Knowledge networks associated with the production of natural resources in Latin America: a comparative analysis[1]

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Abstract

The opportunities for innovation that arise from natural-resource production are associated with the formation of knowledge networks that facilitate learning both within and outside the sectors in question. This article identifies the types of knowledge networks associated with innovation activities in the natural-resource domain using four case studies from the region: the livestock sector in Argentina, the mining sector in Chile, agriculture in Paraguay and forestry in Uruguay. The results show that, in all four cases, natural-resource producers form networks in which scientific knowledge is exchanged. While these have heterogeneous characteristics in terms of the capabilities of the participants, their structure and degree of openness, all display potential to disseminate and create knowledge.

Keywords

Natural resources, innovations, knowledge management, scientific and technical information, case studies, Latin America, Argentina, Chile, Paraguay, Uruguay

JEL classification

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I. Introduction

Until very recently, natural-resource-based activities were viewed as having little potential for economic growth and poor technological dynamism. In the 1950s, this was blamed on the following: deteriorating terms of trade for natural-resource-based products (Prebisch, 1962; Singer, 1950); fluctuations in the prices of commodities based on these resources (Levin, 1960; Nurkse, 1958); the low potential for technical progress in these sectors relative to manufacturing (Prebisch, 1962); and the lack of capacity in industries that work with natural resources to forge linkages with the rest of the economy (Singer, 1950; Hirschman, 1958; Singer, 1975). In the 1960s, the Dutch disease phenomenon, along with a number of subsequent empirical studies, provided additional evidence for the existence of a "natural-resource curse" (Auty, 1993 and 1997; Gelb, 1988; Gylfason, Herbertsson and Zoega, 1999; Nankani, 1980; Sachs and Warner, 1995; Wheeler, 1984). In this context, it became conventional wisdom that natural resources could help overcome the external constraint by exploiting static comparative advantages in the short run; but, in the medium and long terms, they did not foster the creation of dynamic advantages because they offered few opportunities for innovation, and their linkages with other actors in the economy were weak. Thus, natural-resource-rich countries needed to generate a structural change towards other more dynamic activities, such as manufacturing.

In recent decades, however, this view has been changing, as major economic, technological, institutional and social transformations have started to create new opportunities to innovate and add value in natural-resource-related activities (Marín, Stubrin and Da Silva, 2015; Pérez, 2010). These include the following: changing patterns of demand, characterized by greater demand for natural resources, its greater segmentation and the appearance of dynamic niches in the sectors in question; the diffusion of new knowledge-intensive technologies, such as biotechnology, nanotechnology and information and communication technologies (ICTs), which make it possible to diversify and develop new natural-resource-based products; and institutional changes, such as the possibility of patenting living material (Marín, Stubrin and Da Silva, 2015; Pérez, 2010). Along with these changes, there is growing recognition that natural-resource-related activities generate various increasingly important opportunities for value creation (Andersen, 2015; Andersen and others, 2015; Dantas, 2011; Marín, Navas-Alemán and Pérez, 2015; Marin and Stubrin, 2015; Smith, 2007; Ville and Wicken, 2012).

The empirical literature on new opportunities for innovation associated with natural resources is growing but is still limited (Crespi, Katz and Olivari, 2016; Dantas, 2011; Figueiredo, 2010; Iizuka and Katz, 2015; Marín, Stubrin and Da Silva, 2015; Morris, Kaplinsky and Kaplan, 2012). This article contributes to this emerging literature by exploring innovation opportunities associated with four natural-resource-related activities that are important in Latin America. In particular, it focuses on a growing phenomenon: the opportunities that natural-resource-related activities are creating to generate value "upstream", through networks that emerge to provide the knowledge that the sector needs to innovate.

Expanding the base of scientific knowledge and its applications forms a key element of any economic-development process. In natural-resource production, scientific knowledge is increasingly harnessed to create new products and make the extraction and processing of these resources more efficient and environmentally safe (Marín, Navas-Alemán and Pérez, 2015; Pérez, 2010). The development and application of new knowledge in production activities generally require knowledge networks that involve different types of players from both the production and scientific domains. This type of network facilitates the acquisition and exchange of dispersed knowledge and fosters innovation (Etzkowitz and Leydesdorff, 2000; Lundvall and others, 2002; Mazzoleni and Nelson, 2007).

