An Approach to Measure Knowledge Transfer in Open-Innovation

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Abstract: Recent studies show that a growing number of innovations that are introduced in the market come from networks of enterprises that are created based on core competencies of each enterprise. In this context, the characterization and assessment of the knowledge transfer among members within a network is an important element for the wide adoption of the networked organizations paradigm. However, models for understanding the knowledge transfer and indicators related to knowledge transfer in a collaborative environment are lacking. Starting with some discussion on mechanisms of production and circulation of knowledge that might operate in a collaborative environment, this paper introduces an approach for assessing knowledge circulation in a co-innovation network. Finally, based on experimental results from a Portuguese collaborative network, BRISA network, a discussion on the benefits, challenges and difficulties found are presented and discussed.

1 INTRODUCTION

In order to be competitive, enterprises must develop capabilities that will enable them to respond quickly to market needs. According to several authors, one of the most relevant sources of competitive advantage is the innovation capacity (Tidd, 2005); (Argote, 2000). However, innovation capacity requires access to new knowledge that enterprises do not usually hold. As a result, enterprises can improve their knowledge either from their own assets, making sometimes high investments, or from the knowledge that may be mobilized through other enterprises based on a collaborative process. In fact, there is an intuitive assumption that, when an enterprise is a member of a long-term networked structure, the existence of a collaborative environment enables the increase of knowledge production as well as the transfer of knowledge, and thus the enterprises may operate more effectively in pursuit of their goals (Abreu, 2010).

However, in spite of this assumption, it has been difficult to prove its relevance due to the lack of models that support mechanisms that explain the production and transfer of knowledge in collaborative environment. Furthermore, the absence of indicators related to knowledge transfer – clearly showing the amount of knowledge transferred and the impact of this knowledge at a member level, for instance, in terms of capacity for generating new ideas, processes and products, organizational improvement through the combination of the existent resources, and diversity of cultures and experiences of other enterprises – might be an additional obstacle for a wider acceptance of this paradigm.

In this context, the definition and application of a set of indicators can be a useful instrument to the network manager, and also to network members.

This work aims at contributing to answer the following main questions:

- How is knowledge transferred from one network member to another?
- How can competences circulation be analyzed in a collaborative context based on an inter-organizational perspective in order to support decision-making processes?

2 SOME BACKGROUND

Upon reviewing the international literature, we find

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many studies highlighting the societal importance of innovation and knowledge within modern economies (Castells, 2005); (Soete, 2006). "Knowledge Economy" are highly regarded concepts, but we could mention other interesting works from Toffler (2003), Bell (1974), or Giddens (1990).

Knowledge always played an important role in the economy. But only over the last few years has its relative importance been recognised, just as that importance is growing. However, the stock of knowledge upon which economic activity is based today is definitely much larger than in previous eras. In the emergent economy and society, the accumulation of knowledge becomes the main motivational strength towards growth and development (Gosman, 1991); (Maskel, 1999) and (Urze, 2011).

Actually, the last decades have shown a generalised concern about the study on how companies create knowledge and, particularly, on how they operate this transference. Knowledge is recognised as a principal source of economic rent, and the effective management of organizational knowledge has increasingly been linked to competitive advantage and is considered critical to the success of the business firm. One of the distinctive features of the knowledge-based economy is the recognition that the diffusion of knowledge is just as significant as its production, leading to increased attention to "knowledge distribution networks" and “national systems of innovation”. These are the agents and structures which support the advance and use of knowledge in the economy and the linkages between them.

In this line of thought, Gibbons (1994) introduce a distinction between Mode 1 knowledge production, which has always existed, and Mode 2 knowledge production, a new mode that is emerging alongside it and which is becoming more and more relevant. While knowledge production used to be located primarily at scientific institutions (universities, government institutes and industrial research labs) and structured by scientific disciplines, its new locations, practices and principles are becoming much more heterogeneous. Mode 2 knowledge is produced in different organizations, resulting in a heterogeneous practice. The potential sites for knowledge production include not only the traditional universities, institutes and industrial labs, but also research centres, government agencies, think-tanks, and high-tech spin-offs.

