El Colegio de la Frontera Norte
FRONTERA NORTE
e-ISSN: 2594-0260
Revista internacional de fronteras, territorios y regiones / International Journal of Borders, Territories and Regions

FRONTERA NORTE VOL. 32, ART. 8, 2020
http://dx.doi.org/10.33679/rfn.v1i1.1987

Complexity and Emergence on Regional Innovation Systems: Applying an agent based methodology on the Sonoran biotech sector

Emergencia y complejidad en los Sistemas Regionales de Innovación: aplicación de una metodología basada en agentes del sector biotecnológico del estado de Sonora

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ABSTRACT

Using a dataset gathered through a small sample of biotech firms in the Sonora region, we explore concepts of emergency and complexity inside a RIS (Regional Innovation System) in a development stage through the evolutionary microeconomics framework. For this, we explored the implementation of an ABS (Agent Based System) coded in the NetLogo platform, in which we simulated the behavior of firms in network behavior for the cooperation in the exchange of knowledge and new product development. We found this methodology highly useful for predictive analysis of possible courses of network behavior between different types of firms, as well as the future performance of the system. Moreover, the coalescence and modulation of key economic variables for a RIS in development stages in nonlinear systems is an extraordinary and relatively unexplored tool to study Regional Innovation Systems (RIS) in developing countries.

Keywords: 1. Social Network Analysis, 2. Agent-Based Modeling, 3. NetLogo, 4. Regional Innovation Systems, 5. Sonora.

RESUMEN

Este trabajo analiza los conceptos de emergencia y complejidad en el marco de un Sistema Regional de Innovación (SRI), en proceso de formación en el sector biotecnológico del estado de Sonora, México. Para ello, se explora la implementación de un sistema basado en agentes codificado en la plataforma NetLogo, con el fin de simular el comportamiento cooperativo en red de las firmas para el intercambio de conocimiento y el desarrollo de nuevos productos. El método es útil para la predicción y el análisis de posibles cursos de comportamiento en red de las firmas, y para el futuro desempeño del sistema. La incorporación y modulación de variables económicas relevantes para sistemas regionales en vías de formación dentro de sistemas no lineales constituye una herramienta poco explorada para el estudio de los SRI en países en desarrollo, por lo que con este artículo se espera alentar esta clase de investigaciones y contribuir a su mayor conocimiento.

Palabras clave: 1. Análisis de redes sociales, 2. Modelos basados en agentes, 3. NetLogo, 4. Sistemas Regionales de Innovación, 5. Sonora.

Reception: March 21st, 2019
Accepted: July 12th, 2019

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INTRODUCTION

Located in northwestern Mexico, and in spite of being the cradle of the "Green Revolution", the State of Sonora is delayed in terms of biotechnological innovation.[3] However, in such region there is a vibrant academic community (researchers, graduate and undergraduate students and at least three institutions and research centers) working on the biotechnological sector. These people are a solid base of specialized human capital that suggest the possibility that this network enquires on emerging phenomena.

The weakness of this nascent network is noticed both in the scarce presence of startups in this sphere and poor patent generation, despite the existence of a large number of research projects from institutions and research centers that cannot become a firm.

Such institutions, which come from the agricultural, livestock and fishing boom in the state, among them Universidad de Sonora, Instituto Tecnológico de Sonora (ITSON) and Centro de Investigación en Alimentación y Desarrollo (CIAD), gather more than 400 professors ascribed to the National System of Researchers and more than 1000 graduate and undergraduate students. For example, Universidad de Sonora is part of scientific communities of maximum level in five or more fields (material science, agricultural sciences, physics, geoscience, engineering, mathematics and chemistry). Publications concentrate in physics (267), engineering (147) and chemistry (218), according to data from Web of Science for 1981-2003.

The universe of institutions and highly specialized scholars in the field of biotechnology is a valuable quality to potentiate the development of such activity, whose potential justifies studying the interaction as a network of students, entrepreneurs, scholars and researchers, their environment and the possible implications in the development of this emerging sector.

Such interactions are a black box: a system that involves a promising dataset of entries and another, rather discouraging of exits (few firms or startups, patents, utility models and projects, though many research articles); we are not aware of the intermediate relations and processes.

Biotechnology is of vital importance for Sonora, not only because it is a semi-desert zone with great challenges as regards soils, risks and weather conditions, but also because these conditions may become opportunity areas from biotechnology, which make part of the frontier research at present (Kafarski, 2012; Matyushenko, Sviatukha & Grigorova-Berenda, 2016).

The aim of this work is to explore the dynamics of interactions recorded in the biotechnological community of the State of Sonora; to do so, an agent-based model, inspired

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[3] The noticeable increase in agricultural productivity, thereby in foods, between 1960 and 1980's in the United States is known as Green Revolution, later it spread to other countries. It meant the adoption of a series of practices and technologies whose development started in Sonora, Mexico, lead by Norman E. Borlaug in 1943.

by SNA (social network analysis) and CAS (complex adaptive systems), proposed by Beckenbach, Briegel & Daskalakis (2009), was partially applied to identify innovation networks and signs of emergence of regional economic agents. It is intended to verify the convenience of these tools to study the behavior of key variables in a RIS (regional innovation system) in formation.

Complex adaptive systems are an interdisciplinary research field that seeks to explain how a large number of simple entities organize, without the mediation of a central control, becoming a collective whole that creates patterns, uses information and in some others, evolves and learns, and it is increasingly resorted to understand any kind of system. The study of CAS focuses on a system's complex, emerging and macroscopic properties. For its part, the SNA theory provides us with the necessary tools to 1) create networks, 2) obtain measurements, and 3) detect clusters.

Such tools facilitate the exploration of the aforementioned black box, and also test our hypothesis, in which we consider that agents in the region's biotechnological sector operate separately, with scarce scientific collaboration and poor orientation toward innovative practices, which negatively affects RIS efficiency.

The fundamental nature of replicating empirical evidence to build scientific knowledge also motivates this work, as much as the need to rebuild, partially at least, the algorithmic procedures of the referred study, which are not publicly available.

The text is organized into four sections. The first one reviews the fundamental theoretical concepts of emergence and complexity in RIS, and the importance of the network analysis approach and the agent-based models. Following, the creation of networks in the regional biotech sector is discussed, from which a set of data is obtained and turned into an agent-based model. This model is supported on the characterization and segmentation of agents according to a series of categories, whose definition comes from Ajzen-Carnegie's theory of planned behavior.

In the fourth section, the application of the model and the results obtained are approached, as well their implications for the Sonora's RIS biotechnological sector are considered; all this in an environment characterized by an accelerated conversation of which it is essential to partake. Finally, general conclusions are put forward and recommendations are made as regards enhancing and enriching research based on this sort of models.

EMERGENCE AND COMPLEXITY IN REGIONAL INNOVATION SYSTEMS

RIS function as a sort of complex interaction network between nodes that operate as agents of interchange of knowledge and various goods, part of a series of systems (cultural, economic, etc.) that work under their own logic, this is to say, they respond as a CAS; it can receive several degrees of incentives that unleash various and unpredictable responses. The

Complexity Theory indicates that a high degree of stimulation produces a range of activity close to chaos; in such range emergence occurs. Excessive stimulation leads to chaos, while very little produces equilibrium or inertia.

