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Innovation Emergence: Public Policies versus Actors' Free Interaction

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Received: 25 February 2018; Accepted: 18 April 2018; Published: 3 May 2018

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Abstract: The main argument of this work is that innovation flourishes and emerges in a creative environment where the actors interact freely, to the extent that this environment is a complex adaptive system. Public or institutional policies, trying to induce innovation, must be careful to not stifle or interrupt the emergence of novelties in the path from creation and conception to market involvement. Our proposed model argues that innovation emerges wherever evolution, learning, mutation, and competition between individuals and firms are permitted, without restrictions or pre-defined paths to the market. We describe two cases of innovation by way of example: the first case shows how several—and sometimes anonymous—elements interact and compete in a typical environment of innovation, while the second case shows how continuous policies to foment innovation may create results to the contrary. In addition, we show technology clusters as cases where the emergence of innovation can be fostered by policies that observe the complex adaptive system characteristics.

Keywords: Innovation; emergence; complex system; complex adaptive system; Global Innovation Index; cluster; technology cluster

1. Introduction

The word "innovation" has gained popularity in recent decades in business, economic, and social environments, especially after the boost of successful companies in the age of the internet. The internet, the virtual world, and everything associated with computers and the like are related to and recognized as "innovation". In this sense, Silicon Valley is accepted as the mecca of innovation, where the most powerful e-companies have started, sometimes in home garages, of which the history has countless examples, even to this day [1–4]. The study of innovation has had a great contribution to the work of Schumpeter, as can be observed when he affirmed that "the fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates" [5]. Here, he connects the growth of the economy with the continuous revolution of methods, markets, and processes; revolution given by the "Creative Destruction" of old forms, systems, and methods, replaced by new ones. Curiously, Schumpeter used the word innovation only twice in his book, but the term is the flag for what came after him in this matter.

If innovation is so powerful as to generate wealth, why not prioritize and pursue it? This is the question that arises in several parts of the world and specifically in what is known as the "developing world". However, how to pursue innovation? What is its secret? Perhaps, there is not a secret, but countries, associations, institutions, and organizations, in general, have understood that a solution could be to imitate the successful cases. Mimicking the processes and methods of these cases through the establishment of public or institutional policies could induce innovation in a determined region or organization—or at least that is what many managers and governors have imagined and desired over the years. Is it possible? This has been the academic, industrial, and political debate over the years, to which we hope to contribute by connecting the innovation process to the complex adaptive systems theory.

The emergence of innovation: is it the outcome of public and institutional policies or of the actors' free interaction? This question is underlying the reflections of our study. In Section 2, we propose a model, which considers innovation to be the result of a process that begins with the interaction between the very basic elements of the economic environment; it emerges, or not, depending on the conditions of several levels of a process that must scaled to reach success. To understand the principles that govern this whole environment, in Section 3, we review briefly the theories of complex adaptive systems and justify why these systems are the basis for innovation. In Section 4, we discuss two cases of innovation, one successful and the other unfruitful, and also present technology clusters as an interesting solution where bottom-up and top-down initiatives can be combined to reinforce the innovation process. Section 5 presents our conclusions, the limitations and implications of the work, followed by final reflections. The methodology adopted is based on a theoretical approach to propose a hypothetical model of innovation, exploring firstly the evolution of theories of complex adaptive system, followed by case studies to exemplify an argumentative text about the model. Despite the fact that this is not a confirmatory approach, the examples show patterns of innovation to fit the model.

Before we go on, the comment of Schumpeter is noteworthy, considering the process of biological evolution (a central idea of complexity) analogous to innovation as a "process of industrial mutation—if I may use that biological term—that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism" [5].

2. Innovation Model

Innovation is an outcome of the business market, which is a complex adaptive system where the constituent elements, or agents/actors, are individuals and firms in hierarchical levels and with inherent characteristics. In our model, innovation emerges from the lowest levels of the hierarchy (bottom-up processes). Emergent hierarchical processes are dynamic, evolutionary, and dependent on the lower-level agents and their interactions. Public or governmental policies are typically actions on the upper levels of the hierarchy (top-down processes). These policies may help the emergence of the innovation if they are well-designed to respect the ongoing and self-reinforced dynamics of the innovation process coming from the lowest levels, if such movements have emerged. Policies may not work if rules are created to induce innovation, and there are no agents interacting in the lower levels to engage with these rules.

The business market is the ecosystem for innovation, where elements interact all the time. This ecosystem is built by several actors, such as individuals, firms, and institutions, where the individuals are the simplest forms. The individuals can act by themselves or arranged in groups and subgroups, as firms and departments within the firms, or in clusters of firms, and so on, defining several levels of hierarchy in the ecosystem. The interactions, or signals between the elements, are the commercial transactions, the ideas and information exchanging, agreements, contracts, and other kinds of relations alike. These signals flow between the elements of the system and within the level of each one, and when the signals flow between the subgroups or groups, they happen in the level above. Elements react to entry signals depending on the individual culture (in the lowest level), on the group organizational culture (in upper levels), and also on the costumes and traditions of a region or nation. Lack of freedom to exchange ideas and creativity reduces the strength of interactions and limits the network's expansion and its dynamics. The growing of innovation occurs from level to level, climbing these levels according to the evolution process and according to the path of the innovation, meaning that the choice of a wrong path may interrupt its flourishment.

Institutions are part of this ecosystem, considering here educational institutions, governmental structures, foundations, associations, and similar organizations that interfere in the market. Despite the fact that, in general, these institutions are not in the center of commercial transactions, they affect it profoundly either for the best or for the worst when they contribute to interaction (such as educational and communication systems), when they establish rules and taxes (like the acts of governmental departments), and when they improve the general infrastructure and facilities, for instance.

Considering the above assumptions, our model of innovation has the following propositions:

1. The market is a complex adaptive system;
2. Innovation is an emergent outcome of this system (bottom-up);
3. The emergence of innovation comes from a series of small events;
4. These events occur through the interaction of elements (actors);
5. Elements interact in a high-degree of freedom;
6. Innovation happens dynamically, in the time domain;
7. Innovation is path-dependent, while it emerges level by level; and
8. Public and governmental policies are top-down actions.

This model does not cover all the characteristics of innovation and does not discuss such things as creativity or the psychology of the elements, whether they are the individuals, the companies, or groups of people of a nation. The model covers the aspect of how innovation, as a fact of a simple sector or of a whole market, evolves and grows. Despite the fact that we cannot prove the model without a very extensive list of case studies, and that it is perhaps impossible to do so due to the uncountable number of variables with which to deal, we show in this paper two opposite cases of innovation and a description of technology clusters. These cases are illustrations to help us demonstrate how the innovation processes work in complex adaptive systems.