Mode 2 refers to a production of knowledge which is not exclusively reserved for qualified academic research but focuses on the different actors integrated in a contextualised problem-solving oriented process. The importance of knowledge is then assessed by its social value and interest to stakeholders engaged in the process of production.

Five main features of Mode 2 summarise how it differs from Mode 1. First, Mode 2 knowledge is generated in a context of application; Mode 1 knowledge can also result in practical applications, but these are always separated from the actual knowledge production in space and time. A second characteristic of Mode 2 is transdisciplinarity, which refers to the mobilisation of a range of theoretical perspectives and practical methodologies to solve problems. Transdisciplinarity goes further than interdisciplinarity in the sense that the interaction of scientific disciplines is much more dynamic. Theoretical consensus cannot easily be reduced to specific scientific parts. Thirdly, Mode 2 knowledge is produced in a diverse variety of organisations, resulting in a very heterogeneous practice. The potential sites for knowledge generation include not only the traditional universities, institutes and industrial labs, but also research centres, government agencies, think-tanks, high-tech spin-off companies and consultancies. These sites are linked through networks of communication, and research is conducted in dynamic interaction. The fourth feature is reflexivity. It means that researchers become more aware of the societal consequences of their work (‘social accountability’). Sensitivity to the impact of the research is built in from the start. Novel forms of quality control constitute the fifth characteristic of the new production of knowledge. Traditional discipline-based peer review systems are replaced by additional criteria of economic, political, social or cultural nature.

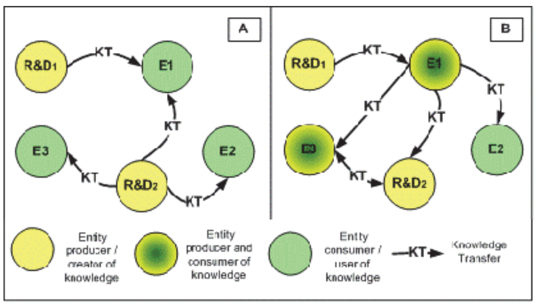

Figure 1: Production of knowledge environment 1A) Mode I and 2B) Mode I.

In Mode 2, research is carried out in the context of application in which there is a continuing dialogue between interested parties – including producers and users of knowledge – from the beginning. Thus, the concept of knowledge transfer has to be reconsidered. It cannot be understood as a simple transmission of knowledge from the university to the receiver. The participants may include business people, venture capital, industry, research centres and many others in addition to the university. In short, all need to become actively engaged in the process of knowledge production and its transfer.

Figure 1 illustrates the two modes (I, II) of knowledge production and its transfer taking as environment the collaborative networks.

3 A MODEL TO ANALYSE KNOWLEDGE TRANSFER

Based on the literature (Gibbons, 1994); (Forzi, 2004); (Abreu, 2008); (Camarinha-Matos, 2008); (Urze, 2012), and taking into account the context of collaborative networks, to analyse and understand the processes and mechanisms of knowledge transfer in a collaborative network, it is necessary to develop a model that supports, as a first approach, the following perspectives:

- **Transfer Mechanisms** – This perspective focuses on the identification and characterisation of distinct ways of "physical" interrelationship that support the process of knowledge transfer between enterprises within a network, such as internal publications, external publications, reports, patents, exchange of resources between organizations, videoconferencing, infrastructure to support collaborative processes (e.g. workgroup tool), telephone / mobile phone, informal meetings, and periodic meetings.
- **Competences Management** - This perspective addresses the principles, policies, and governance rules that may facilitate or constrain the processes of creating the competence and searching for competences by the members of the network. Therefore, general issues such as definition of accessibility levels (e.g. public, internal to network members or private), definition of policies in terms of competence dissemination among members of the network, definition of principles to assure the transparency and traceability of the competences in the network), and definition of rules in terms of Intellectual Property rights (IPR) (e.g. confidential or non-confidential) are considered here.
- **Nature of the Relationships** - The nature of the relationships determines the way collaborative space enables or facilitates the flow of knowledge among enterprises. Thus, this perspective focuses on the identification and characterisation of the various types of relationships that enterprises may have with other enterprises within the network: the relationships with new enterprises created from existing enterprises that belong to the network (e.g. spin-offs and start-ups) and also the relationships between the network as a whole and external entities (e.g. suppliers, customers, end-users, competitors, external institutions, and potential new partners).