If natural-resource-related activities enable new knowledge networks to arise or existing ones to expand, there will be an opportunity for firms in the network to scale up towards activities with more value added. There will also be opportunities for participation by other actors that subsequently relate to one of the existing members of this network and, more generally, for expansion of the knowledge base, which would galvanize the system as a whole. With the aim of analysing the new value creation opportunities that the natural resource sectors are generating, this study makes an in-depth analysis of the collaboration networks that have been established, based on biotechnological scientific knowledge requirements in four selected natural-resource sectors: livestock in Argentina; mining in Chile; agriculture in Paraguay and forestry in Uruguay. The chosen sectors are major players in the four economies studied, and also have a very significant tradition of innovation in the region. Biotechnology was chosen as an area of knowledge and technology that is present in the four sectors, since this will occupy a central place in future growth phases in the global economy (Pérez, 2010) and it has a very fertile field of application in natural-resource production.

To understand the potential value-creation impact of the development of natural-resource knowledge networks, the study characterizes the different networks chosen according to a set of dimensions that the literature identifies as important for explaining their capabilities to innovate and disseminate knowledge. The results show that networks for the exchange and creation of scientific knowledge associated with innovation activities in the natural-resource domain do indeed exist. In all cases studied, these networks show some of the characteristics, in terms of the capabilities of the players and structure, which the literature have identified as promising for the diffusion and creation of scientific knowledge.

The article is divided into six sections including this introduction. Section II reviews the conceptual framework of the research and the criteria that will guide the empirical work. More specifically, it identifies the characteristics that the literature considers favourable for knowledge creation and diffusion. Section III describes the production sectors chosen in each country, in terms of their recent evolution and the basic features of innovation in each case; and section IV describes the methodology used to collect and analyse the data. Section V analyses the networks and their potential to create and disseminate knowledge, evaluating the capabilities of the players, the structure of the network and its degree of openness. Lastly, section VI draws conclusions and identifies policy implications.

II. Which networks are most favourable for knowledge creation and diffusion?

Innovative activity often develops within knowledge networks, particularly in the course of overcoming complex problems that firms are unable to resolve individually, so they draw on knowledge that can be provided by a multiplicity of players (Mazzoleni and Nelson, 2007). The creation and application of new knowledge in production is generally a costly activity with uncertain results. For that reason, private firms cooperate with other enterprises to spread the costs and risks; and they engage in partnerships with the scientific community to access knowledge not found in the industrial sphere (Lundvall and others, 2002).

The literature has identified numerous examples of knowledge networks that have created learning opportunities for their participants, in developed and developing countries alike (Bell and Giuliani, 2007; Cabral, 1998; Etzkowitz, Carvalho de Mello and Almeida, 2005; Giuliani, 2013; Schmitz and Nadvi, 1999; Stubrin, 2013).[2] Nonetheless, the benefits derived from knowledge networks are not confined to their participants, since the new knowledge generated to address innovation problems within the network can also be used in other networks and production activities, which stimulates the system as a whole. In other words, the knowledge and technologies that are created in a specific context, such as natural-resource production, could be useful for other production activities, in a process that Lorentzen (2005) has dubbed "lateral migration".

[2] For example, the literature has documented how, in the case of the South African coal industry, the need to wash the extracted coal (owing to its poor quality) stimulated the development of capabilities and products that migrated to other areas —such as the washing of spirals in the Canadian tar sands (Morris, Kaplinsky and Kaplan, 2012)— through the production and knowledge networks that were created in that activity.

Not all networks give rise to the same opportunities to innovate and disseminate knowledge, however. Networks can be differentiated by the types of players (the nodes) that compose them, or else by their capabilities, the distribution of those capabilities in the network and the type of knowledge that is exchanged. Moreover, the links between the nodes produce networks with a variety of structures (hierarchical, centralized, highly embedded, disperse and others) that affect individual performance and that of the network as a whole.

The literature has generally found that the capabilities of network participants are crucial both for generating innovations and for disseminating knowledge inside and outside the network (Giuliani, 2013; Giuliani and Bell, 2005). For example, knowledge exchanges are more likely to occur, and the evolution over time is likely to be positive, in networks that involve firms with higher capabilities. This is because firms endowed with greater capabilities have resources to share, and they generally seek to complement their capabilities with others existing in the network. In the case of firms with more limited capabilities, the opposite effect occurs. Altenburg and Meyer-Stamer (1999) note that, in low-capacity environments, the imitation culture makes entrepreneurs reluctant to share information of any kind and gives rise to opportunistic or even predatory behaviour (p. 1697). Moreover, firms with greater capabilities are more likely to be invited to collaborate on different projects, and they have a greater chance of absorbing and reusing the knowledge that flows across the network in a way that is profitable for themselves and for the network as a whole (Giuliani and Arza, 2009). It could be said, then, that it is particularly important that the central players in the network, which have more opportunities to disseminate knowledge within it, have greater capabilities.