For more than a century, innovation in research, products, and business has been happening incessantly in the region known as Silicon Valley, California. Is it a result of public and institutional policies or an emergent process coming from unknown/anonymous actors? On the other hand, Brazil has been pursuing innovation for decades, but several indicators show that failures are followed by failures persistently. On the other hand, technology clusters around the world seem to show good results when the interaction of elements in the lower levels of the hierarchy are combined with dedicated and well-addressed public policies from its upper levels.

But, before we go to these cases, we provide a basic overview of some theories of complex systems in the following section.

3. Complex Systems

This section offers a brief review of complex systems theory: its development from the beginning of the 20th century through recent findings and its relations to the theme of innovation that we propose here. Complex sciences and systems are fields with no consensus, as some researchers are still confounding complex systems with complicated systems or with networks. However, several concepts are well-consolidated, even though there is still no general framework with which to define or constrain them.

A pioneering explanation of complexity came from Warren Weaver in 1948 [6], defining it in three aspects: simplicity, organized complexity, and disorganized complexity. These concepts are arranged in three different regions according to the number of variables involved. In his view, the first region, simplicity, has just two variables with which to deal. Physical sciences were concerned with two-variable problems before the 1900s, using traditional calculus for modeling their problems. The other extreme is the third region—that of disorganized complexity. This region has uncountable variables, which have been treated by powerful advances in statistics and probability theory in the 20th century. Between these two extremes, from two-variables to uncountable variables, is the middle region of organized complexity, a region of a large but countable number of variables. This second region has complex problems that involve new techniques and mathematical tools to deal with a sizeable number of factors, interrelated as a whole and with an organic behavior [6]. The boundaries between the second and third regions are defined by the problem that must be addressed; that is, the region must be delimited to find a closed group of elements (variables), and then, new techniques must work with elements that interact and change organically (network theory fits here, but with constraints with respect to the dynamic of the system). Figure 1 illustrates a suggestion of this view of complexity, including the mathematical tools as distributed along the regions. From this view, we understand innovation as occupying the middle region, where one can find a group of actors (individuals and/or firms) interacting in a determined place and focusing on certain technologies—that is, countable variables interacting and changing as time goes by.

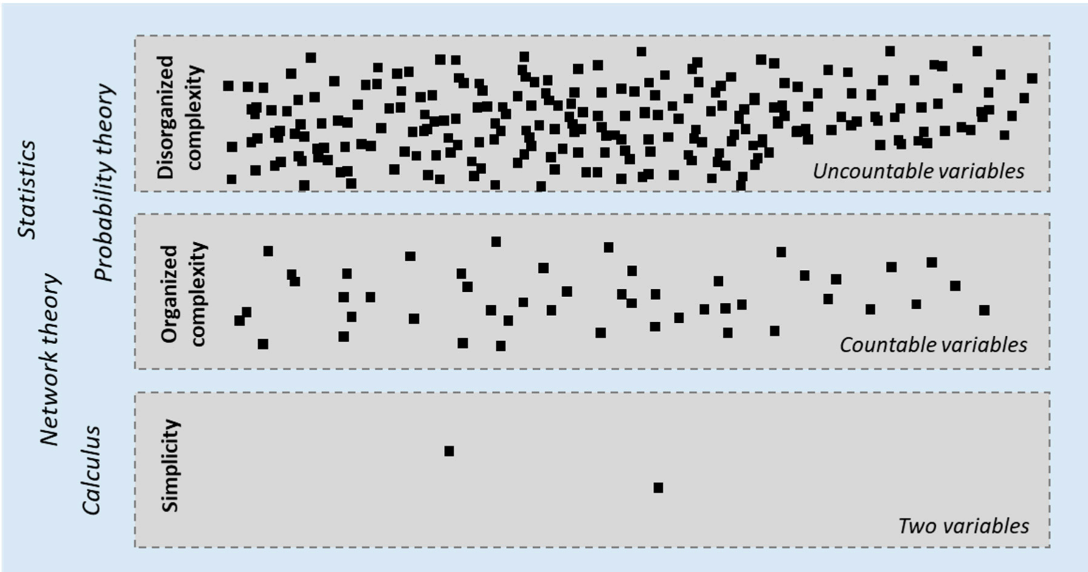

Figure 1. Complexity distributed in the three regions of simplicity, organized complexity, and disorganized complexity. An adaptation of the Weaver's concept [6] and the applicable mathematical tools.

Going beyond this initial (but very inspirational) view of regions of complexity accordingly to the number of variables, in 1962, Herbert Simon [7] defined an architecture of complexity by searching for common properties among several different complex systems described in his work. The main property he found is hierarchy; that is, complex systems are composed of subsystems, and these subsystems are composed of their own subsystems and so on. The emergence of the evolutionary process is another property, and this evolution obeys the hierarchy of the system through paths from level to level. The third property of this architecture is that evolution is dynamic in these hierarchically organized systems. Simon argues that evolution is random: complex forms arise from the simplest ones randomly. The direction of evolution is given by the stability of the complex forms, where stable forms mean "fittest forms" [7]. Therefore, this can be viewed as survival of the fittest, and as an example, problem-solving is a kind of natural selection, because it requires selective trial and error. Here, again, the innovation process complies with the theory. It is a process of problem-solving, and solutions emerge in natural selection due to the relationships between the simplest forms evolving into more complex ones (i.e., the successful solutions). Communication within the whole complex system occurs according to the position in the hierarchy. Communication between members is within the boundaries of the subsystem to which these members belong, and communication between the subsystems, in general, occurs in the superior hierarchical level. Of course, this is an assumption of formal communication, because other kinds of communication can be established [7]. Systems in which boundaries are loose and more relaxed favor innovation, because communication happens through the internal boundaries of the hierarchy (intrasystem) and externally to other systems (intersystem).

As the theme of complexity has gained projection in the literature, science and “pseudo-science” have disputed the arena of ideas in several papers, courses, books, institutes, and “best-sellers”. In his efforts to clarify the boundaries between science and pseudo-science when talking about complexity, Steven Phelan refined several concepts about the theme, questioning: what is complexity science, really? [8]. First of all, in his work, he regards complexity as a new science. A new science because it looks for methods to study regularities, instead of the traditional way that science focuses on cause–effect relationships. Complexity arises from simple rules, by agents interacting within their environment over time, with feedback and learning always present in the dynamical process [8]. In addition to the keywords of hierarchy, emergence, and evolution (from Simon), he adds feedback, learning, interaction, and simple rules. In fact, these concepts are already embodied in the previous three works, but Phelan more precisely defines how the processes work.