Figure 2 illustrates the proposed model for the analysis of knowledge transfer in the context of network organizations.

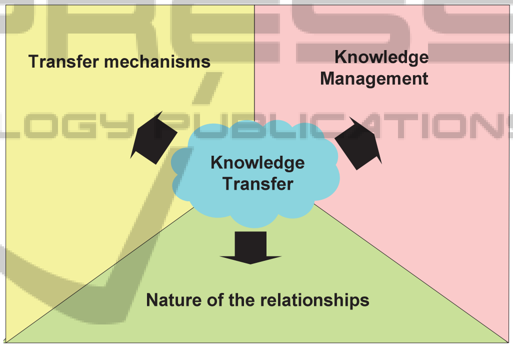

Figure 2: Knowledge transfer model.

In order to analyse the processes of knowledge transfer in a collaborative network, it is necessary to develop a model that supports the analysis of knowledge transfer among enterprises.

In an attempt to contribute to such need, we start with the assumption that the processes of knowledge transfer in a collaborative network can be represented graphically through a graph.

Therefore, as a first approach, using concepts from Social Network Analysis it is possible to apply several graph properties and relating them to circulation of knowledge.

To illustrate the potential application of graph properties let us consider some simple examples "archetypes" in this discussion. Assuming the degree of a node is a measure of the "involvement" of the enterprise in the network, it may be relevant to analyze the knowledge transfer process based on this perspective. According this approach, a network can be classified as decentralized or centralized. A network is decentralized when all enterprises have equal value of nodal degree (in-degree and out-degree), otherwise the network is centralized.

Figure 3A illustrates an example of decentralized knowledge transfer network supported by a mechanism of indirect reciprocity and Figure 3B) shows an example of centralized knowledge transfer network supported by a mechanism of direct reciprocity. However, comparing these two types of network, a knowledge transfer process supported on a decentralized network might be more attractive, since the number of provide/receive new competences is identical for all enterprises.

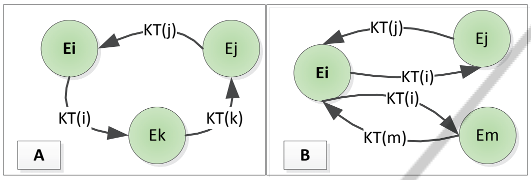

Figure 3: Decentralized *vs*. centralized knowledge transfer network.

Based on analyse of network connectivity Figure 4A) shows an example of acyclic network. This type of network is characterized by a weak connectivity among enterprises.

According to this approach the existence of acyclic knowledge transfer network means that there are enterprises that provide/receive competences to/from someone and do not receive/provide none from/to others. As a result, for some enterprises (in this case, enterprise E_i and E_m) the participation in a collaborative process supported by acyclic knowledge transfer network might not be advantageous, unless one of the following assumptions is verified:

- The enterprises believe that its actions can be perceived as an investment and later on, they can get some competences or benefits from others.
- The enterprises that receive new competences recognize a “debit” as a result of contributions received in the past.

On the other hand, Figure 4B) shows an example of cyclic network. A cycle is a closed walk of at least three nodes in which all links are distinct, and all enterprises except the beginning and ending enterprises are distinct. Consequently, the development of a knowledge circulation process based on a cyclic transfer network assumes that enterprises provide/receive new competences to/from someone and simultaneously receive/provide new competences from/to others. As a result, the participation in a knowledge transfer process supported by cyclic or closed walk knowledge transfer network is usually more attractive.