In CAS everything is in permanent change; inside them, patterns always depend on the context (Taylor, 2003). The main difference between a complex adaptive system and another that is not is the nonlinearity derived from the simple addition of the parts, as it is the case, for instance, of the global financial system (crises, recessions) or the immune system (fever, antibodies).

Regional innovation systems from the network theory

RIS can be defined as "places in which close interfirm communication, social structures and the institutional environment may socially and territorially stimulate collective learning and continuous innovation" (Asheim & Isaksen, 2002, p. 85). From the General System Theory, network-systems and studies on industrial and innovation studies (Cooke, 2008), that concept is one of the most accepted in academic circles and public policies (Carrillo & Contreras, 2015).

These systems have a central role to facilitate innovation processes (Molle & Djarova, 2009). Systems are composed of networks, which create an intermediate proximity whose generic space is the region (Beckenbach *et al*., 2009).

What distinguishes the current complexity moment is the appearance of a truly global network culture (Taylor, 2003). RIS are subject to a series of (local and global) cultural and economic stimuli that make information travel in real time (collaboration is or can be immediate). The scenario is the region, though "behind the scenes", interaction lines transcend latitudes and time zones.

The importance of studying RIS from the standpoint of networks is continually mentioned in scientific literature, yet scantly approached. Works usually state that networking and collaborating between stakeholders are necessary; however, this standpoint provides tools to thoroughly analyze, beyond the inventory of infrastructures and capacities, the universe of relations and interchange of tangible and intangible goods between the agents comprised in a system. Such approach allows peeking through the keyhole instead of only settling for the entrance and exit components (Beckenbach *et al*., 2009), leaving the linear look behind.

Basic concepts of emergence and complexity

There is no formal definition to describe a complex system, however several agree on the same central elements. For Holland (2006, p.1), CAS are "systems composed of a broad number of components, sometimes called agents, which interact and adapt or learn". Some contemporary examples of problems related to complex systems are incentivize innovation in dynamical economies, prediction of changes in the global transaction system,

http://dx.doi.org/10.33679/rfn.v1i1.1987

understanding markets, ecosystem preservation, Internet control and strengthening the immune system.

Although Melanie Mitchell warns it is an informal definition and somewhat circular, she characterizes it as a system with a large number of components that interact with one another, in which these components are relatively simple in comparison with the system as a whole, and in which there is no central control or global communication between them and that interaction gives rise to complex behavior (Snodgrass, 2011). According to Holland (2006), CAS share four fundamental characteristics: 1) parallelism, this is, a large number of agents that interact sending and receiving signals; 2) conditional actions, the agents' actions in a CAS usually depend on the signals they receive, i.e., agents have an IF/THEN structure, this way if the signal vector "x" is present, action "y" is performed, which can also be a signal that triggers complicated feedback cycles, or a manifest action in the agent's environment; 3) modularity, in an agent, a group of rules often combines to produce subroutines; and, 4) adaption and evolution, which imply that the agents may change over time and these are usually adaptions, not random changes, to improve performance.

The improvement of "adaption and evolution", the fourth of these fundamental characteristics, is at present the object of research in NetLogo, a language utilized in CAS simulation; for which, the Agent-Centric Montecarlo Cognition (ACMCC) model is proposed, as it uses a separate model for the agents' cognition, aided by LevelSpace extension. This model is later resorted to by the agents in the primary model to predict the results of their actions and guide their behavior.

Emergence in CAS

Emergence occurs far from balance and close to chaos. In a CAS, an emergent behavior appears as a response to stimuli that can be both intrinsic and extrinsic. It is the gap, the intermediate zone that disturbs what previously was deemed immobile, it fragments what had been verified and shows the heterogeneity of what was thought to be self-consistent (Taylor, 2003).

Emergent behavior, such as that of an army of ants making a bridge, interconnecting their own bodies to overcome an obstacle, is impossible to predict and cannot be explained by only studying the components of the system.

Interconnections between components in a network have the answer, though this does not appear in isolation, but inside a combinatory alchemy that becomes the object of frontier research in the field of complexity. We enter into the sphere of the unpredictable. Within the observable universe, the only possibility is to quantify reality avoiding to the extent possible reductionism and model behavioral patterns which, if recognized, can lead to the identification of triggers or catalyzers maybe not of an emergent behavior, but of the election of the modes of action.

The method described above is the approach applied in this work as an approximation to emergence through the partial application of a multiagent model using data from a little sample of the nodes of the innovation network of the regional biotech sector. The model was originally developed by Frank Beckenbach, Ramón Briegel and María Daskalakis in the University of Kassel, and it is one of the earliest attempts to incorporate complexity studies in Regional Innovation Systems and their networks.

ER INNOVATION AND SCALE-FREE NETWORKS IN SONORA'S BIOTECHNOLOGICAL SECTOR

The difference between ER (Erdös and Renyi) networks and Scale-free Networks is their topology; whereas ER networks are designed after an associational random variable –or several–, Scale-free networks exist on their own (Hein, Schwind, & König, 2006). An example of this is the hyperlinks' network that make up internet, or a network of mentions within a micro-blogging system.

In ER networks, clustering coefficients produce a normal curve, this is, there is little deviation or all the nodes are somewhat connected within standards, which does not occur in Scale-free networks, in which a few nodes tend to be closely connected, which produces a peak and a "fat tail" of many nodes scarcely connected. The difference is defined by the way in which both sorts of networks are built. On the one side, in an ER network the addition of new nodes is rather uniform among the existing nodes; while on the other, in Scale-free networks new nodes most frequently adhere to highly connected networks (Hein *et al.*, 2006).

Another difference is the influence that one or the other topography has on the process of information dissemination. While in the ER model there are statistic thresholds under which it stops or does not affect all the nodes, the result on Scale-free networks is utterly different. In this case, technically there is no threshold, this way all the nodes may be affected: tragic if it is an epidemic, though benefic for knowledge generation.

Scale-free networks are a closer representation of networks than traditional ER networks, as they are in "the real world"; however, they are more difficult to translate into simulation models, especially if nodes are individuals.

Methodological aspects of ER network generation

Sonora has a high connectivity degree, yet the use of digital social platforms reduces largely to interchange and dissemination of news, personal, cultural or entertainment information.

Few are the researchers, professors, students and/or professionals with an account on Twitter to share ideas, knowledge, events or data from their specialty, particularly regarding STEM (Science, Technology, Engineering and Mathematics). Some higher education institutions (HEI) have entered into this space, via their press departments, though they have focused on the promotion of their institutional achievements, not on knowledge dissemination. This makes it difficult for colleges and departments, through students and professors themselves, to take control, share relevant information and elicit a conversation.[4]

At first, the design of the ER network was set for four stages: 1) the creation of a primary network which comprised the connections of researchers, members of academic bodies taken from PROMEP databases, in the research lines akin to biotechnology in local HEI; 2) broadening of the primary network by means of a list of firms made out of RENIECYT;[5] 3) application of the snowball method through a questionnaire designed for the nodes of the primary network; and, 4) the incorporation of the nodes for which scale-free network connections are identified,[6] also by means of the application of the questionnaire via email.