Assuming economy as a complex system in his theory about path dependence and increasing returns, Brian Arthur [9] says that this kind of system is evolving and unfolding all the time. Path dependence typically occurs in hierarchical models, and increasing returns in the economy are dynamical processes from random events with positive feedbacks. The evolution of the system depends on random events through the interaction of the elements and the lack of central control. For Arthur, if this is the case, government policies for the economy should avoid the two extremes: coercing the desired outcome or remaining completely hands-off. Policies to coerce an outcome will not work, because the outcomes will be the results of dynamical processes from random events. In his opinion, government policies could be useful if they just favor structures that could emerge naturally [9]. Innovation is at the heart of these random events, and clearly it is a question of emergence.

Complexity continues to raise questions about its existence as a science, in part because there is neither a framework to define it, nor methods or models to conform it exactly. Perhaps this sense comes from its own evasive nature. To answer the question of what constitutes a complex system, Ladyman, Lambert, and Wiesner [10] did a deep review of the ideas of the complexity problem and whether there is such a thing as complexity science. In their research, a tentative definition of complexity considers (as a physical account of complexity) that a “complex system is an ensemble of many elements which are interacting in a disordered way, resulting in robust organization and memory” [10]. From this, we can derive characteristics, such as emergence, hierarchy, and learning processes, which could be linear or non-linear, coming from disorder to order all the time through interactions with no central control. Several concepts described in the previous paragraphs are synthesized here, and the concept of “disorder and order” is deepened, because this definition reflects that cycles of disorder and order follow each other all the time (it is the process of evolution). In addition, it considers both linear and non-linear processes as possible characteristics of complex systems. Innovation fits these characteristics fully, as market novelties enforce a cycle of a transitory disorder followed by order and so on. If the market has a powerful central control, then it may suppress or stifle the innovative process when trying to control these disruptive novelties (trying to control, paradoxically, the “Creative Destruction” [5]).

Emergence from chaos into order in a hierarchical process has unfolding outcomes that derive from distinctive models: the metaphor and the “source-target” model. These ideas are proposed by John Holland [11] to talk about the process of emergence and its relationship to innovation in a complex adaptive system. In his view, metaphor and the “source-target” model result in innovation, because both enable us to see new connections. Creativity is inherent to innovation, and it only works when multiple parts of the “ideas” (or “building blocks”, in his words) are well-known by the “creator”. For him, innovation demands a target from the starting point of creation, and the mechanisms of the creative process are akin to those of evolutionary selection in complex systems. A small number of rules can generate systems of complexity when changing over time. This changing occurs when elements interact and have the capacity to adapt and learn without a central control. John Holland says then that innovation results not from a deductive process, but from a metaphor-driven process, which is intuitive and insightful [11]. Thus, by including intuition and insightfulness as underlying processes, which are contrary to the deductive and the over-oriented processes, he agrees with the idea that innovation comes from a bottom-up, natural process. Nonetheless, we must observe that intuition, insightfulness, and metaphor are characteristics inherent in the elements (individuals), and these characteristics will affect the behavior of the system through the interaction process. (The discussion about these inherent characteristics escapes the scope of the present article and will be addressed in a future work.)

The conceptual development of complex systems and complexity sciences brings questions about what methods and techniques could be useful to approach problems on this matter. Among several methods and techniques, one theory to deal with complex models is the network theory. Borgatti and Halgin in their text about the context of the network theory [12] explain Granovetter's idea of the "strength of weak ties" [13]. This concept shows that bridging ties is a potential source of new ideas and innovation in a context of a complex system with connected networks interacting. For example, if we have two dense networks connected through a bridge, one element from one network can hear things from the other network that are not circulating among his own network [12]. The theory shows that weak ties are likely to be bridges, and only through bridges can the novelties flow. If clusters of firms have bridges among them, these novelties will flow freely, and innovation can flourish. If there are barriers and no bridges—that is, the firms are closed in on themselves and strong relations are inside their walls—probably innovation will not be fostered.

Nevertheless, weak ties—the bridges—are the perception of a network in a determined moment, the static picture from a network. John Holland [14] refers to the "network theory" as graph theory, and for its use on complex adaptive systems, he understands that we must go beyond static networks and examine the mechanisms that make networks change. The problem is that studies on changing networks are still under-researched. Static networks can be used just as a way of sharpening intuition. For Holland, the evolution and coevolution of networks go well beyond network studies, because networks change as agents co-adapt. External changed affect boundaries and the possibilities of interaction; internal changes affect interior signal processing. Innovation is dynamic; it cannot be depicted from a static network. Studies of weak ties, centrality, betweenness, and the like are not sufficient for its analysis, because the agents have continuous changes in their boundaries and signals, as Holland says [14].

This perspective of continuous changing, evolution, and free interaction of the simplest elements in the network is the basis for the discussion that follows in Section 4.

4. Discussion

This section presents the case of the long-lasting success of innovation in Silicon Valley, which has resulted from a profound process of interaction between creative elements. Then, this section discusses the case of the successive failures of Brazilian innovation, where public policies and growing investments have resulted in decreasing market novelties and lower quality of education. Finally, this section shows the example of technology clusters and incubators as a kind of intermediary solution, where bottom-up and top-down initiatives can go hand in hand to develop innovation. The idea is to depict the model using cases to illustrate it in different forms: when the actors' free interaction results in robust innovation, in the first case; when public policies do not achieve good outcomes, in the second case; and how technology clusters could work as examples of successful integration of processes coming from opposite levels of the system hierarchy.