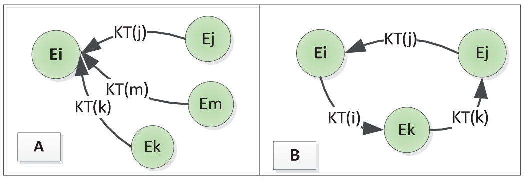

Figure 4: Acyclic vs. Cyclic network of knowledge transfer.

Table 1: Indicators for competences production and circulation analysis.

Indicator	Potential Use	Expression
Total of Competences (C)	This indicator measures the level of versatility/polyvalence of the network.	C – Number of distinct competences involved in the network
Total of enterprise Owned Competences (TOC)	This indicator measures the level of expertise and the potential capacity of an enterprise in terms of knowledge transfer.	TOC = Number of competences held by an enterprise.
Apparent Owned Competence Index (AOCI)	An enterprise with an AOCI close to one means that this enterprise is the owner of nearly all competences available within the network.	$AOCI = \frac{TOC}{M}$ M – Number of competences held by the network
Owned Competences Index (OCI_i)	Normalization of the number of competences held by an enterprise in relation to other members of the network. Benchmarking with enterprises involved in other networks.	$OCI_i = \frac{TOC_i}{\sum_{j=1}^{N} TOC_j}$ N – Number of enterprises involved in the network
Owned Competences Progress Ratio ($OCPR_i$)	The aim of this ratio is to measure the progress of competences held by an enterprise over a period of time. If: $OCPR_{i[t_1,t_2]} \begin{cases} =1 & \text{there is no change} \\ >1 & OCPR_i \text{ increased} \\ <1 & OCPR_i \text{ decreased} \end{cases}$ Benchmarking with enterprises involved in other networks	$OCPR_{i[t_1,t_2]} = \frac{(OCI_i)_{t_2}}{(OCI_i)_{t_1}}$ $t_2 > t_1$
Competences Abundance (CA_i)	This indicator measures the level of abundance of a competence inside the network. A competence with a CA near to zero means that it is exclusive because it is owned by few enterprises of the network.	CA_i = Number of ownership relations connected to competence i.
Apparent Competences Exclusivity Index ($ACEI_i$)	This index gives a simple to compute measure of exclusivity of a competence. A competence with an ACEI near to zero means that such competence belongs to few enterprises. On the other hand, a competence with an ACEI close to one means that such competence is owned by all enterprises in the network.	$ACEI_i = \frac{CA_i}{N}$ N –Number of enterprises involved in the network
Competences Exclusivity Index (CEI_i)	Normalization of the level of exclusivity of a competence in the network. Benchmarking with other networks.	$CEI_i = \frac{CA_i}{\sum_{j=1}^{M} CA_j}$ M – Number of assets held by the network
Competences Exclusivity Progress Ratio ($CEPR_i$)	The aim of this ratio is to measure the variation of exclusivity of a competence over a period of time. If: $CEPR_{i[t_1,t_2]} \begin{cases} =1 & \text{there is no change} \\ >1 & CEPR_i \text{ increased} \\ <1 & CEPR_i \text{ decreased} \end{cases}$ Benchmarking with other networks	$CEPR_{i[t_1,t_2]} = \frac{(CEI_i)_{t_2}}{(CEI_i)_{t_1}}$ $t_2 > t_1$

Since, the most favourable network for promotion of knowledge transfer is dependent on the existence of cycles or close walk processes, it is useful to analyse in detail the conditions that drive the emergence of this type of structure. Therefore, in order to establish a close walk process it is necessary to satisfy the following three conditions:

- **Provide Condition** – Enterprises must provide new competences. For each enterprise E_j, there is at least another enterprise E_k to which E_j provides a new competence.
- **Receive Condition** – Enterprises have to receive new competences. For each enterprise E_k there is at least another enterprise E_j from which E_k receives a new competence.
- **Identity Condition** – Enterprise $E_k \neq E_j$.

