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Title

Modelling technology transfer: a proposal to measure the intensity of knowledge flows transferred between science and industry.

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Abstract

This study propose an innovative approach to design an analytical index to evaluate the intensity of knowledge flows transferred between the scientific community and the business sector in an effort of measuring the impact of such collaborations. The observation of the frequency on the development of different channels of collaboration between university and firms is only the starting point and quite a simplistic way of looking at the knowledge transfer. The issue of measuring the level of knowledge transfer involves an analysis in depth of the internal dynamics and the nature that underline the variety of collaboration channels as dimensions of the intensity of knowledge exchange. The concept of knowledge transfer intensity is dependent on the features associated with the channels of interaction, such as the degree of transformation of the knowledge involving, the exchange of tacit knowledge that occurs, the relational intensity that entails the interaction, as well as the frequency with which the agents interact. Thus, according to the features of the different types of collaboration we design a composite index to measure the intensity of knowledge transfer in an innovation system. To gain a better insight of the analytical proposal, it is applied to four regional innovation systems in Spain in order to evaluate and compare the intensity of knowledge transfer in different contexts. The results suggest that this methodology offers relevant conclusions to policy evaluation methods, increasing the understanding of patterns of collaborations and helping on the management of the knowledge transfer in different contexts.

Keywords

Evaluation, knowledge transfer, innovation system

1. Introduction

Empirical studies about knowledge transfer between universities and firms are primarily focused on those collaborations that produce direct and tangible output to measure, such as patents, licenses and spin-off (Siegel et al. 2003; Geuna and Muscio 2009). Nevertheless, other type of activities, for example, consultancy services, personal exchange and research projects are considered propitious for the generation, transfer and application of new knowledge (Shartinger et al. 2001; D'Este and Patel 2007). In addition, this type of collaboration involves the exchange of tacit knowledge strengthening the learning capacity of firms, essential condition for the development of innovations (Lundvall et al. 2002). Many authors confirm that interactions between universities and business sector involve different patterns of knowledge transfer, from more formal relations based on joint research projects or joint research centers, up to informal relationships (Cohen et al. 2002; Agrawal and Henderson 2002; Perkmann and Walsh 2007; D'Este and Patel 2007; Shartinger et al. 2002; Arza 2010; De Fuentes and Dutrénit 2012; Ponomariov and Boardman 2012).

However, despite the prominence of the development of a wide range of collaboration activities, there are no appropriate indicators to measure the intensity level of knowledge transfer that these types of activities involve. The analysis and evaluation of university-industry collaboration are based fundamentally on the exploitation of official sources data, which do not reflect the complexity of the specific knowledge flows transferred. The limitations of official data sources from universities or governments stem mainly from the fact that not all research activities are necessarily related to a direct and tangible commercialization outputs. Consequently, this gap difficult the evaluation of knowledge transfers between key stakeholders of an innovation system. In this sense, Bozeman (2013) has suggested the requirement of focus on a "more careful measurement of impacts as opposed to outputs" on the study of interactions between universities and business sector.

Thus, the main question this paper addresses is: how can design a composite index based on a theoretical and analytical framework to evaluate the intensity of knowledge transfer between university and industry in different innovation systems. Several authors have pointed out theoretical background to measure knowledge transfer flows, but there is little empirical evidence that it has so far made progress in knowledge concerning this issue. The measurement of these interactions is difficult and most efforts have focused on such channels more easily quantifiable due to official available data. To go about this question, the value of this proposal lies not only in

the observation and quantification of the diversity channels through which takes place the knowledge transfer between research teams and firms in each context. Moreover, this analytical proposal includes a qualitative approach that allows evaluating and measuring the degree of knowledge flows involved in each type of collaborations. We consider the intensity of knowledge transfer as qualitative dimensions of the impact of such collaborations, thus interactions with higher intensity are more relevant to the extent that represents a greater learning opportunity for firms.

The paper is organized as follows. The first section provides a brief theoretical review to indentify and quantify the wide range of types of knowledge transfer channels and to define the analytical framework to measure the intensity of knowledge transfer process. The second part describes the method and strategy followed to build the composite index and the data and context of the four regions where it is applied. The third part presents the results of the index to evaluate four regional innovation systems, of Spain, using data from a representative sample of research groups in the mentioned country. Finally, we present main conclusion and implications of the results of this proposed index of evaluation.