4.1. Silicon Valley, California

Studies have tried to understand the development of Silicon Valley's industry and how innovation is so strong in this region. Some superficial opinions have talked about its sudden rise during the 1960s despite its lack of prior industrial history. However, this is not the case. The work from Sturgeon [1] traces the movement back since before World War I, when the radio industry began in the San Francisco

Bay Area, with its successors unfolding in telegraphy, electronics, television, and military products. For sure, this kind of development was also happening elsewhere in the country, but the Bay Area had cultural aspects that fertilized decades of continuous innovation in a very broad range. Sturgeon emphasizes its environment of creation, where elements (individuals and firms) move freely in their spaces, provoking movement and agitation, which grows as time goes by [1]. Elements interact with each other loosely and, from this interaction, information and knowledge flowed (and flow) freely, with no control. Inventions have commercial protection (by patents), and rights are respected. Cooperative relations are a common sense rule. All these characteristics are adherent to the complex system theory, shown in the previous section. Sturgeon observes that cooperative relations between elements create dense groups that unfold in new groups (spin-offs). These new groups grow again, and relations are maintained between groups and subgroups. Here is a clear connection to the theory of Granovetter's "strength of weak ties" concept [13], when bridges link groups despite the fact that sometimes these groups are competing firms. These interactions allow new ideas, creativity, and innovation, because the interaction is open in the sense that no barriers disturb the interchange of ideas. When discussing Silicon Valley's long-lasting success, Sturgeon says that the best results in innovation come when three skills are wedded: "practical mechanical brilliance", "advanced technical training", and "theoretical knowledge". These skills need time and persistence to be acquired, and they can be in talented individuals or groups of individuals interacting. As we can see, the complex system's keywords are repeating themselves here: elements; interaction; and no central control.

Kenney and von Burg [2] talk about the creation and growth of Silicon Valley in terms of path dependency, as the concept was defined by Arthur [9]. For them, innovation is a non-deterministic process; it is path-dependent. They argue that paths are a creation of human actors when interacting over time, and path dependency is intimately related to path creation. Decisions in a moment of history will reverberate through certain paths, closing some of them, validating others or even just one path. The validation of a path is not necessarily a rational process, and path dependence accepts the fact that even small events can have large effects and impacts. Social constructions and strategic maneuvering are critical for these paths when the environment is non-deterministic [2]. Kenney and von Burg argue that technological advance is the result of the interaction of path-dependent processes, which are in these cases the actions of actors—individuals creating and reshaping the nature of institutions and organizations. That is, technological advance is a result of a culture of creation not of just a policy. They use as examples the tech industries in Silicon Valley, such as Hewlett Packard (founded in the 1930s), IBM, Ampex, Xerox, and many others since the 1940s and 1950s, just to cite a few. Kenney and von Burg consider Silicon Valley's success to be the result of two interrelated economies: one that includes several firms of hardware and software of all dimensions and also universities; and another that includes companies of venture capital, specialized lawyers, consultants, and accountants [2]. When discussing the first group, they found that a dense block of semiconductor firms created conditions for even more semiconductor firms. Why? The turbulence that comes from inter-firm and intra-firm relations opens space for the emergence of new products, new ideas, and, sometimes, entire new industrial categories. Spin-offs appear when a new idea is blocked internally in a company. But for a spin-off to be launched there must be an ecosystem that nurtures this new type of firm. Then, the interaction between firms and economies is the keyword for innovation [2].

The work of Saxenian [3] compares the evolution of innovation in Silicon Valley and in the Route 128 beltway around Boston, Massachusetts, because, despite the apparent similarities between both regions, they had divergent performance over the same period of time. From this study, several findings arise to confirm innovation as a typical adaptive system. Similar firms concentrated in a specific region gain the benefits of self-reinforcement through a dynamic process of increasing returns, which is a concept defined by Arthur [9]. Companies in Silicon Valley compete intensely among themselves, but, nevertheless, there is an informal environment of communication and collaboration; that is, despite the competition, the relationships are strong, and information flows freely, horizontally. Boundaries between firms, universities, and institutions are porous [3], describing an environment where bridges shape weak ties between them (Granovetter, [13]). On the other hand, the Route 128 companies persist in secrecy and corporate loyalty, where information flows vertically inside them. Here, there are no bridges; groups and subgroups are closed and internally connected. Saxenian also found that the high performance of Silicon Valley cannot be attributed to the differences in costs, taxes, or wages. The most strategic relationships are local and face-to-face, because high technology is fast-changing, uncertain, and complex. Therefore, it depends on individuals' relationships, even exchanging information through competing firms. The local culture of Silicon Valley institutionalized practices of informal cooperation and exchange and from this came a process of collective learning in the region. On the other hand, Route 128 was risk-averse and committed to formality, institutional hierarchy, and long-term stability [3]. The Route 128 environment discouraged free relationships and thereby, continuous learning.

When studying the continuous success of Silicon Valley, Zhang [4] found the same as Kenney and von Burg [2]: this success comes from the constant emergence of successful start-ups, where the venture capital and high-tech industries grew and matured together, side by side as "two economies" strongly intertwined. Analyzing several cases of new companies, Zhang noticed that the founders of new start-ups were employees of incumbent firms, which shows the phenomenon of emergence coming from the interactions of individuals in a hierarchical system; that is to say, elements in one level interact and then come up to create a group at the next, higher level. Another interesting major finding of the study is that state and local government policies had a minor role in the early years of the growth of Silicon Valley, and its evolution is due to the culture of innovative thinking and industry–university networks, reinforced by a free flow of information between peers and even by competing firms [4]. Finally, it is noteworthy in the study that quality of life is also a prominent factor in high-tech start-ups, because the founders launch their businesses in the locales where they would like to live. This means that a favorable place in which the elements interact, in a very broad sense, comes from the cultural view, not just from the restrictive theme of technology.

Summing up, the success of Silicon Valley demonstrates the continuous interaction of individuals and firms for decades, free of moorings despite the strong competition among them, where new start-ups come from incumbent firms, and this fact does not create conflict, but by the contrary, benefits the game of innovation. Innovation covers a very extended range of areas, from electronic to software, from retail to tourism services, from entertainment to the Internet-of-Things, and the list does not stop because one cannot know where the next step will take place.

4.2. The Brazilian Innovation Case

Considering the consistent success of Silicon Valley throughout the years, several countries, institutions, and individuals have paid attention to what was happening there, and some have tried to mimic it. Sure, some countries or regions have their own ways of pursuing innovation and are not looking to what happens in California, but others, especially developing countries, understand that they could learn good lessons from Silicon Valley, bringing and adapting initiatives and policies to accelerate their own innovation systems. Brazil, a country in Latin America with more than 200 million people as of 2017, is one such example, and the Brazilian innovation case is what we discuss in this subsection.

Since the 1980s, several Brazilian government initiatives and public policies have arisen with this purpose: innovation. Despite the fact that this text has no intention to list all them nor to analyze them, we mention a few emblematic and very distinctive policies to build a basis for the discussion that follows.