Taking into account the context of collaborative networks, and combining concepts borrowed from the Social Networks Analysis (SNA) area. Table 1 shows a number of basic indicators that can contribute to evaluate the level of expertise of an enterprise and how production and circulation of knowledge is done within the network. Furthermore, these indicators can be determined for a particular collaboration process or over a period of time (average values) and can be used in decision-making processes, such as the planning of a new collaborative network.

However, the use of graphs implies a partial view and consequently, a limitation of this approach. In order to have a full description it is important to combine other tools (such as: game theory, causal models, fuzzy tools, belief networks, etc.) to analyse in detail the impact of the three dimension proposed in a knowledge transfer process.

4 BRISA CASE STUDY

The paper's empirical section is based on one case study pointed to the largest Portuguese motorway operator. *Brisa* - Auto-estradas de Portugal, founded in 1972, currently operates, on a concession basis, a network of 11 motorways, with a total length of around 1096 km, constituting the main Portuguese road links. The Brisa co-innovation network is a long-term collaborative network that has more than 30 members from several domains and business activities (e.g. researches institutions, universities, associations, governmental entities, start-ups, business angels, and suppliers).

The empirical work is grounded on two main projects developed by BRISA, namely E_TOLL – *Electronic Tolling System* a self-service toll lane where it is possible to pay by a bank card, money and ALPR – *Advanced License Plat Recognition* an enforcement system based on the automatic license plate recognition for situation where the vehicle is not equipped with an on-board-unit (OBU) or the OBU fails to electronically identify the vehicle. In the case study three techniques were combined to carry out the empirical research: *in-locu* observation of the work processes, semi-directive interviews and questionnaires addressed to actors belonging to different organizations that take part of E_TOLL and ALPR.

Taking into account the data collected, Table 2A shows the types of competences used by each partner in the collaborative projects, and Table 2B identifies the types of competences held by each partner in the end of the collaborative projects.

Applying the equations defined in Table 1, Table 3A evaluates the production of new knowledge based on the number of distinct competences held by network in the end of the project E_TOLL and ALPR, and the number of different competences used by the network when the projects started. Based on these data, it is possible to verify that 6 new competences were produced (C19, C20, C21, C22, C23, and C24).

Table 2: Record of the competences.

A

	Competences																								
Entity	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	Total
O1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
E1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
E2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
E3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
E4	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
E5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
E6	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	5
E7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	3
O2	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Total	2	3	1	3	1	1	1	1	1	1	1	1	1	1	2	1	1	1	0	0	0	0	0	0	18

B

	Competences																								
Entity	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	Total
O1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	9
E1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
E2	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3
E3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
E4	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
E5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
E6	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	5
E7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	3
O2	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	5
Total	3	3	3	4	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	34

Table 3B shows indicators to analyse, for instance, how the competences are held by network members, and the benefits of the entities' participation in a collaborative process. Assuming that the benefits of an entity can be viewed as the capacity of involvement in a collaborative process; in this case, we are not particularly concerned with whether this benefit is due to the development of exclusive competences, but rather in analysing how many distinct competences might be performed by a member. According to Owned Competences

Progress Ratio (OCPRI), at the end of those two projects, there are three members, O1, E2, and E4 that had a significant increase in terms of acquiring new competences that might be used in the future, and consequently, they have more opportunities to participate in collaborative processes than those who have a low ratio.

Table 3C illustrates some examples of indicators to evaluate, for instance, the level of exclusivity of each competence and the circulation of competences among members. Based on these data, it is possible to verify, for example, that according to Competences Exclusivity Progress Ratio (CEPR), the highest value belongs to competence C3 (infrared illumination) that had a great proliferation among members of the network.