2. Conceptual considerations

2.1 Knowledge interactions between science and industry: a diverse map of relations forms

There is a broad consensus among academics about the relevance of the generation of new scientific knowledge and its transfer as the basis of socio-economic development of the environment. Nevertheless, there is a lack of understanding about how circulate this knowledge beyond the boundaries of the institution that have generated it. As Bozeman (2013) highlights "Knowledge transformation" may take many forms, and this is the reason why it is a concept closely related to the "relational intensity" and the "complexity" of the knowledge involved.

Clearly, the literature specializing on science-industry collaboration recognizes the complexity of the nature of these interactions. This relationship do not respond to a single specific pattern, or uniform channels (Bozeman 2000; Perkmann and Walsh, 2007; Geuna and Muscio 2009), and highlights the existence of important lacks in the understanding of the wide range of strategies of collaboration (D'Este and Patel 2007). Thus, for example, the systematic review of the literature reveals that empirical studies have focused mainly on three types of relationships:

patents, licensing and spin-off (Bozeman 2000; Geuna and Muscio 2009; Mowery and Sampat 2001; Agrawal and Henderson 2002; Owen-Smith and Powell 2003; Valentin and Jensen 2007).

Such types of collaborations tend to prevail as a measure of the university output due to both the market expectations generated and the increased availability of data bases registered by their technology transfer offices and government bodies. Despite the nature of patents and licenses that involve direct marketing (Perkmann and Walsh 2007), only a low proportion of the research generated at universities could be coded according to these knowledge transfer mechanisms (Geuna and Muscio 2009).-Other more widespread channels of knowledge transfer are based on informal collaborative relationships, such as technical assistance, consulting and collaborative research (Link et al. 2007). Moreover, nowadays, the exchange of tacit knowledge is a key output of knowledge transfer (Ponomariov and Boardman 2012). In this sense, the map of knowledge transfer has been expanded to include human resources training, joint research, personal contacts for information exchanges, research contracts or diffusion activities (Cohen et al. 2002; Agrawal and Henderson 2002; Perkmann and Walsh 2007; Bekkers and Boda-Freitas 2008). Therefore, studies of patents or spin-offs provide a limited picture of the reality of university-industry collaborations.

The acceptation of the wide range of collaboration channels is only the starting point and quite a simplistic way of looking at the evaluation of knowledge transfer. Going a step further in this field of study, we analyze which are the effects of each collaboration strategy, taking into account the influence of the different interaction channels on the generation and use of knowledge. In this paper we assume the interaction mechanisms involve exchanges of knowledge of different nature and intensity, meaning that the intensity of knowledge transfer is an important area of impact of the interaction between the business and the academic sphere.

2.2 The intensity of knowledge transfer process: an analytical approach of measuring

The theoretical framework of this paper is based on the features associated to the internal dynamics of the different channels of knowledge transfer and on the quantitative aspects related to the contractual linkage. The variation in the logics and structures of university-industry collaborations are predominantly a function of the nature of the knowledge to be transferred and

the feature of the relationship between the agents. The combination of both levels of analysis has not been tested in an empirical model.

The study of internal dynamics of knowledge flows allows identifying three main dimensions of analysis based on previous theoretical studies: the degree of knowledge transformation, the degree of "relational intensity" and the degree of transfer of tacit knowledge. Several authors highlight the relevance of some of such dimensions to measure knowledge transfers. For example, Shartinger et al. (2002) analyzed the variations on the pattern of knowledge interactions between university and industry according to the intensity of knowledge flows in each type of collaboration used. On the one hand, the study suggested that the intensity of knowledge flows varies by type of channel of collaborations. On the other hand, interactions with high level of relational intensity based on closed and frequent face-to-face contacts between agents are assumed to be strongest on the intensity of knowledge flows university-industry. In addition, Perkmann and Walsh (2007) classified the types of collaboration based on the relational intensity involving each activity between the direct agents: the researcher and the manager of the firm.