The degree of similarity between the players in terms of knowledge levels has also been identified as an important variable explaining the creation of links and the sharing of knowledge (Giuliani, 2013; Giuliani and Bell, 2005). When firms possess an advanced level of knowledge, they prefer to establish knowledge links with others that have a similar level of technology or knowledge. This is because they only have incentives to establish links if they foresee benefits from the interaction in question (Giuliani, 2007). If the knowledge bases are too different, cooperating and knowledge-sharing will be less likely. Thus, networks need to have a relatively high minimum capacity.

The literature also notes the need to complement knowledge, since firms search outside for knowledge and skills that are not available internally. In the most technologically dynamic industries, the complexity and extension of the knowledge base needed to compete encourages firms to set up alliances with other agents to gain access to new knowledge. These links are not established between two firms at random, but, above all, between those that share a common knowledge base, but also have some differential knowledge that justifies collaboration (Ahuja and Katila, 2001; Duysters and Schoenmakers, 2006; Gulati and Gargiulo, 1999; Mowery, Oxley and Silverman, 1996).

In terms of structure, networks in which all participants tend to be interconnected (clustering) seem to favour the diffusion and creation of new knowledge within the network (Cowan, 2005). Some authors argue that cooperative networks involving participants with common contacts (a phenomenon known as “structural embedding”) are generally rich in social capital (Coleman, 1988). In this type of network, opportunistic behaviour tends to be minimized, since firms have incentives to preserve their reputation in the network and thus maintain their chances of collaborating and participating. Part of the literature also considers that these characteristics help foster the circulation and exchange of knowledge among network members, which can thus strengthen the capacity of firms to innovate. From an empirical perspective, it has been found that structural embedding is a significant factor explaining the innovation and learning capacity of firms in industries such as textiles (Uzzi, 1996) and biotechnology (Ahuja, 2000; Powell and others, 1999), and in information and communication technologies (ICT) (Hagedoorn and Duysters, 2000).

The literature has also underscored the value of reciprocity (Ahuja, Soda and Zaheer, 2012; Giuliani, 2013), which exists when each firm both gives and receives. This characteristic is seen as fostering the development of links and the sharing of knowledge, since it reduces imbalances and power relations. It also counteracts opportunism, since a reputation for opportunistic behaviour does not encourage the sharing or circulation of knowledge. In contrast, reciprocity fosters the spreading of knowledge and the establishment of new links.

Links with agents outside the network are also critical for promoting and sustaining enterprise competitiveness, since they can renew and expand the knowledge base (Breschi and Malerba, 2001). External links can be particularly important in new and dynamic activities that are subject to major technological changes, since forging links with agents outside the network (with which there is neither a prior relationship nor an indirect connection) can give access to new and diverse knowledge, as well as to resources that make it possible to gain an advantage in the market or simply avoid technological lock-in. For example, in the biotechnology industry (Rees, 2005) and also in the semiconductor industry (Rosenkopf and Almeida, 2003), alliances with agents located in other regions were found to be valuable for renewing the knowledge base among local players.

In short, the literature highlights several dimensions of knowledge networks, in terms of both the characteristics of the nodes and the links, to enable them to successfully generate innovations and disseminate knowledge. These notions suggest that networks will tend to be more effective when the following criteria are met.

In relation to capabilities:

(1) The average capacity of the players is high.

(2) All the players have a high minimum capacity level.

(3) Players occupying a central place in the network as emitters of knowledge have high capabilities.

In terms of cohesion:

(4) The network has a high level of clustering.

(5) There is a high level of reciprocity in the network.

(6) There is a high level of structural embeddedness (transitivity).

Relative to network openness:

(7) Links are set up outside the central core of the network.

(8) External players have high capabilities relative to those at the core.

In the following paragraphs, after presenting the cases (section III) and the methodology (section IV), this article analyses the networks (section V) in terms of the capabilities of the players, cohesion and degree of openness.

III. The sectors studied and their knowledge networks for innovation

Innovative activities and knowledge networks are studied in four natural-resource sectors in four countries: the livestock sector in Argentina; mining in Chile; agriculture in Paraguay, and forestry in Uruguay. Recently, each of these sectors has made major innovations to meet new challenges, as briefly described below.