The methodology described a hybrid network that intended to account for the academy or HEI, stakeholders in the government and enterprises and even the student population. Although the search for nodes focused on potentially innovative actors (SNI researchers, startup entrepreneurs, patent generators), it did not exclude other possible agents. The generation and analysis of ER network was carried out supported by UCINET, in which a multiplex matrix (tridimensional or multi-relational) linked to attribute vectors was produced.

ER network analysis

For the pilot test of the ER network, six consolidated research groups and three in consolidation were selected from the institutions with the most registered activity: Unison, CIAD and ITSON. Our random variable was to establish a connection or academic-work relationship between research groups, consolidated or in consolidation.

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4 This work's original methodology included the creation of a scale-free network aided by NodeXL; albeit, it had to be discarded because 1) the response rate of the questionnaires was extremely low, and 2) the logic of the Beckenbach model required a uniform agent, in this case, the firm. The broadening of the model in order to include various sorts of agents surpasses this research scope. However, the authors intend to do so in a future research work.

5 RENIECYT, National Register of Scientific and Technologic Firms, contains information on the subjects in the several support funds of CONACYT (National Council of Science and Technology). For its part, PROMEP, Program for Professors' Improvement, promotes the training of professors to attain the desired profile in higher education institutions, this is, professors who carry out teaching, tuition, knowledge production and management activities.

6 The use of social media by innovative agents in the region is very limited, at least in relation to other places. Far from becoming an autonomous node specialized in content and interaction, the "discussion" is a monologue, that of university. As a result, not only do we have a fragmented scale-free network, but rachitic. Owing to this reason, at least, regionally scale-free networks only allow complementing the information gathered through the generation of a traditional network, via exercises, which allow the monitoring of the gradual evolution of the network, so as to enhance its comprehension.

Table 1. Academic sector stakeholders for ER biotechnology network

Research Group	*Consolidation Level*	*Institution*	*Biotech Code*	*Research Lines*
Biophysics and soft condensed matter (UNISON-CA-119)	Consolidated	Universidad de Sonora	GREY	Biophysics and physical chemistry of self-assembling materials Complex fluid physics Physical chemistry of nanomaterials
Plants' defense mechanisms, fruit transformation and ripening	In consolidation	CIAD	GREEN	
Biotechnology and natural products	Consolidated	ITSON	GREEN	Biochemical characterization and product processing
Material sciences. CA 86	Consolidated	Universidad de Sonora	GREEN (New materials)	Polymer chemistry Electroconductive polymers Biopolymers Composite materials with polymeric matrix
Water sciences (ITSON-CA-03)	Consolidated	ITSON	BLUE	Hydroecology-Echohydrology
Aquatic biosystems (ITSON-CA-42)	In consolidation	ITSON	BLUE	Aquaculture biotechnology
Biopolymers	NA	CIAD	GREEN	NA
Sustainable development and management of aquaculture production	NA	CIAD	BLUE	NA

http://dx.doi.org/10.33679/rfn.v1i1.1987

Biology and sustainability of arid zones	NA	UNISON	BROWN	NA

Source: own elaboration with information from the database of academic bodies recognized by PROMEP and fieldwork revision of the information provided by Unison, CIAD and ITSON in their Internet websites.

Owing to the scarce participation of the involved agents, the possibility of generating a network of agents at the level of individuals from all the components of the triple helix was discarded, and a second questionnaire was designed focusing only in the exploration of nodes at representative level (firm), in which information is gathered as regards various attributes of it (annual revenues, intention to broaden their market share, trust in regional partners) and of the individuals that make part of it (curiosity, knowledge specialization). This decision facilitated the application of the logic focused on the firm of Beckenbach' *et al.* (2009) model, in spite of restricting the number of regionally available agents; the identified agents are listed in table 2.

One of the topics addressed in the research project, from which the present work comes, is that the lack of willingness to cooperate and participate between disciplines among agents of a RIS in consolidation negatively affects its performance; such situation has to change.

Table 2. Regional stakeholders and local capabilities in the biotechnological sector

	HEI	*GOVERNMENT*	*FIRM*	*AC*
Brown Biotechnology Desert biotechnology: Space and geomicrobiology; biotechnology of arid and desert areas	UNISON, ITSON, IGI Northwest regional station	Centro de Investigaciones Agrícolas del Noroeste (CIANO), Secretaría de Agricultura y Desarrollo Rural (SAGARPA)	Hermosillo Drone Lab	

Green/Grey Biotechnology Agriculture Environment	UNISON, ITSON	Laboratorio Nacional de Sistemas de Concentración y Química Solar, Comisión de Energía del Estado de Sonora (COEES), Secretaría de Educación Pública (SEP/SES), Fundación Produce	Sunbionics, Solarscape de México S.A. de C.V., Maeve Tecnología productores especializados de energía S.A. de C.V., Globalmet Sapi de C.V., CITRO DES	Patronato para la Investigación y Experimentación Agrícola del estado de Sonora, AC (PIEAES), CITRO DES
Blue Biotechnology Aquatic (marine) biotechnology : aquaculture, sea and coasts, fish health and nutrition, aquatic animal breeding, Cloning and genetic modification, Pest and disease control and Aquaculture and fish-farm diseases.	UNISON, CIAD	Centro de Investigaciones Biológicas del Noroeste (CIBNOR) campus Hermosillo y Guaymas. CONACYT	Llaos Acuacultura S.A. de C.V.	Colegio de Oceanólogos de Sonora A.C.
White Biotechnology Classic biotechnology Fermentation industrial biotechnology Bioprocesses and classic fermentation Engineering and	Centro de Investigación en Alimentación y Desarrollo (CIAD), Instituto Tecnológico de Sonora (ITSON), Unison, Instituto Tecnológico de Hermosillo		Zyptek México S.A. de C.V., Biosistemas y Seguridad Privada S.A. de C.V., Gening Proyectos Biomédicos S.A. de C.V., Rubio Pharma y Asociados S.A. de C.V.	SonoraLab