One important initiative in Brazil was the creation of tech incubators in the surroundings of public federal universities in the 1980s. These incubators were launched in the north, northeast, south, and southeast of Brazil, aiming to foster new innovative companies. Another government policy is to give subsidies to hardware companies. In the education sector, which has been dominated by public universities since the beginning of higher education in Brazil, rules and indicators for faculty members were established by the Ministry of Education, indicators such as the number of publications and number of citations that are fundamental for job promotion. These rules were followed by new rules and more funding for tertiary education, and this process of strict regulation finds no end (because the outcomes are not reaching expectations, as we will see below). The government's contracts with the information technology sector were another initiative focused on the development of high-tech companies (the result was the growing of reseller companies, not necessarily developers). The theme of innovation took so much importance in Brazil during the 2000s and after that a ministry even added the word to its name—Ministry of Science, Technology, Innovation and Communications—compounding a mixed name as if this could impact favorably the innovation process.

However, as said above, the intention of this text is not to do a survey or list or to discuss these initiatives. The idea here is to verify the results of the Global Innovation Index [15], where Brazil consistently appears in a very low position, decreasing in the ranking yearly (Table 1 illustrates the top 10 countries compared to Brazil and other countries of South America, from 2012 to 2017). The Global Innovation Index is an independent institution, which provides an index of innovation, creating metrics to analyze the innovation performance of countries. This index began in 2007 and has changed over the years as the concept and indicators grew, until its consolidation in 2012/2013, including themes like political and business environment, education, infrastructure, and so on (the complete list and information about the index are in [15]). The institution says that some indicators are quantitative, and others are qualitative; and they are not intended to be authoritative, just relative. The index has been gathering information on a varying group of around 125–145 countries over the years, and two of its partners are the National Confederation of Industry Brazil (CNI) [16] and the Brazilian Service of Support to Micro and Small Enterprises (Sebrae) [17], which are major public forces in Brazilian innovation development, linked or not to the Ministry of Science, Technology, Innovation and Communications (MCTIC) [18].

Table 1. The Global Innovation Index—years 2012 to 2017. Ranking position for the top-10 countries (considered year 2017) and the four top-ranking in South America. The bottom line shows the total number of countries ranked each year.

-	2012	2013	2014	2015	2016	2017
Switzerland	1	1	1	1	1	1
Sweden	2	2	3	3	2	2
Netherlands	6	4	5	4	9	3
USA	10	5	6	5	4	4
United Kingdom	5	3	2	2	3	5
Denmark	7	9	8	10	8	6
Singapore	3	8	7	7	6	7
Finland	4	6	4	6	5	8
Germany	15	15	13	12	10	9
Ireland	9	10	11	8	7	10
Chile	39	46	46	42	44	46
Colombia	65	60	68	67	63	65
Brazil	58	64	61	70	69	69
Argentina	70	56	70	72	81	76
Countries in the survey	141	142	143	141	128	127

So, considering the Brazilian ranking year by year, what happens in this country and why is innovation so poor despite government efforts? Why does innovation struggle and why does it not grow despite the public investments? To shed light on the problem, we could look at the Global Innovation Index indicators (from 2012 to 2017) and rearrange them to see how indicators related to each other and how public policies, on the one hand, and elements' interaction, on the other hand, are the basis for the corresponding indicators.

The first comparison is pictured in Figure 2, which shows three indicators. First, business environment, which reflects the "ease of starting a business, ease of resolving insolvency and ease of paying taxes" [15]. Second, the growth of gross domestic product (GDP) per person engaged, which "provides a measure of labor productivity (defined as output per unit of labor input)" [15]. Third, public expenditure on education per pupil in the secondary level, which is, "government spending on education divided by the total number of secondary students, as a percentage of GDP per capita" [15].

The public expenditure on education is clearly a government policy, and the Brazilian ranking is growing slowly year by year. This is a top-down initiative with relative success when we relate it to labor productivity. Labor productivity, which depends on the individuals involved in their jobs and related processes, is falling very quickly when compared to other countries, as the indicator shows. Workers do not find ways to develop better or creative solutions to perform their jobs. Perhaps, the business environment is not propitious for good performance, and that is what the other indicator shows. Considered one of the worst business environments in the world, the Brazilian business environment is a result of all kinds of difficulties posted contradictorily by the same government that pursues innovation. Elements cannot interact freely, because rules, taxes, and other issues stifle the environment, despite the individuals' levels of education or the efforts spent by them.

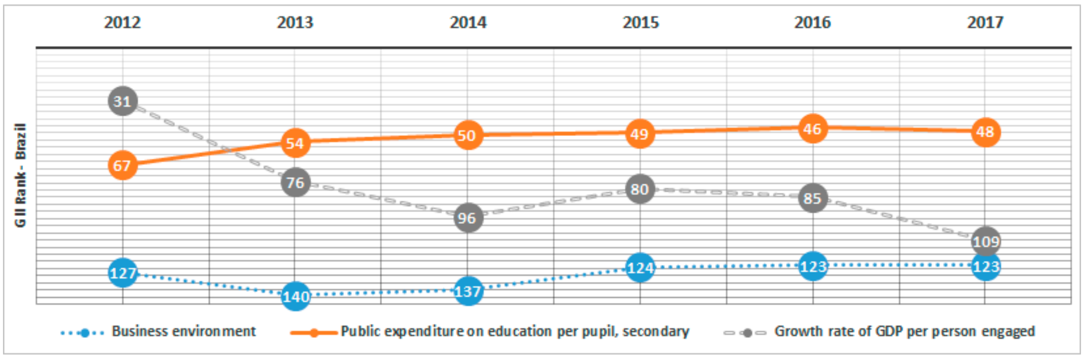

Figure 2. The Global Innovation Index [15] Brazilian rankings for business environment, public expenditure on education per pupil in the secondary level, and growth rate of GDP per person engaged, from 2012 to 2017.

Figure 3 shows a comparison between three other indicators. First, expenditure on education is defined by the "government operating expenditures in education, including wages and salaries and excluding capital investments in buildings and equipment, as a percentage of gross domestic product" (GDP) [15]. Second, graduates in science and engineering reflect "the share of all tertiary graduates in science, manufacturing, engineering, and construction over all tertiary graduates". Third, the intellectual property payments, which are "charges for the use of intellectual property not included elsewhere payments (% of total trade) according to the Extended Balance of Payments Services Classification EBOPS 2010" [15]. What we apprehend from this graph is that the Brazilian government continually expands its expenditure in education, and thus its ranking is improving, which apparently means good news. However, the number of graduates in sciences and engineering does not grow and, worst of all, intellectual charges are increasing because new technologies must be imported. The country is ranked in the top ten for paying for intellectual property and has a very low ranking position when talking about new engineers and scientists. Individuals prefer professions that are more rewarding and attractive, reflecting a process of evolution of elements in a culture and environment that do not favors science nor engineering.