Consequently, following the analytical concept of "relational intensity" of these authors, first of all, those collaborations based on stable forms of organization, like joint research centers or spin-off, are positioned as activities that involve an increased relational intensity. Secondly, are distinguished the relationships based on the mobility of personnel. Thirdly, are included the transfer of knowledge activities focusing on the provision of services, such as consulting and research projects, followed by those activities focused on the use of facilities. In addition, Shartinger et al. (2002) associate personal relationships with the exchange of tacit knowledge through activities such as "talking and listening or demonstrating and copying" (Machlup 1980). Those types of activities allow a new combination of existing knowledge which generates new scientific knowledge to be applied. Hence, personal interactions and communication processes between agents are essential for the creation of new knowledge. The exchanges of personnel or the employment of new graduates by firms are relevant cases of tacit knowledge transfer.

Similarly, in recent years, Ponomariov and Boardman (2012) highlight the relevance of both dimensions in the measure of knowledge transfer: the level of knowledge transformation that takes place in the interaction and the intensity of the relationship between agents. However, the presence of each dimension varies depending on the type of channel of collaboration (Ponomariov and Boardman 2012). In general, university-industry collaborations involve not only

the exchange of codified knowledge, furthermore, implicate a knowledge transformation processes in different levels. The generation and use of new knowledge results not only from the transfer of codified knowledge but also tacit knowledge (Nonaka and Takeuchi 1995) which is facilitated by personal interactions (Lundvall 1992). Thus, it is usual that innovation is produces from a creative combination of knowledge that already exists in the enterprise (Shartinger et al. 2002).

One further dimension essential in assessing the intensity of knowledge transfer according to the internal dynamic of the different channels is the measurement of the tacit knowledge involved. Several authors highlight the link of the processes of creation, conversion and diffusion of knowledge, mainly in its tacit dimension, with the organizational learning, which is necessary for the innovative activity of firms (Nonaka and Takeuchi 1995; Cowan and Foray 1997; Ancori et al. 2000; Cowan et al. 2000; Davenport and Prusak 2000; Haldin-Herrgard 2000; Johnson et al. 2002; Hall 2006). Therefore, each channel of knowledge transfer contributes in a different way in the innovative capacity of firms, since they involve different levels of conversion and exchange of knowledge. In additions, knowledge which is difficult to encode and transmit would require during the transfer process a high degree of interaction between the agents, in other words, will mean more relational intensity. For example, whereas publications or patents are channels of knowledge transfer characterized by the exchange mainly of knowledge of explicit nature associated with a low level of intensity relational, joint research activities or research services involve highest intensity relational and entail an increased generation and exchange of tacit knowledge (Rossi 2010).

Finally, we combine the dimensions to measure internal dynamics of different channels of collaborations with the quantitative aspects relate to the contractual linkage. These activities can be quantified and measured regularly. In this sense, a relevant indicator to quantify the intensity of knowledge transfer is the number of times that has been established some type of link with any firms. Shartinger et al. (2002) measured the knowledge interactions asking the heads of university departments how many times they had made with firms each one of collaboration activities listed in their study. Moreover, the duration of the partnerships give an account of the intensity of knowledge transfer between two agents. The more long-lasting relationships are also the likely facilitate greater exchange of knowledge flows. In this study is used as a variable the number of firms that have collaborated with the research teams. We assumed that the more

linkages are established with the business sector, more increases the chances of transfer of knowledge flows between both agents.

In sum, the conceptualization and measurement of the internal dynamics of university-industry knowledge flow is related to degree of knowledge transformation, the relational intensity of the contact between the agents involved on the collaboration and the frequency of collaboration. In the following table, we classify the variety of possible types of collaborations according to the three dimensions previously mentioned: the "relational intensity", the tacit knowledge transfer and the knowledge transformation. Such analytical approach allows evaluating qualitatively the internal dynamics of knowledge flows involved in each type of collaboration.