http://dx.doi.org/10.33679/rfn.v1i1.1987

technologic equipment for bioproduction Output via intensive bioproduct science

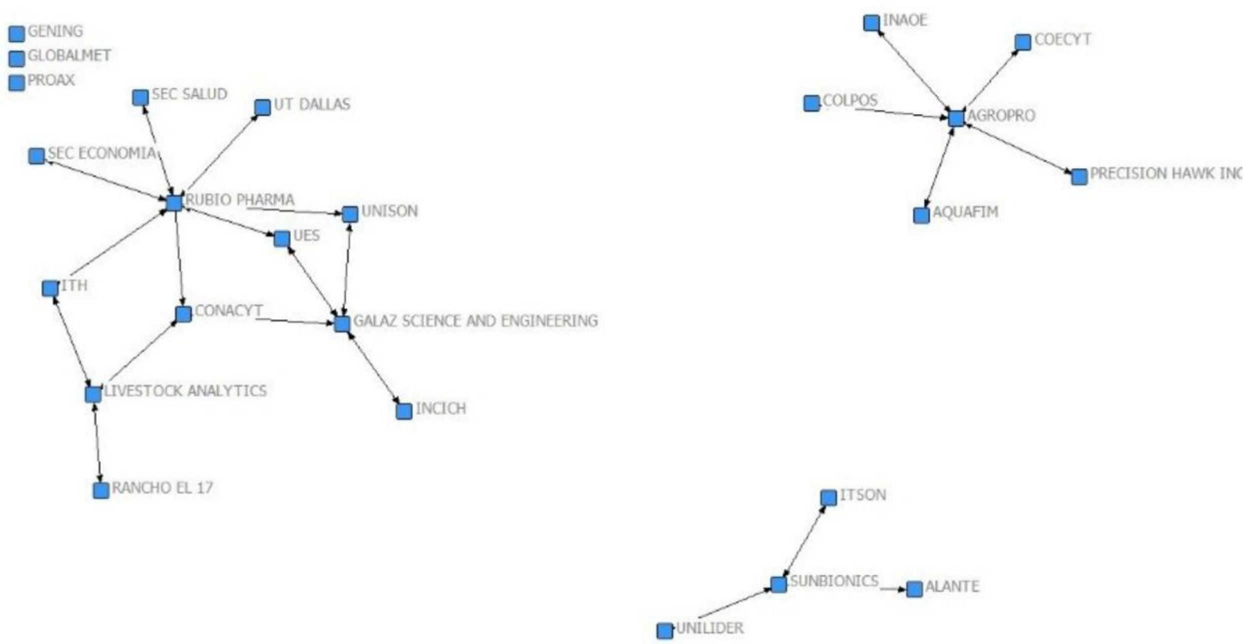
Source: own elaboration based on biotechnology's rainbow code, databases of the National Register of Scientific and Technological Institutions and Firms (RENIECYT) and fieldwork.

The network displayed in figure 1 was obtained from the information gathered, in which according to centrality measures' data specified in table 3, firms such as Rubio Pharma, Agropro and Galaz Science & Engineering are at privileged positions in terms of intermediate centrality, followed by Livestock Analytics and Sunbionics; at the other end, apparently isolated are the firms Gening, Globalmet and PROAX.

The centrality degree measures the number of ties with which an agent is connected to others. The minimum centrality degree is 0 if an agent does not have connections; the maximum is d=g-1 (being g the number of nodes). A network's intermediate centrality is given by the rate of the actual number of links between the agents and total nodes (g).

Most of the firms selected for the survey are deemed innovative for they have been allotted support from *Programa de Estímulo a la Innovación*, PEI [Program for Stimulation to Innovation], by CONACYT on one or several occasions. In other cases, they are considered innovative because of the emergent area they are engaged in.

Figure 1. Biotechnological sector agent network



Source: own elaboration / Ucinet 6

Table 3. Centrality measures for the biotechnological sector stakeholder network

	DEGREE	BETWEEN NESS	CLOSENESS	HARMONIC CLOSENESS	EIGENVEC TOR	2-LOCAL EIGENVEC TOR
GENING	0	0	625	0	0	0
GLOBALMET	0	0	625	0	0	0
PROAX	0	0	625	0	0	0
ALANTE	1	0	555	2	0	3
UNILIDER	1	0	555	2	0	3
ITSON	1	0	555	2	0	3
PRECISION HAWK INC	1	0	509	3	0	5
AQUAFIM	1	0	509	3	0	5
COECYT	1	0	509	3	0	5
COLPOS	1	0	509	3	0	5
INAOE	1	0	509	3	0	5
RANCHO EL 17	1	0	385	4.17	0.09	3
INCICH	1	0	383	4.42	0.14	4
SEC ECONOMIA	1	0	377	5.17	0.23	7
SEC SALUD	1	0	377	5.17	0.23	7
UT DALLAS	1	0	377	5.17	0.23	7
ITH	2	5.33	373	6.08	0.31	10
UES	2	3.17	373	6.08	0.36	11
UNISON	2	3.17	373	6.08	0.36	11
SUNBIONICS	3	3	553	3	0	3
LIVESTOCK ANALYTICS	3	11	375	6	0.16	6
CONACYT	3	14.33	369	7	0.45	14
GALAZ SCIENCE AND ENGINEERING	4	12.83	373	6.67	0.25	8
AGROPRO	5	10	505	5	0	5
RUBIO PHARMA	7	35.17	367	8.67	0.41	12

Source: own elaboration / Ucinet 6.

The governmental agent with the most centrality is indubitably CONACYT; as for HEI, those with the most connections are Instituto Tecnológico de Hermosillo (ITH), Universidad Estatal de Sonora (UES) and Universidad de Sonora (Unison). Although ITH and UES were not considered at first in the exploration of the biotechnological sector stakeholders, they became relevant over the questionnaire application because they were mentioned by firms surveyed as agents with which they establish cooperative relationships.

Even if this data set is still small and does not allow definitive conclusions, it does show signs of network activity concentration in terms of innovation. The small set of agents which can be formally accessed at present may broaden as more startups and innovative firms engaged in biotechnology appear, which allow enriching the scarce available information and feed the model with new data as well.

A broadening of this model with a logistic apparatus capable of including agents other than firms, especially HEI, would be very useful in the study of RIS in formation in regions such as Sonora, where a large part of the activities in the biotechnological sector is still concentrated there.

Some of the firms mentioned here establish close collaboration links with universities and governmental institutions, which are expressed as institutional arrangements, advice, laboratory exchange, stays and residences, among others. On occasion, the links are double and triple, so that not only does the firm has an institutional arrangement with a higher education institution, but also they interchange laboratories and carry out stays and residences, at once they maintain relations with other firms and institutions. Some stated not having any links whatsoever.

The questionnaire proposes the following forms of collaboration with other firms, governmental institutions and HEI: 1) mentoring; 2) scientific text interchange; 3) laboratory interchange; 4) interchange of materials; 5) advice; 6) text authorship; 7) institutional agreement; and, 8) stays and residencies; some firms, which appear with no links in figure 1, left such section blank.

The Analysis of Social Networks should not be restricted to descriptive and exploratory assessment exercises, as they play a very important role in the generation of high-value quantitative network indicators at the level of firm and cluster, including centrality indicators in econometric estimates that may help measure the impact of a Cluster Development Program (CDP) in an inter-organizational network, the very network that is considered responsible for the effectiveness of a program of clusters (Giuliani & Pietrobelli, 2011). The implementation of an assessment of such nature requires a longitudinal analysis that surpasses this work's scope; this problem comes from the need to build models that help assess the behavior of the networks of the various agents comprised in a cluster in formation, or a RIS as a whole, according to the variables and parameters observable at present and in which elements can be introduced with the purpose of testing their impact on the performance of the agents in the middle and long terms.

Such models allow us to distance from the thinking oriented to the sterile count of the components of a nascent cluster or a RIS in formation, instead of concentrating efforts in prospective analyses that provide useful information for the creation of optimized public policies, with better understanding of the advantages and limitations of the various positions and structure of the network.