The Brazilian ranking position for the indicators of gross expenditure in research and development, research collaboration between university and industry, and scientific and technical publications are shown in Figure 4. The gross expenditure on "R&D (GERD)" means the "total domestic intramural expenditure on R&D during a given period as a percentage of GDP". Scientific and technical publications are the "number of scientific and technical journal articles (per billion PPP$ GDP - purchasing power parity)". University/industry research collaboration is given by the "average answer to the survey question: in your country, to what extent do people collaborate and share ideas in between companies and universities/research institutions?" [15]. What we see is that publications have a stable middle position and that the expenditure in research is also stable and has a better position in the ranking. However, the perception of collaboration between industry and university is decreasing yearly. While the expenditure in research in Brazil, roughly speaking, is a matter of public funding—that is, a public policy—the attitude of collaboration is a phenomenon that depends on the interaction between the actors specified. On the other hand, the number of publications is mainly an outcome of a policy that charges faculty results by a national periodic process of assessment. This rule forces faculty to publish as many articles as possible, and in a process of survival and evolution, the natural effect is publications with several co-authors, crossing citations, and little or no relation with the industry needs, because this demands time and no clear rewards for the academic researchers.

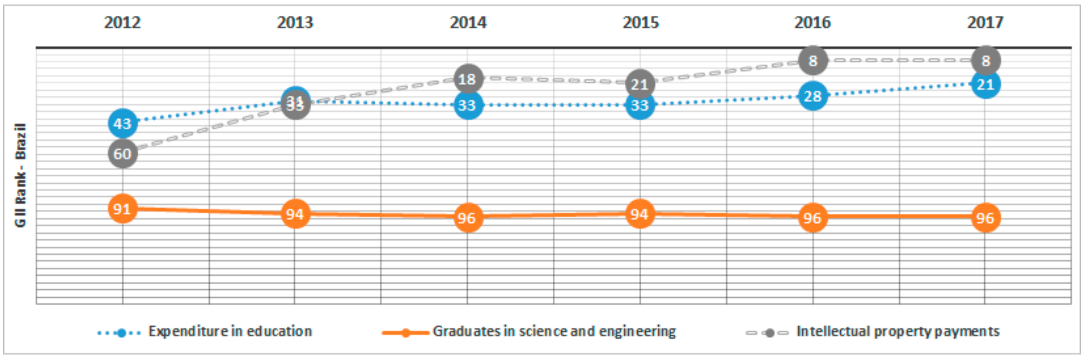

Figure 3. The Global Innovation Index [15] Brazilian ranking for intellectual property payments, graduates in science and engineering, and expenditure on education, from 2012 to 2017.

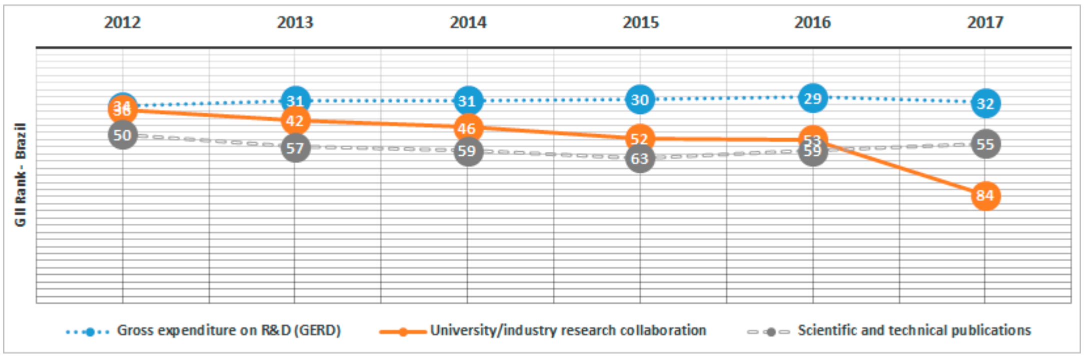

Figure 4. The Global Innovation Index [15] Brazilian ranking for gross expenditure in research and development, research collaboration between university and industry, and scientific and technical publications, from 2012 to 2017.

A direct output of the weak relationship between industry and university, despite the good number of publications in Brazil, is shown in Figure 5: there is a good index of citations but a very weak knowledge impact index. Figure 5 shows the indicator of citable documents related to the H index, which is "an economy's number of published articles (H) that have received at least H citations in the period 1996–2014" [15], and the knowledge impact (i.e., the outputs of knowledge and technology in the society). What the chart shows is somewhat of a paradox. How can a number of documents be well-cited, but this does not impact favorably the society where these documents were produced? Worst, the knowledge impact is decreasing yearly. An answer here could be that the public policy favors a high number of citations. The Brazilian govern created a system to assess courses, programs, and institutions based on the number of publications and citations in qualified magazines, journals, and newspapers. The belief that underlies this policy is that by favoring publications, an impact on knowledge will follow naturally. As the country is huge, with a large number of professors, it has created its own ecosystem of publications and its own process of assessment and scores, which benefit its own members (the official assessment platform is called Sucupira [19]). Several years of this policy has created a closed circuit of cross-citations with several authors for each paper, published in journals referenced at the Qualis Capes [19], resulting in a good ranking in the Global Innovation Index. Nonetheless, the knowledge impact of all this research production falls in a low ranking. Despite the public policy, the elements in this research ecosystem are forced by an obvious sense of survival, publishing as much as possible but detached from the society's interests.

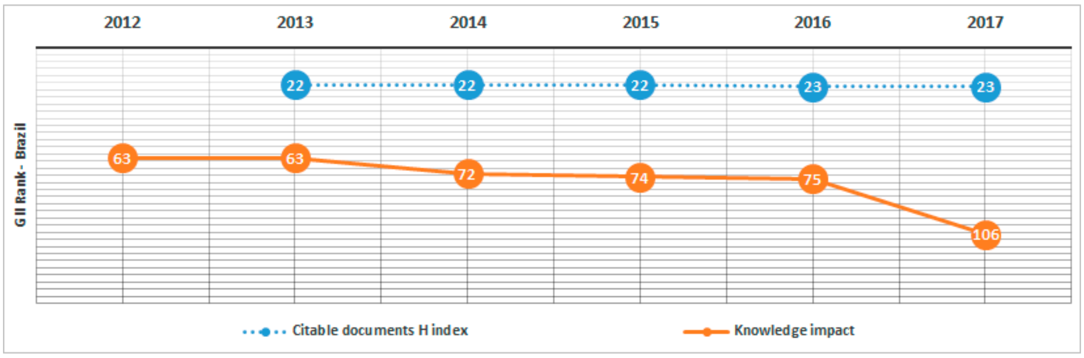

Figure 5. The Global Innovation Index [15] Brazilian ranking for citable documents H index and knowledge impact, from 2012 to 2017.