Table 1. Classification of different collaboration channels according to the internal dynamics of knowledge flows (*)

Collaboration Channels	Relational intensity	Tacit knowledge transfer	Knowledge transformation
• Joint research projects	++	++	++
• R&D contracts	++	++	+
• Consultancy	++	++	+
• Scientific publications	+	+	-
• Personnel exchanges and mobility	+	+	-
• Use of research facilities	-	-	+
• Conferences and profesional meetings	+	+	-
• Informal interaction	++	++	-
• Joint research centers	++	++	++
• Spin-off	+	++	++
• Commercialization of property rights	-	-	+

Source: Adapted from Cohen et al. (2002), Perkmann and Walsh (2007), Schartinger et al. (2002) and Ponomariov and Boardman (2012)
(*) ++: High; +: Medium; -: Low.

First, regarding the relational intensity dimension, we assumed that joint research projects, research contracts, consultancy and joint research centers are interaction channels associated with a high relational intensity. In these cases, the exchange of knowledge flows is based on the personal contact between the agents. Clearly, such channels of interaction are not understood without high levels of personal interaction. In addition, those mechanisms characterized by higher intensity relational are at the same time the most favorable for the transfer of tacit knowledge, the second dimension of our analytical framework. Accordingly, we assumed that the exchange of tacit knowledge between firms and research groups will be increased in cases in which the agents work together in a new organization for the development of a specific project or when research results produced will be applied by the firm. Such is the case of joint research centers and the spin-off, as well as joint research projects. At an intermediate level, there are located the

activities related to mobility of human resources and diffusion activities. While, at a lower level, are positioned the publications and patents, based essentially on analytical knowledge (Asheim 2009), in order words, of scientific component and, mainly, coded.

Finally, related to the third dimension, the literature recognizes the highest levels of knowledge transformation in activities as joint research projects, in the creation of spin-offs and joint centers (Ponomariov and Boardman 2012). On the opposite side are publications, the personnel exchanges, conferences and informal relationships, which are not characterized as being the most appropriate framework for the knowledge conversion processes. For example, in the case of scientific publication, it is possible to affirm that are characterized for being mainly a source of explicit knowledge and with low capacity to transform this type of knowledge into tacit, as occurs in other type of activities.

In conclusion, we assume that there is more intensity of knowledge transfer in those activities in which takes place more knowledge transformation, as well as supported process in the level of tacit knowledge that is transferred in the linking and when these relationships are built with a high degree of intensity relational. In addition, all these aspects are favored in cases where the relationship between the agents is frequent or stable in time. In this way, first, the highest values in the intensity knowledge transfer are represented by links based on joint research projects, the marketing of research results through spin-off or an alternative highly formalized as is the creation of joint research centers or joint research projects between universities and firms. In a second level of intensity, are located the research contracts, consultancy services and the informal relationships between the agents. Such activities involve a high rate of relational intensity, whereas represent a low capacity to lead knowledge transformation processes opposite to the previous group of type of collaborations. Finally, in the lower level are distinguished for example, publications, conferences and patents as interactions of less intensive knowledge transfer, given the low level of presence of all the dimensions considered in the analysis.

Nevertheless, this classification of the different types of collaboration according to the intensity of knowledge transfer must not be understood as separate compartments. Rather, these dimensions represent a continuum that serve as interpretative strategy for the construction of a measuring instrument. The composite index proposed allows realizing an approximate evaluation of the intensity of knowledge transfer developed between the universities and the companies in an innovation system.

3. Data

In this paper, we applied the proposal index to four different regions of Spain: Andalusia, the Basque Country, Madrid and Canarias. In order to evaluate the level of intensity knowledge transfer of each region, we consider as unit of analysis the research teams of their public R&D sector. The data were collected by a survey to a representative sample of 851 research teams of the different regions. The sample was designed, based on a proportional stratification by region and scientific disciplines. The central part of the questionnaire was focused on the analyses of the collaboration with business sector. In order to measure such collaboration, the questionnaire collected information about eleven activities carried out between 2010 and 2011: consultancy, R&D contracts, joint R&D projects, use of facilities, patent and licensing exploitation, internships, personal mobility, external training, joint research centers, spin-offs and conferences.