Table 3: Indicators for Knowledge production and circulation analysis.

A

	Start	Finish
C	18	24

B

	Start			Finish			
Entity	TOC	AOCI	OCI	TOC	AOCI	OCI	OCPR
O1	4	0,22	0,17	9	0,38	0,27	1,64
E1	2	0,11	0,08	2	0,08	0,06	0,73
E2	1	0,06	0,04	3	0,13	0,09	2,18
E3	1	0,06	0,04	1	0,04	0,03	0,73
E4	3	0,17	0,13	5	0,21	0,15	1,21
E5	1	0,06	0,04	1	0,04	0,03	0,73
E6	5	0,28	0,21	5	0,21	0,15	0,73
E7	3	0,17	0,13	3	0,13	0,09	0,73
O2	4	0,22	0,17	5	0,21	0,15	0,91

C

		Start			Finish			
	Competences	CA	ACEI	CEI	CA	ACEI	CEI	CEPR
C1	Computer vision	2	0,22	0,11	3	0,33	0,09	0,79
C2	Software Engineering	3	0,33	0,17	3	0,33	0,09	0,53
C3	Infrared illumination	1	0,11	0,06	3	0,33	0,09	1,59
C4	Automatic pattern recognition	3	0,33	0,17	4	0,44	0,12	0,71
C5	Toll systems	1	0,11	0,06	1	0,11	0,03	0,53
C6	Information Systems Architecture,	1	0,11	0,06	1	0,11	0,03	0,53
C7	Industrial Design	1	0,11	0,06	1	0,11	0,03	0,53
C8	Modelling of products	1	0,11	0,06	1	0,11	0,03	0,53
C9	Rapid prototyping	1	0,11	0,06	1	0,11	0,03	0,53
C10	Development of molds	1	0,11	0,06	1	0,11	0,03	0,53
C11	Plastic injection	1	0,11	0,06	1	0,11	0,03	0,53
C12	Functional Tests	1	0,11	0,06	1	0,11	0,03	0,53
C13	Software Development	1	0,11	0,06	1	0,11	0,03	0,53
C14	Software Architecture	1	0,11	0,06	1	0,11	0,03	0,53
C15	Project Management	2	0,22	0,11	2	0,22	0,06	0,53
C16	Functional Analysis	1	0,11	0,06	1	0,11	0,03	0,53
C17	Remote monitoring	1	0,11	0,06	1	0,11	0,03	0,53
C18	Supplier of equipment for image capture	1	0,11	0,06	1	0,11	0,03	0,53
C19	Electronic Toll Collection (ETC) systems	0	0,00	0,00	1	0,11	0,03	----
C20	Information Systems open to multi-vendor	0	0,00	0,00	1	0,11	0,03	----
c21	Automatic vehicle identification systems	0	0,00	0,00	1	0,11	0,03	---
C22	Communication systems between vehicles	0	0,00	0,00	1	0,11	0,03	---
C23	Classification systems of vehicles	0	0,00	0,00	1	0,11	0,03	----
C24	Short run production	0	0,00	0,00	1	0,11	0,03	---

5 CONCLUSIONS

Reaching a better characterization and understanding of the mechanisms of production and circulation of knowledge in collaborative networks is an important element for a better understanding of the behavioral aspects, and also to improve the sustainability of this organizational form.

The development of a set of indicators to capture and measure the circulation and production of knowledge can be a useful instrument to the manager of this network, as a way to support the promotion of collaborative behaviors, and for a member as a way to extract the advantages of belonging to a network. Using simple calculations as illustrated above, it is possible to extract some indicators. Some preliminary steps in this direction were presented. However, the development of indicators to measure the potential impacts and worth related to production and circulation of knowledge, for instance, at a member level, in terms of capacity of generating new ideas, development of new processes, new products or services, organizational improvement through the combination of the existent resources and diversity of cultures and experiences of other enterprises is not yet well understood and requires further research and development.

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