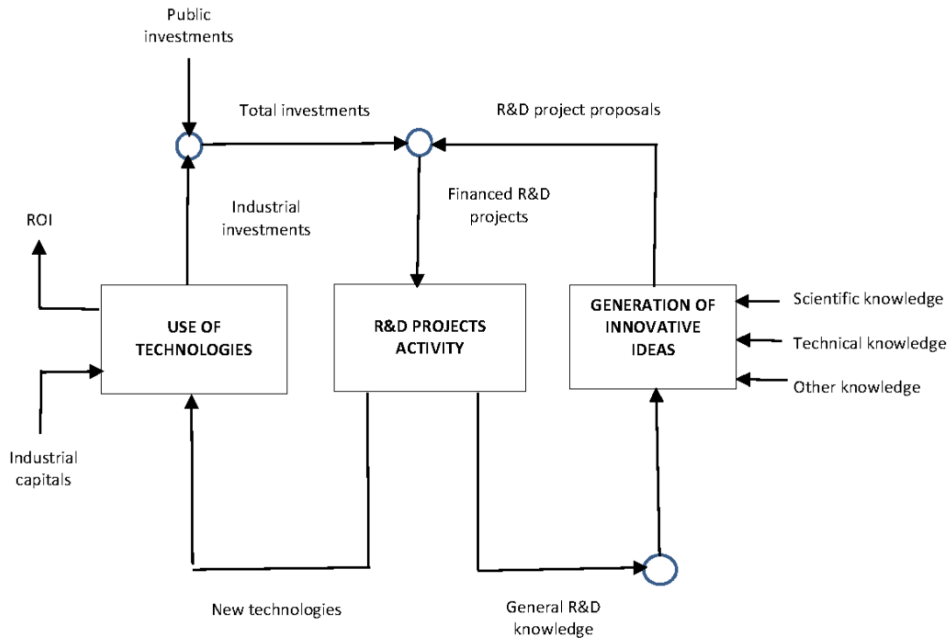

Figure 1. Flows of knowledge and capitals in the industrial R&D system of a territory.

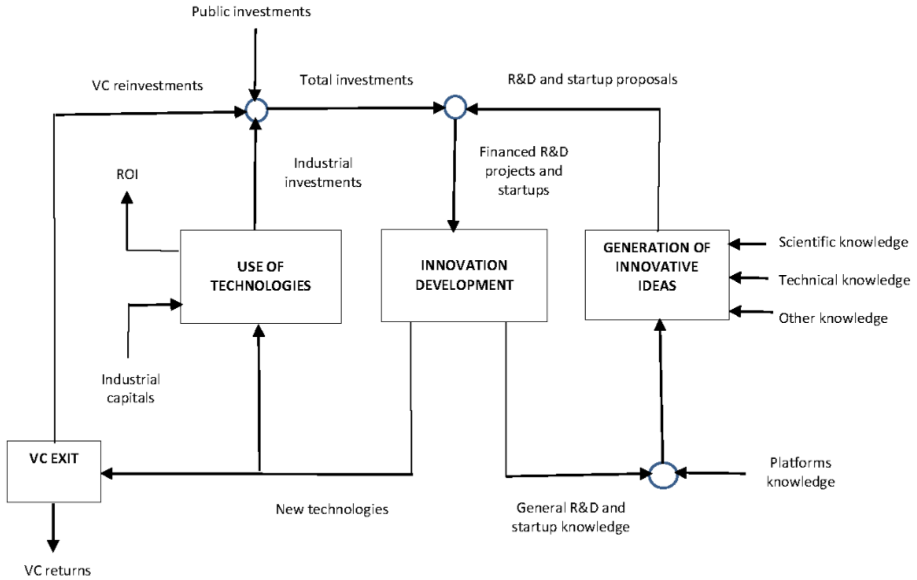

Figure 2. Flows of knowledge and capitals in the technology innovation system of a territory.

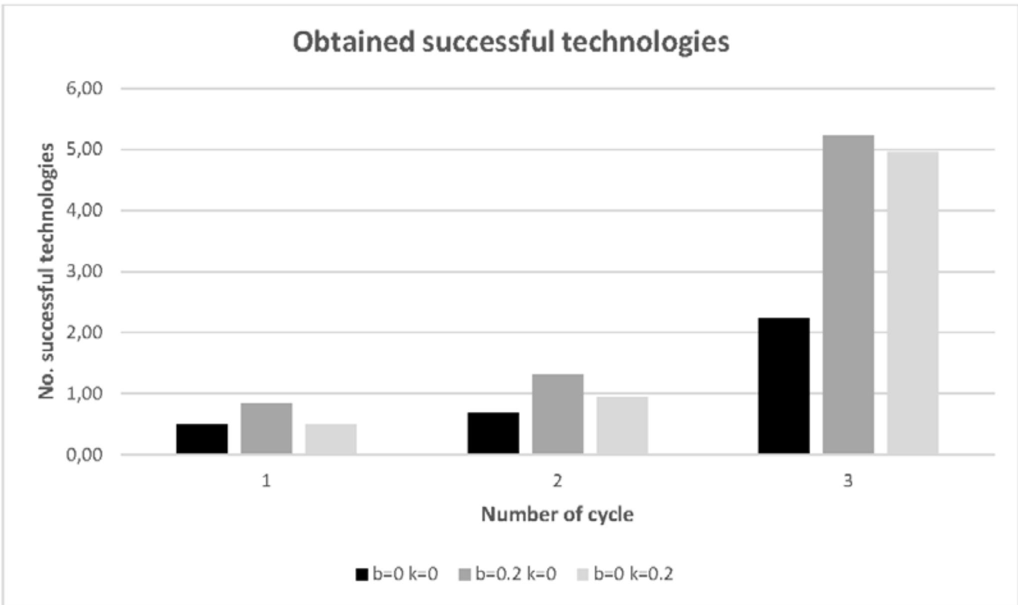

Figure 3. Number of obtained successful technologies after three cycles.

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The technology innovation of a territory is considered as the result of R&D activity. This view represents the basis for statistical studies of innovation guidelines. However, studies on technology dynamics have shown that technology innovation is also the result of organizations, other than R&D, such as the startup-venture capital or the industrial platform systems, which differ in terms of financial strategies or generation of knowledge. In this paper, we develop a mathematical simulation model of a technology innovation of a territory in which all these three organizations are operating by calculating the number of developed successful technologies, which are considered as triggers of the economic growth. The results show that both startups and industrial platforms boost the formation of successful technologies compared to industrial R&D activity only. Due to the uncertainty of the parameters used, this model is just a rough representation of the reality. However, it presents a detailed description of the processes of generation, use of knowledge, and new technologies' development. Regardless of industrial or economic factors, this model is still valid for any industrial or economic situation. Its descriptions and results may be useful in R&D and technology management as well as in statistical studies for the innovation policies of a territory.

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