Looking to another aspect, the innovation index also shows some results regarding applied science and how the country relates to technology consumption. Figure 6 illustrates three indexes for intellectual property payments, high-tech imports, and technology services export. Intellectual property payments are the "charges for the use of intellectual property not included elsewhere payments (% of total trade) according to the Extended Balance of Payments Services Classification EBOPS 2010", which is how much the country pays to use intellectual property from abroad. The high-tech imports' indicator is given by "high-technology imports minus re-imports (% of total trade)". Technology services export is the "telecommunications, computer and information services (% of total trade) according to the Extended Balance of Payments Services Classification EBOPS 2010" [15]. Companies and individuals from Brazil are intensive consumers of technology. From the companies' points of view, technology is bought to be resold inside the country or to use in their internal processes. From the individuals' points of view, it is a way to be up-to-date with several gadgets, from mobile phones to game stations and from television devices to social networks. In the same way that it imports high-tech products, the country is also a great importer of knowledge (paying for intellectual property). Both movements are dependent on the elements not on public policies, and this implies in a heavy dependency on external knowledge and technology—that is, low level of internal innovation combined with the weakness of research (as shown in the previous charts). Even regarding the export of services related to telecommunications, computer, and information, an index that is increasing slightly each year, the ranking position is poor.

A society immersed in the age of the internet is a reflex of modernity, some say, and Brazil follows this trend. Figure 7 shows two indexes about this and its impact on innovation, accordingly to the Global Index of Innovation. One index is the online e-participation, which is "based on the survey used for the UN Online Service Index" for e-participation, and the survey emphasizes "quality in the connected presence stage of e-government"; the other is the Wikipedia monthly edits, defined by "Wikipedia yearly page edits (per million population 15–69 years old)" [15]. The regular and good position of online e-participation reflects the involvement of Brazilians in the age of the internet, using regularly its services and applications, especially social networks and government services. On the other side is the weakness of content production; the creation of text, edits, and posts on Wikipedia denote the behavior of a consumer, not a producer of knowledge. This does not depend on public policies. Is it a question of culture?

In summary, the indexes presented for the Brazilian case seem to demonstrate a combination of problems that causes its poor position in the global ranking. Public policies try to stimulate and foster innovation in a top-down process, but the results return in the opposite direction. Movements that arise from the bottom—that is, the interaction of actors trying to launch new companies or to create relationships between university and industry—are suffocated by several restrictions imposed by other government policies (such as taxes, bureaucracy, restrictions, and so on). If innovation is path-dependent, any restrictions or barriers in the hierarchical process will affect or even destroy it. Years or decades of this kind of reality created an ecosystem that favors consumption more than creation, and the inherent evolution process rewards the ones that take advantage of this consuming condition, no matter how many new policies are implemented over time (as Table 1 shows year after year). Despite the poor indicators presented in the Global Innovation Index and even after years of investment on public policies precisely done to boost innovation, the Brazilian government and its institutions keep launching more and more policies to induce it, trying to "prioritize the social impact of knowledge and technology engendered" [20].

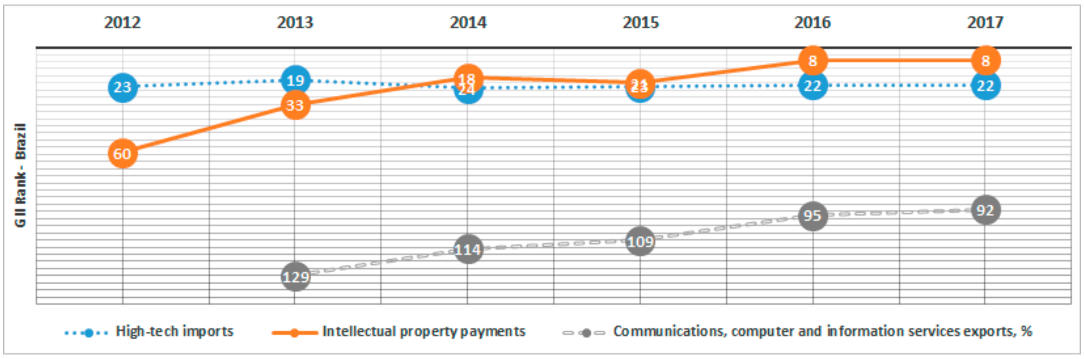

Figure 6. The Global Innovation Index [15] Brazilian ranking for intellectual property payments, high-tech imports, and technology services export, from 2012 to 2017.

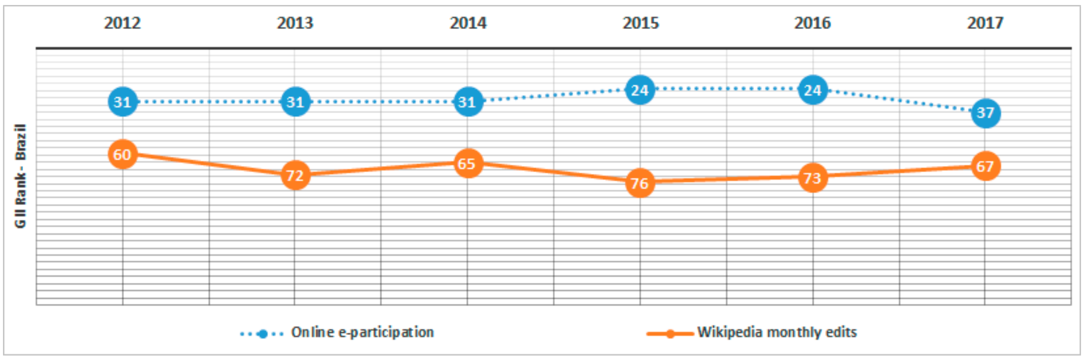

Figure 7. The Global Innovation Index [15] Brazilian ranking for online e-participation and Wikipedia edits, from 2012 to 2017.