The full study from which this work comes, additional to the biotechnological sector, approaches ITC and aerospace sectors in the State of Sonora.

APPLICATION OF AN AGENT-BASED MODEL ON A RIS

The network previously described only represents a time slot, i.e., a manner of a photograph of the temporary space over which this research was carried out. Even if it keeps information on 1) the topology of the network created by the agents, 2) the agent's attributes at the level of firm, and 3) the multiple contents that demarcate each link, it does not allow us to deepen into its morphology, and consequentially, in the multiple feedbacks between the agents' states and the network as a whole (Beckenbach *et al.*, 2009).

The only way to enter such "new world", in which the network behaves dynamically, is using a simulation model, in which the agents' attributes or empirical information are turned into variables, which as a whole define a state of the firm. This way, agents are capable of reacting after a stimulus, feedback or threshold set by the application process of a model, evolving over each cycle or iteration.

To illustrate the application process of an agent-based model, we resort to the model proposed by Beckenbach *et al.* (2009), which was applied at a large scale in Germany. We believe that it is a useful approximation in emerging regions, for although the necessary information to apply standardized innovation surveys is missing, it enables deepening into relevant aspects for innovation processes such as leaning toward scientific cooperation and trust in regional partners.

Beckenbach, Briegel & Daskalakis (2007) identify four behavioral aspects relevant for innovation processes: 1) declarative and procedural knowledge; 2) abilities (in terms of finding new heuristics and recombination and association capacities of the elements of knowledge); 3) intrinsic and extrinsic motivation; and finally, 4) personality traits (curiosity, risk acceptance, et cetera).

The interaction between the innovation process' social, competitive and individual dimensions may be characterized establishing a typology of agents and another of competence. For example, one type of agent may be characterized with a combination of pessimistic expectations, innovation goals of reactive nature and certain loyalty to paradigms, while a type of competence, for instance, may be implying low concentration degree, low entrance barriers and orientation to the dimension of cost (Daskalakis, 2016).

Teaming along with psychology: the innovative personality

Innovation is a specific mode of action. It does not occur out of "nothing"; this is to say, it is not automatically generated by the market's competitive conditions. It needs agents willing to innovate and promote the corresponding activities, leaving other action models behind (Beckenbach *et al*., 2009).

For the authors, distinguishing such agents with the binary label "innovative / non-innovative" is too simplistic in the context of a RIS. The thorough analysis of a regional system needs to take into consideration all the agents involved, their distinct modes of action and their embedding into several coordination mechanisms.

More so, each of the agents has motivations, capabilities and limitations to act in a network context. The multiple modes of action (routine, searching by imitation, searching by innovation) compete with one another to be activated by the agent owing to endogenously generated forces.

Multimode approximation based on the schools of Ajzen and Carnegie

In the context of RIS, there are two requirements for the behavioral explanation: 1) the various specific modes of action of each RIS layer (routine, imitation, innovation) must be part of the explanandum; and, 2) the explanation must be empirically significant (Beckenbach *et al*., 2009).

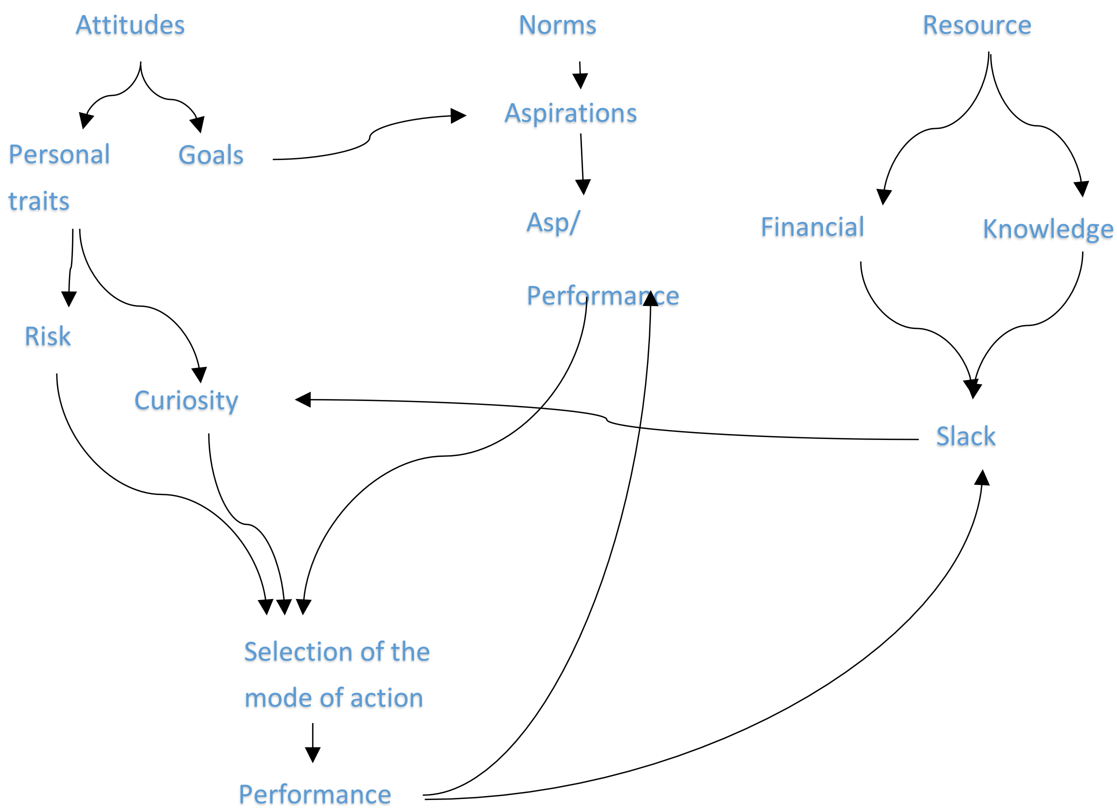
Beckenbach et al. (2009) point out that there is no concept in the behavioral scientific literature that meets both requirements, so they propose to summarize two well-known approximations, both of which have been applied to empirical problems and resorted to explain more than one mode of action. These approximations are, on the one side, the school of Ajzen, with the Theory of Planned Behavior, and on the other, Behavioral Economics.

Table 4. The approaches of Ajzen and Carnegie

Ajzen	*Carnegie*
Ajzen's approach is to explain intentional activities, that is, activities that come from a consistent plan to do something. This plan or intention is influenced by three cognitive factors: 1. The agent's attitude toward the attributes of the planned activity. 2. The appropriateness of this activity for the social norms pursued by the agent. 3. The agent's ability to manage or control such activity.	This approach sheds light on the two ways of decision usually overlooked: routines and search.

Source: adapted from Understanding Complex Systems (2009).

Figure 2. Causal chain diagram to select a mode of action



Source: Understanding Complex Systems (2009).

Following the diagram in figure 2, the selection of a mode of action is determined by attitudes, expressed as personality traits (risk aversion, curiosity) and goals, also regulations, which are closely related to the accomplishment of goals. High-profile goals become aspirations which for their part will have as a result a determinate performance rate, constrained by various factors. The performance resulting from the selection of a mode of action feedbacks this rate to the extent iterations advance, which over time may affect both the selection of the mode of action and performance itself. Furthermore, intellectual and financial assets generate a component called slack. This accounts for a margin for maneuver that may be high or low, and linked to the component of curiosity, also affects the subsequent mode of action, and at once, the agent's future performance.