4. A method for the construction of the variable intensity of knowledge transfer process

After dealing with university-industry collaboration from a conceptual view and reviewing the literature, we construct the complex index to evaluate the intensity of knowledge transfer in a region. First of all, we proceed from the classification of different types of collaboration based on the review of the literature. In particular, as table 3 represent, we consider 11 types of possible collaboration Ci. Where $ci = 0$ if the research team have not done this type of collaboration with a firm; and $ci = 1$ if the research team have done this type of collaboration.

For the classification of each type of collaboration has been estimated the value Vi of the intensity transfer of each channel Ci, by adding the value accorded to each analytical dimension of the intensity of transfer:

D_1i Relational intensity; D_2i Tacit Knowledge; D_3i Knowledge transformation

$$Vi = \sum D_1i \;\; D_2i \, D_3i$$

Table 3. The intensity of knowledge transfer for each type of collaboration

Type of Collaborations Ci	ANALYTICAL DIMENSIONS			VALUE Vi
	Relational intensity D_1i	Tacit knowledge D_2i	Knowledge transformation D_3i	
• INT_Joint research projects	++	++	++	6
• INT_R&D Contract	++	++	+	5
• INT_Consultancy	++	++	+	5
• INT_Use of research facilities	+	+	-	2
• INT_Personnel exchanges and mobility	+	+	-	2
• INT_Scientific publications	-	-	+	1
• INT_Conferences and profesional meetings	+	+	-	2
• INT_Informal interaction	++	++	-	4
• INT_Joint research centers	++	++	++	6
• INT_Spin-off	+	++	++	5
• INT_Commercialization of property rights	-	-	+	1

++ takes value 2, + takes value 1, - takes value 0

The second step of our complex index is the introduction of a correction factor to quantify the frequency that each collaboration has been done: FC. The value of the correction factor were normalized to enable comparison between regions. The FC is constructed with the indicator of the number of firms with which the research teams had collaborated. The value of this indicator is as follow:

$$FC \begin{cases} \mathbf{1} = \boldsymbol{collaboration\ with\ 1\ firm} \\ \mathbf{1,5} = \boldsymbol{collaboration\ with\ 2-5\ firms} \\ \mathbf{2} = \boldsymbol{collaboration\ with\ 5-10\ firms} \\ \mathbf{2,5} = \boldsymbol{collaboration\ more\ than\ 10\ firms} \end{cases}$$

Thus, we can calculate the intensity of collaboration for each research team from the following index:

$$\boldsymbol{I_{ktG}} = FC \sum_{i=1}^{11} (C_i\, V_i)$$

Finally, we estimate the complex index of the average intensity of knowledge transfer in a region:

$$\boldsymbol{I_{KTR}} = \mathrm{X}\,(\,FC \sum_{i=1}^{11} (C_i\, V_i))$$

The index calculated takes values from 0 to 100, so the result for each region can be defined as follows:

$$I_{KTR} = \begin{cases} 1-20 = Low\ intensity\ of\ knowledge\ transfer \\ 20-40 = Low-Medium\ intensity\ of\ knowledge\ transfer \\ 40-60 = Medium\ intensity\ of\ knowledge\ transfer \\ 60-80 = Medium-High\ intensity\ of\ knowledge\ transfer \\ 80-100 = High\ intensity\ of\ knowledge\ transfer \end{cases}$$

The application of the index to our case study leads to the following results:

	I_{KTR}
Andalusia	17,89
Canarias	11,81
Madrid	17,52
The Basque Country	20,32

5. Conclusions

The aim of this paper was to provide an exploratory model to measure the intensity of knowledge flows and its application to evaluate and compare different regional innovation systems. The study makes an important contribution in the field of measuring and evaluating the intensity of knowledge transfer processes between universities and companies. The results highlight the potential possibilities of this proposal for a comparative analysis of the intensity of knowledge transfer in different contexts, for instance, between universities and research centers, different regional innovations systems, different business sector. Moreover, the applications of the model increase the understanding of the effects that the patterns of relationship have adopted in regional innovation systems. Since the scope of the policies it would be interesting to note that, in addition to promoting in quantitative terms the collaboration between university and industry, more attention will be given to qualitative aspects related to the internal dynamic of the knowledge flows.

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