1. The livestock sector in Argentina

Historically, the livestock sector has accounted for a large share of Argentina's agricultural production and in its exports; but, since the 1990s it has faced difficulties associated with land disputes, owing to the spread of agricultural activities, especially those related to soybeans, as well as conflicts with national public policies aimed at guaranteeing the supply of meat to the domestic market at affordable prices.[3] Despite these challenges, cattle stocks have remained relatively stable in Argentina (around 50 million head), owing to a process of production intensification to boost efficiency and enhance meat quality through genetic improvement. Biotechnological tools, such as artificial insemination, in-vivo and in-vitro fertilization and the sexing of embryos and semen, have been central elements in this process.[4] These tools are used to modify the animal's genetic profile; and the genetic improvements introduced are then transmitted, along with the ownership of the breeding animal, or else through the sale of semen or embryos of selected breeders. This study chose a network of knowledge on bovine genetic improvement.

2. The mining sector in Chile

The mining industry has been key to economic growth in Chile, which is the world's leading copper producer (34% of world production) and owns nearly 30% of the world's copper reserves.[5] Currently, however, the sector faces numerous challenges, such as declining ore grades and rising energy and water costs. To address these challenges, innovative suppliers are increasingly being used (Fundación Chile, 2012 and 2014), including those that provide services based on scientific knowledge. A key example has been the development of "bioleaching" —a biotechnological process to separate the mineral from the rock that requires less water and energy than other traditional methods. Currently, over 500,000 tons of fine copper (about 10% of all copper production in Chile) is obtained through this new technology; and its use is expected to increase as mineral sources become depleted. In 2009, there were seven bioleaching operations controlled by five different mining groups (COCHILCO, 2009). This study selected a knowledge network associated with biotechnological solutions that are used in mining.

3. The wheat sector in Paraguay

Wheat production is a strategic activity in Paraguay, since this grain has a high priority in the food basket. In the late 1980s, thanks to the use of higher-yielding varieties and more efficient production technologies (use of fertilizers, chemical disease control and cultivation at appropriate times, among others), Paraguay managed to supply its domestic market and even export wheat. Today, wheat ranks fifth among the cereal crops produced by the country, with over 600,000 hectares planted. Nonetheless, the major expansion of soybeans nationwide has created the need to maintain wheat production, which functions as an alternate crop in winter. As a result, efficiency has had to be increased and production adapted to areas that are not naturally suited to it.[6] With this aim, the wheat sector is implementing major innovations based on the diffusion of new and better agronomic practices and the genetic improvement of seeds. The case study chose a knowledge network associated with both types of activities.

[3] To that end, in 2006 the national government started to introduce a series of policies, such as restrictions on meat exports, an increase in withholding rates, control of prices at different stages of the production chain and the establishment of minimum slaughter weights.

[4] Quantitative genetics has provided another tool, which is used to evaluate certain characteristics of the animals which are of economic interest (for example, birth weight, weaning weight, meat tenderness, quantity and location of fat, and level of milk production, among others). These measurements are then used in the selection process performed by the firms that "produce" breeding animals ("breeders" or "*cabañas*").

[5] In 2012, the value of mining production in Chile represented 12% of gross domestic product (GDP), mining exports were equivalent to 60% of total exports, and the sector's contribution to the public treasury represented 14% of all tax revenues.

[6] According to data from the Paraguayan Chamber of Grain and Oilseed Exporters and Marketers (CAPECO), between the 2002/2003 season and 2013/2014, the soybean production area more than doubled from 1.5 million to 3.5 million hectares.

4. The forestry sector in Uruguay

In Uruguay, forestry activity has grown vigorously in recent decades, to become the country's third most important export sector (after meat and soya). This has been associated with the expansion of the forested area and production. The former went from 650,000 to 1 million hectares between 2000 and 2012, and the latter more than tripled in 2000–2011, from roughly 3 million m^3 in 2000 to 10 million m^3 in 2011. Innovation activity and the introduction of technological advances have been central to this growth (Bervejillo, Mila and Bertamini, 2011). Innovation aims at introducing genetic changes in the species used for production and reduce the time that elapses between the selection of a tree and its commercial exploitation. The case study focuses on the second of these innovation activities, which is done in two stages. The first takes place in micropropagation laboratories, where plant tissues are cultured aseptically, and the volume of microplants grows exponentially in a small time and space. The second occurs in the nursery, where the final propagation is carried out by vegetative reproduction (using grafts) from mother plants.