Model adjusted to the needs of a RIS in emerging state

Limitations from an incipient RIS such as absences of metrics and the difficulty to record the totality of the variables proposed in the Oslo and Bogota manuals lead to search for an alternative not to "measure" innovation, but to explore innovative potential.

http://dx.doi.org/10.33679/rfn.v1i1.1987

Even if there is a temporary absence of homogeneity that allowed comparing results at global scale, the use of a model adjusted to the regions' characteristics provides more useful information for the application of effective public policies. This way, instead of resorting to the usual top-down approach, this research follows a bottom-up approach, interested in the agent's motivations and capabilities, as well as in their limitations to act in a network context.

In the model proposed by Beckenbach *et al.* (2009), the interconnected subnetworks comprised in the network are sublayers in which a first outer layer is noticed; it consists of the political and institutional regulations of the regions shared by all the agents; an intermediate layer that agglomerates agents interested in innovating and a nucleus in which innovative agents concentrate (as if it were an onion).

In this context, the modes of action are: 1) routine; 2) imitation; and 3) innovation, (this may be individual or collaborative). The main adjustments to the model as regards that used by Beckenbach *et al.* (2009) have to do with the sort of population and sample size. Beckenbach's team applied a questionnaire to more than a thousand firms located in Kassel, i.e., they focused on the firm as agent. Our initial intention to include all the actors that take part in a RIS into this model had to be dropped, thereby the government and the academy had to be excluded. Furthermore, the number of surveyed firms is significantly shorter, simply owed to the poor participation of firms engaged in biotechnology in the region.

A second adjustment was made in relation to the amount of codified components in the model, since a full codification not only surpasses this work's scope, but darkens one of its main goals: contributing to understand and replicate the construction of an agent-based microeconomic model within a RIS using the programming language NetLogo.

The simulation of the multiagent model is performed using NetLogo, a free open-source software program, which was obtained over the course "Introduction to complexity" offered by the Santa Fe Institute, directed by Dr. Melanie Mitchell, via the online learning system Complexity Explorer.

APPLICATION OF THE MODEL AND RESULTS

The implementation of the model was carried out on the basis of eight agents using variables that measure attitudes (risk aversion, curiosity, goals) and regulations (intended profit, obtained profit), which motivate the election of one or another mode of action, as well as intellectual and economic endowment variables of the firm (specialized knowledge, financial capacity). The criterion to choose an initial mode of action is modulated by three behavioral parameters (aspirational attitude β, imitation propensity and cooperation propensity).

Following the characteristics of the model are described:

If we name

g – incomes obtained in the last cycle or iteration s – corresponding aspiration level

The mode of action is defined by the following criteria:

$$\frac{g}{s} \geq \beta : routine$$

$$\beta - i \leq \frac{g}{s} < \beta : imitation$$

$$\beta - x \leq \frac{g}{s} < \beta - i : cooperative\ innovation$$

$$\frac{g}{s} < \beta - x : individual\ innovation$$

We have that the election of the mode of action works as a function of income rates / aspiration level. Therefore, if the firm aspires to earn 100 pesos over the quarter, and in the last one it earned 200, i.e., twice as much, the rate is higher than the aspirational attitude, thus the mode of action routine, or keeping things as they are, is chosen. If, on the contrary, such rate is below the aspirational attitude –this is, the firm obtains revenues under its expectations–, but higher than the result of subtracting the value assigned to variable i (imitation propensity)[7] from aspirational attitude, imitation is decided as a mode of action. For example, if the firm intended to earn 100, but it only obtained 50, imitation propensity is high; there is motivation to come up with a new product, even though it is only a copy of other items in the market. In the case of the modes of cooperative and individual innovation, the variable x (cooperation propensity) has to be included.

The above is carried out by means of the code:

```
ask turtles [

if g / s >= B [set color blue ] ;; routine

if g / s < B and g / s >= B - i [set color pink] ;; imitation, i is imitation propensity

if g / s < B - i and g / s >= B - X [set color yellow]

;; cooperative innovation, X is cooperation propensity

if g / s < B - X [set color red] ;; individual innovation

forward 3
```

[7] This value, as that of x, varies depending on the firm and is obtained from the answers to the questions included in the research questionnaire.

At this point, by running the code above we obtain the total number of agents (*turtles*) on screen, each one identified with a color that indicates the mode of action chosen according to the parameters defined through the research questionnaire.

Unlike aspirational attitude β, the aspirational level updates at the end of each step, following the equation:

$$s\ (t+1) = (1-\Phi)\ s\ (t) + \Phi g(t)$$

where Φ represents each firm's adaption flexibility. In NetLogo, the previous expression is written as follows :

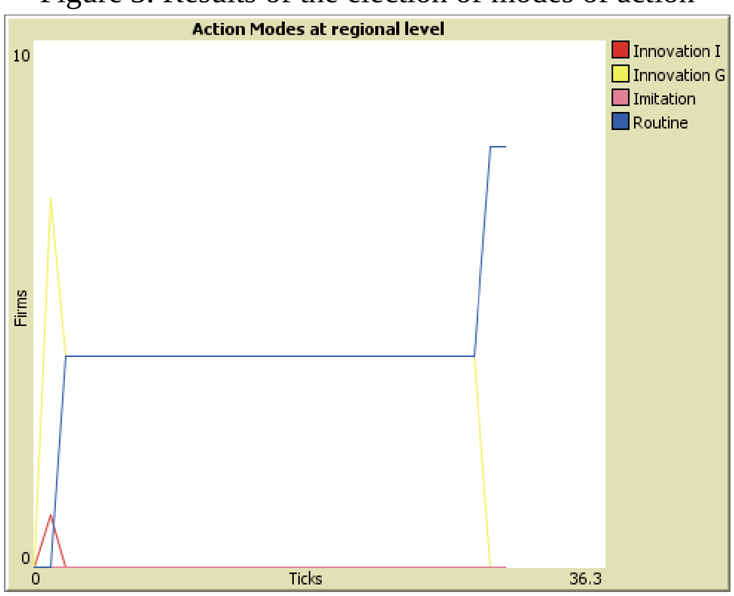
*set s1 ((1 - fa) * s) + (fa * g)*

set s s1

Hence, using these expressions and the available dataset, we notice that in the case of the firms under study in Sonora's biotechnological sector, initially most of them locates within the cooperative innovation mode of action. By the 20th iteration, 50 percent of the firms moves to routine, while the other 50 percent remains in cooperative innovation mode. By the 30th iteration, all the firms operate in routine mode; hereafter, this behavior repeats.

Variables i and x, which represent each firm's imitation propensity and cooperation propensity, respectively, are defined by the answers to a set of questions associated to such phenomena in the research questionnaire.