4.3. Technology Clusters

One initiative that has been connecting the elements from the lower levels of the market innovation system with the upper levels' policies is the concept of technological clusters, with their incubators to foster technological novelties and start-ups. As defined by Petruzzelli, Albino, and Carbonara [21], a technology cluster is constituted by the technology district's actors in a geographically defined region, connected with external actors by means of organizational and cognitive proximities. Geographical boundaries define the region of the district as a dimension of the cluster, whereas the organizational links (such as the branches of a multinational company) and the cognitive links (such as similar interests and areas of research) define the other two dimensions. The authors emphasize several characteristics of these clusters that fit the complex adaptive systems theory, particularly the model we have presented. They consider that these clusters favor the process of learning by imitation and learning by interaction "based on the continuous exchange of information and knowledge among complementary firms, among firms and customers, and among firms and universities/research centres" [21]. These interactions clearly describe the communication between elements in several levels of the innovation system. These interactions may be face-to-face when the elements are within a region, but knowledge also can "circulate through global pipelines" when the cognitive and organizational proximity dimensions are present, and then "radical innovations" can be developed, characterizing the path dependency of these innovations. Clusters can create connections, and then, "weak ties" [13] between these clusters will favor free interaction, because these ties happen in the middle of "loosely coupled networks", deriving "positive effects on both connectivity and receptivity caused by a variety of communication channels" [21]. When studying knowledge sources for technology clusters, Petruzzelli, Albino, and Carbonara [22] emphasized the importance of networks in innovation, because "individual actors are seldom capable of innovating independently, and never in vacuum", and the networks "greatly enhance the processes of knowledge creation and diffusion". The technology clusters cited in their studies are the Castel Romano, in the province of Roma, Italy, specialized in the aviation and military industries, and the technology district of Toulouse, France, specialized in the aviation and aerospace industry [22].

Cluster initiatives have been important issues for regional development, competitiveness, and innovativeness. Several actors, such as firms, universities, research institutions, agencies for regional development, associations, local government, and other cooperating entities, work together for the cluster growth. Considering knowledge flow to be crucial for innovation development, Dyba [23] analyzed how knowledge flows from entrepreneurs to market upper levels (bottom-up processes) and how public policies can affect knowledge spillover (top-down processes). The author studied two cluster initiatives that had different approaches in the very beginning: the Swarzędz Cluster of Furniture Producers, launched by local entrepreneurs, and the Leszno Flavours Food Cluster, created by the municipality authorities. From his findings, the author suggests that knowledge flow depends on the origins of the cluster; that is, when the cluster is a top-down initiative, knowledge spillover mainly occurs between entities in the upper levels, such as universities, institutions, and research centers. On the other hand, firms and individuals are mainly responsible for these flows in clusters created formally or informally by these very basic elements of the ecosystem [23]. These conclusions seem to agree with the Brazilian and Silicon Valley cases, respectively.

Most of the technology clusters were the result of arrangements between firm associations on one side, and public policies from local authorities on the other, with more or less emphasis on each side. The questions that arises is: will top-down public policies affect innovation positively? One answer comes from Petruzzelli, Albino, and Carbonara [22] suggesting that "local governments should address their actions to help and promote the openness of technology districts and the formation of technology clusters", by sustaining local firms, increasing competition, and fostering the diffusion and sharing of knowledge. As in the words of Arthur [9], government policies should just favor structures that could emerge naturally and not try to coerce an innovation outcome.

5. Summary and Conclusions

Innovation is related to creativity, and creativity is a personal attribute. In our model of innovation proposed here, the problem of creativity was not addressed, because we do not deal with the internal boundaries of the element, as defined by Holland [14]. These internal boundaries, with their internal signals, have to be with metaphors and other insights, such as multiple parallel stories and analogies, which are themes of our other current research, yet to be published.

Here, our model is focused on innovation as an emergent phenomenon of a hierarchical system composed of individuals, firms, institutions, and organizations that belong either to specific markets or to whole economic systems. Our model says that innovation happens when the very elementary agents of the economic system interact freely and with simple rules of coexistence, aiming to develop creative and profitable solutions. This process begins at the lowest levels of the hierarchy and emerges through unpredictable paths until its success (or failure). As innovation is an emergent outcome of this system, rules or policies coming from the higher hierarchical levels could affect it. Public or institutional policies developed to induce and foster innovation that encourage freedom and multi/interdisciplinary relationships will benefit the process of emergence.

The model is based on the theories of complexity and complex adaptive systems, as detailed in Section 3. The famous case of Silicon Valley's continuous success was described in Section 4 to show that innovation has had its roots in that area long before the computer and software revolution in the 1960s and 1970s. It comes from the beginning of the 20th century or even before, through the frequent interaction between individuals and firms in an environment that mixes cooperation and competition, where the actors pursue investment for new ideas anchored in the academic background. These new ideas pointed to a large range of business, without restrictions and not following predefined areas if they existed. On the other hand, the Brazilian case shows how several public and institutional policies, trying to direct and induce innovation, create opposite outcomes. Innovation in Brazil is getting worse yearly, even when the national approach to innovation spends more resources and efforts. In this case, top-down initiatives interrupt the natural movements of the elements (and get the perverse result of discouraging these lowest-level systems actors). Unfortunately for the country, its government, institutions, and even universities insist on general policies, launching initiatives to induce lines of research to prioritize social and technological impact [20]—typically a top-down initiative. As an alternative, or intermediary solution, the case of technology clusters was presented to show that when the interests of individuals, firms, universities, institutions, and local government authorities join efforts, innovation can flourish through the flow of bottom-up processes reinforced by well-designed, top-down rules.

Considering the theoretical approach of this work, where we propose a model for innovation based on a complex adaptive system, the main limitation of the study is that the examples and case studies cannot cover all the model's possible implications. The problem of the Brazilian innovation case, for instance, seems to be due to its coercive and restrictive rules, but evidence of punctual cases of success appear here and there within the country to show contrary perspectives. Another limitation is that the propositions of the model, despite being based on complex system theory, have no easy way to be proven, because there are no mathematical tools to simply test and confirm them nor field experiments to verify them. However, we consider that this model has the practical and theoretical implication of bringing innovation as an object of research into the complex adaptive system field. Further research will now focus on how the elements behave when signals flow within the network and reach them with implications on learning and evolution.

Author Contributions: M.F.F. conceived of the model proposed in the paper. M.F.F. and M.L.H. analyzed the data. M.F.F. wrote the text.

Acknowledgments: The authors acknowledge the contributions, discussions, and suggestions given by Enio Padilha and the suggestions and constructive critiques expressed by anonymous reviewers, which helped us in the improvement of this work. In addition, we acknowledge Universidade do Sul de Santa Catarina—UNISUL—for its support.

Conflicts of Interest: The authors declare no conflict of interest.

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