IV. Methodology

1. Design of the research

The main objective of this study is to reconstruct and characterize the networks associated with the knowledge needs of four natural-resource sectors in four of the region's countries. In each country a key player was selected for knowledge development aimed at solving the problems of the natural-resource suppliers. This key player was identified as the "network ego" and was used to reconstruct the knowledge network, including other players with which the "ego" interacted to exchange knowledge.

In Argentina, the natural-resource firms studied are the *cabañas* or entities that develop and sell bovine genetics. To reconstruct the *cabañas'* knowledge network, a player was identified that was central for the exchange of knowledge on the use of biotechnology for bovine improvement,[7] namely the IRAC-BIOGEN enterprise, ego of the livestock network. This firm undertakes two types of activity: research, training and product development (IRAC); and transfer and marketing (BIOGEN). IRAC does research in the field of in-vivo and in-vitro reproduction, the freezing of semen and embryos, superovulation and the sexing of embryos and spermatozoids, among other biotechnological techniques. It also formulates work protocols enabling local producers to apply highly complex techniques. Its milestones include the development of in-vitro bovine reproduction technologies, which were applied for the first time in Argentina in 2012. BIOGEN, the commercial pillar of the institution, provides technology transfer services, advice and tailor-made solutions to meet the demands of livestock producers. The export of genetics is another of the firm's regular activities.

In Chile, the natural-resource producers studied are the large mining companies. The knowledge network was reconstructed around Aguamarina S.A., a firm that provides biotechnological services to mining companies and represents the ego of the mining network. It is a firm based on national capital, providing solutions for medium- and large-scale mining based on the use of microorganisms. One of its key products consists of a biotechnological solution to reduce the amount of particulate matter in suspension. The firm also develops solutions and services in the field of bacterial bioleaching and applications in which bacteria are used to combat pollution (tailings).

[7] As noted above, genetic improvement uses two tools: quantitative genetics and biotechnology. In this study, the network was constructed around the second of these, although some entities use the first tool.

In Paraguay, the players selected to represent the natural-resource sector are wheat producers, which can be classified into three types: (i) large firms, which produce and market cereals and oilseeds; (ii) medium-sized agricultural cooperatives that undertake activities related to the commercial production of cereals and oilseeds, and also produce agribusiness products (flours, oils and dairy products) and agricultural inputs (fertilizers and agrochemicals); and (iii) independent farmers that are not members of cooperatives. The network studied for this research was formed around a consortium of players that implemented a project entitled “Strengthening Research and Dissemination of Wheat Cropping in Paraguay”, consisting of the Paraguayan Chamber of Grain and Oilseed Exporters and Marketers (CAPECO), the Paraguayan Institute of Agrarian Technology (IPTA) and the Institute of Agricultural Biotechnology (INBIO). This project aims to develop innovations and form technological capabilities in the wheat sector. Its specific goal is the genetic improvement of wheat and the identification of best agronomic practices taking account of local conditions in the country’s various agricultural areas (Kolhi, Cubilla and Viedma, 2009). The project’s ultimate objective is to increase wheat production and enhance its industrial quality. The consortium is the ego of the wheat network.

Lastly, in Uruguay, the firm UPM Forestal Oriental is used to represent the natural resource sector since it encompasses different links in pulp production, and the forestry sector is quite concentrated. The study focuses on the activity of the firm responsible for optimizing forest productivity, specifically through the genetic improvement of varieties. As an integrated multinational, this firm uses its own nurseries and laboratories as its main knowledge source. Therefore, unlike the other networks, the ego of the forest network is part of the same firm that produces natural resources: the Santana nursery and the micropropagation laboratory.

Table 1 summarizes the main characteristics of the knowledge possessed by each network ego, as well as the type of knowledge produced and disseminated within them.

Table 1

Players that constitute the ego of each network and the type of knowledge produced and disseminated

Country	Network knowledge	Ego	Activity	Area of specialization	Knowledge produced	Knowledge milestones
Argentina	Genetic improvement used in bovine reproduction; network built around a firm that provides genetic services	IRAC-BIOGEN	Sale of services Training Research	Development and application of advanced animal reproduction technologies	Creation of new scientific knowledge and recombination of existing technical knowledge to facilitate its diffusion and transfer	Development of in-vitro embryo production technology in Argentina
Chile	Biotechnological solutions in which microorganisms are used to solve mining problems	Aguamarina S. A.	Sale of services	Development and application of technologies for mining based on the use of	Scientific knowledge and recombination of technical knowledge	Biotechnological solution to reduce the amount of particulate matter in suspension.