Figure 3. Results of the election of modes of action



Source: own elaboration / NetLogo 5.3.1

Using the notation by Beckenbach *et al.* (2009), the innovation network's TC (Transaction Cost) is a function of knowledge specificity (s), the number of knowledge components (q) and trust (r) in terms of successful knowledge transferences in the past.

$$TC = f\ (s, q, r)$$

F2 (Innovative Force) is defined by:

$$F2 = \frac{\alpha f0 + f1 + f2}{cin}$$

Where: α represents risk acceptance; *cin*, the expected cost of innovation; and, f(i), curiosity or inclination to explore with a value of 0; intended income with a value of 1; and, intended market share with a value of 2.

Moreover, $F1$ (Imitative Force) is defined by:

$$F1 = \frac{f1 + f2}{cim}$$

And $F0$ (Preservation or Routine Force) is 1.

to obtain $F2$, it is necessary to solve

$$f0 = w0\ (kr + fr)$$

$$f1 = w1\ \left(\frac{asp}{p}\right)^{E1}$$

$$f2 = w2\ \left(\frac{asm}{m}\right)^{E2}$$

Where: *w*0 represents proclivity to explore; *kr*, knowledge reserves; *fr*, financial reserves; *asp*, the level of intended incomes; and *asm*, the level of the intended market share. *E*1 and *E*2, market elasticity parameters, are used with values of 8 and 16 in the reference standard parametric constellation utilized by Beckenbach *et al*. (2009).

Table 1. Statistical calibration of the model's behavioral parameters

		Empirically obtained measures			
Variable	*Parameter*	*F_IR*	*F_IIM*	*F_ROUT*	*Scale*
Risk acceptance	α	4	5	-	1-5

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Inclination to explore		4.5	4	-	1-5
Intended incomes		3.6	4	-	1-5
Intended market share		4.6	5	-	1-5
Cooperation propensity	X	4.8	5	-	1-5
Regional trust		4.5	4.5	-	1-5

Source: own elaboration based on the dataset generated out of the research questionnaire sent to Sonora's biotechnological sector firms.

To derive relevant measures, it is necessary to distinguish various sorts of behaviors firms; as regards the model, three sorts are classified: radical innovators, imitators and firms that operate following routines. In the case of Sonora, the distribution of the sort of firms is as follows: 80 percent locates in category F_IR (innovators); while 20 percent does in the category of imitators (F_IIM). None of the respondents identified themselves as a firm with no innovation (F_ROUT).

As it is an emerging sector, there is a reduced number of firms in the region, most of them recently created and running on public / private funds obtained from calls, awards and innovation incentives. All the surveyed firms have a product in the market.

After identifying relevant parameters, two are distinguished:

a) Behavioral parameters that influence the election of the models of action. In this point, the questionnaire design allows researching the parameters: "risk acceptance", "inclination to explore", "intended market share" and "intended revenues".

b) Behavioral parameters that influence the election between individual or cooperative innovation, as well as the development of the collaboration. These are "cooperation propensity" and "trust in regional cooperation partners".

Given the importance of innovative cooperation for RIS, it is necessary to explain the microeconomic conditions for this sort of connected activity in the model's context. The triggering conditions for innovative cooperation come from the union of behavior and empirical observations (Beckenbach *et al*., 2009).

The authors distinguish the combination of personal attitudes, subjective norms and conditions that influence the orientation of an agent's will toward a cooperative mode of innovation. At first, the three forces that forge innovation capacity are basic for the agent's willingness to cooperate in terms of innovation; these forces are related to agent's current market performance of the agent. Secondly, the various sorts of agents have different cooperation propensities. This considers that not only is the current market position important, but also some deeper attitudes that come from several communication styles in a number of innovation horizons. Third, at least in a regional context, the frequency of cooperative innovations may be observed. This may help reduce the uncertainty associated with this sort of innovative activity, as it simplifies searching for partners and demonstrate possibilities to overcome opportunism. Fourth, subsidies from political institutions as an exogenous incentive to produce cooperation.

The results of Beckenbach *et al.* (2009) are virtually impossible to replicate with a small set of data and a RIS in formation. However, implementing the firms' election of the modes of action and the variation in their behavior over the iterations shows in which way it is possible to codify these equations and translate them into a programming language that allows analyzing all sorts of data.

In the absence of metrics, it is possible to resort to other strategies, as in fact it is made in the model described. Some of them are the use of arbitrary constants and/or parameters defined randomly within certain limits.

In the case of our model, we decided to use a *Boolean* variable to find out whether a firm possessed differenced knowledge, then going on to establish a cooperation link or a *match* each time the iteration finds two firms whose variable value is 1, and this link has not been previously established.

The code is the following:

```
set asset-specificity? one-of [false true]


 show [asset-specificity?] of turtle 0

 show who

 show match

 if asset-specificity? = true [set potential-match potential-match + 1]

 if counti = 0 and asset-specificity? = true [set match who

  set counti counti + 1 ]


 if who != match and asset-specificity? = true and potential-match > 1 [

  create-link-with turtle match

  set potential-match 0 set counti 0]
```

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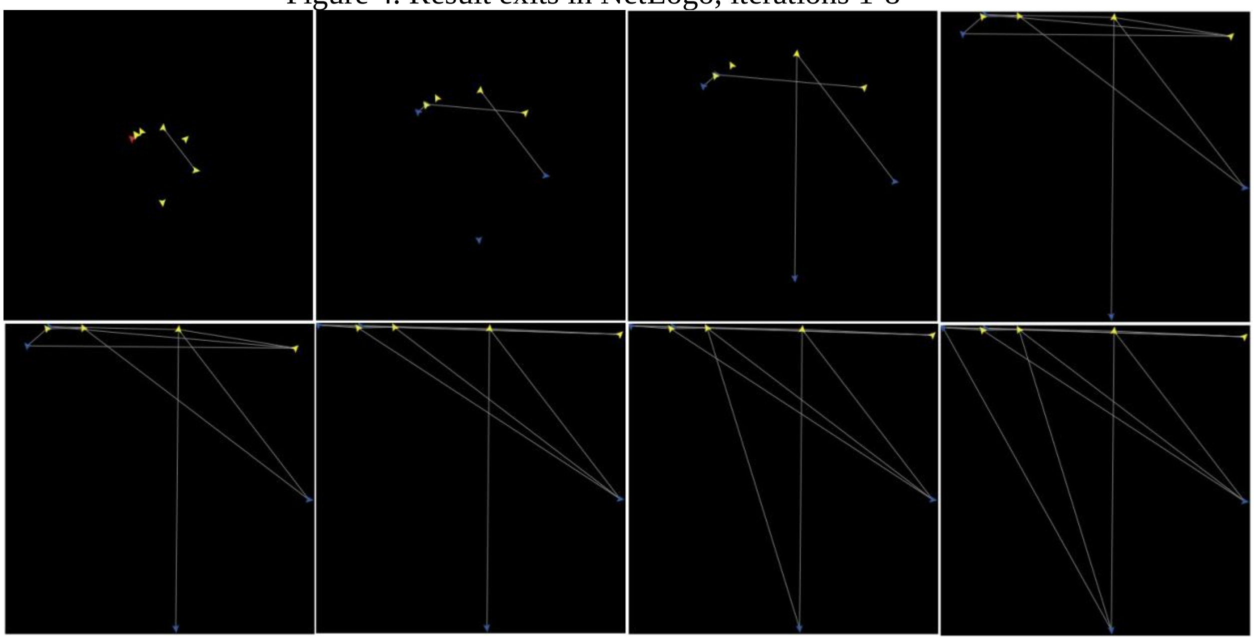
fd 1

show count links

The code above produces the next exit after eight iterations, cycles or ticks, which is how NetLogo identifies the conclusion of a cycle, in this case economic. This code's only action is to generate a random state in each one of the agents, which may be positive or negative; if it is positive, it means the firm has specific assets (knowledge, capital); while if it is negative, it is not a candidate to a possible relation of cooperation with another firm. This way, over the first iteration and once the first states are randomly generated, the first links are established. This is the easiest way to simulate a process of cooperation; though it lacks feedback elements, thresholds and other variables that characterize a process of this nature.

Figure 4. Result exits in NetLogo, iterations 1-8



Source: own elaboration in NetLogo.

The graph displays the results of running the model for eight iterations. This way, over the first cycle, seven out of the eight firms are yellow, i.e., they take an innovative mode of action, and only one is red, individual innovation mode of action. Over this cycle, only one cooperation relation is developed between two firms. In the second cycle, we notice one new cooperation relation, and three firms have adopted routine mode (indicated in blue). The third cycle indicates four cooperation relations. In the fourth, half of the firms choose routine mode. Over the eighth cycle, we have 14 links, whereas the rate of the selection of the mode of action remains constant.

Table 2. Variables' behavior from 4th to 8th iteration

Iteration	Agent	g	s	b	i	x	S1	fa
4	0	5000000	5000000	1	0	1	5000000	1
	1	1000000	1000000	1	0.1	1	1000000	1
	2	5000000	5000000	1	0.1	1	5000000	1
	3	500000	500000	1	0	0.8	500000	1
	4	1000000	1015625	1	0	1	1015625	0.75
	5	250000	252929.6875	1	0	1	252929.6875	0.75
	6	1000000	1005859.375	1	0	1	1005859.375	0.75
	7	1000000	1015625	1	0	1	1015625	0.75
8	0	5000000	5000000	1	0	1	5000000	1
	1	1000000	1000000	1	0.1	1	1000000	1
	2	5000000	5000000	1	0.1	1	5000000	1
	3	500000	500000	1	0	0.8	500000	1
	4	1000000	1000061.0351	1	0	1	1000061.0351	0.75
	5	250000	250011.4440	1	0	1	250011.4440	0.75
	6	1000000	1000022.8881	1	0	1	1000022.8881	0.75
	7	1000000	1000061.0351	1	0	1	1000061.0351	0.75

Source: own elaboration based on the values obtained while running the model in NetLogo.

The results observed in figure 4 reflect a simplification regarding the large amount of variables that concur in a cooperation project, from considering the transaction costs as it is actually developed to the changes that have to be made in algorithmic terms to alter variables such as trust (tr) and amount of knowledge (kr), which should change with each successful cooperation, or the way in which such cooperation affects demand and / or market share.

Conceptually, Beckenbach's *et al.* (2009) model is nothing but an iterative process that simulates cooperation between the various agents in a sector of a RIS, which implies, among other things, knowledge transference and absorption, as well as generation of products and/or innovations result of such cooperation relations. Over the course of this iterative process, the knowledge inventory of each firm can improve depending on the model's various feedback factors; as iterations advance, trust can increase or decrease depending on whether collaboration relations are successful.

The parameters used for each one of the agents' variables are based on the empirical data gathered through the research questionnaire. Owing to the sample selection, which focused on firms innovating in biotechnology, the agents' typology is similar, and corresponds to a firm with high level of knowledge specificity and moderate trust capacity, nevertheless willing to cooperate and transfer knowledge, linked to firms oriented to services, not to the industrial.

The amount of knowledge transferred over each iteration depends on both the level of trust and cooperation propensity of each firm, and it is thus that these factors affect the general capacity of RIS to produce cooperation relations and innovations in the market. The generation of a full code for such conceptualization is only the beginning and leaves the door open to a vast field of research, which allows testing the influence of various variables on a RIS efficiency.

Although these considerations surpass the scope of the present text and it is expected to carefully address them in the future, we consider that the code generated is sufficient to illustrate the powerful tool social sciences have in the incorporation of CAS-based research, which allows modeling all sorts of systems aided by a programming language, relatively simple and widely used by the scientific community.

CONCLUSIONS AND RECOMMENDATIONS

In Latin America there is still much to do as regards homogenization of data on innovation measures. In Sonora, very few are the firms engaged in biotechnology, and even fewer those willing to provide information, so the analysis of the data available is a merely exploratory exercise.

Most of the firms under study identify themselves as innovative, prone to cooperative innovation, owners of highly-specialized human capital, possessors of a high level of knowledge; which, by and large, sets relatively ambitious goals, in terms of revenues, market penetration and expansion.

The forgoing clashes with some observations made along this research such as the marked reticence to cooperate by answering a questionnaire among a large group of agents, including academics and entrepreneurs, and a sort of mistrust from governmental actors. They had to be excluded from the set of data in this model, so a future research that incorporates them is recommended.

Capabilities are latent; firms such as Rubio Pharma, Agropro and Galaz Science and Engineering, engaged, respectively, in pharmacology, precision agriculture and production of biomedical instruments, have strong connections abroad, and significant links with research centers and centralized institutions, local HEI and foreign universities .

The scientific community must be attentive to the evolution of the behavior of the RIS, studying this and other emerging sectors, enlarging the available datasets and providing relevant economic information so that to the extent possible it becomes an agent of change in its growth and consolidation

In the simulation model set up by Beckenbach *et al.* (2009) in Germany, cooperative innovation has an important role in knowledge dissemination at regional level. Not only do the agents' differenced behaviors provide them with heterogeneous chains of knowledge, but the knowledge on the region as a whole is different every cycle and the importance of each field knowledge varies over these.

In general, for Beckenbach *et al.* (2009), the number of cooperative innovations and dissemination of knowledge among the agents are the most important indicators of the RIS performance. The agents that choose the mode of cooperative innovation are the core of it and this mode of action is the source of multiplex relations both in the market and hierarchy. This analysis shows that the parameters for cooperative innovation reveal a "network landscape" behind the dynamics observable in a RIS.

The broadening of the perspective toward such landscape sheds light on the conditions for a good performance; thereby, such simulations may be a starting point for the bottom-up improvement of RIS –including networks– unlike the usual top-down optimization perspective in network research and that of the “master minds” behind a RIS.

Future research of this nature in Sonora and other regions of the world on RIS in formation will require the incorporation of new variables for the prospective study of various productive sectors and the firms comprised in them, especially those related with scientific and technologic cooperation and collaboration, in addition to ensure technical clarity and replicability.

In like manner, the pressing need of collaboration between social sciences and computer sciences is evinced, as they are necessary as a bridge to generate multiagent simulations based on social and economic theories taken to the algorithmic sphere.

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