Determinants of the International Influence of a R&D Organisation: A Bibliometric Approach

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Abstract

Traditionally, studies on the influence and impact of knowledge-producing organisations have been addressed by means of strict economic analysis, stressing their economic impact to a local, regional or national extent. In the present study, an alternative methodology is put forward in order to evaluate the international scientific impact and influence of a knowledge-producing and -diffusing institution. We introduce a new methodology, based on scientometric and bibliometric tools, which complement traditional assessments by considering the influence of a R&D institution when looking at the scientific production undertaken and the recognition of its relevance by its international peer community. Focusing on the most prolific scientific areas of the R&D institution (INESC Porto), and resorting to published scientific work recorded in the *Science Citation Index* (SCI), we show that the R&D institution has enlarged its international scientific network. The logit estimations demonstrate that the wide geographical influence of INESC Porto scientific research is a result not of its international positioning in terms of co-authorships, but rather a result of the quality of its scientific output.

Keywords: Impact and influence assessment methods; R&D Institutions; Bibliometrics, Scientometrics; knowledge network; INESC Porto

1. Introduction

It is broadly recognised how Research and Development (R&D) and innovation breakthroughs have the potential to deeply expand or even alter economic growth, which in the end has a strong influence over world-changing dynamics, favouring countries that support knowledge research and innovation (Martin, 1998). The flow of ideas and technologies from universities and R&D institutions therefore has profound consequences over several economic variables. The truth is that international economic activity is increasingly technology-driven and knowledge-based, and this has forced firms to produce stronger linkages with innovative knowledge-based institutions, which in turn also seek scientific partnerships to better respond to the higher innovative technology or knowledge demand (Grandstrand et al., 1997; Langlais, 1997; Brusoni et al. 2000; Meyer, 2000b; Meyer, 2004). The importance of such linkages with Research and Development (R&D) and innovation-based organisations has long been defended and reasoned due to their influence over regional, national and international economic growth

(Kuznets, 1966; Martin, 1998). These different-levelled impacts have for long time attracted and challenged researchers within economic science.

Traditionally, the measurability of the economic impact of an university or a R&D organisation was based on several economic variables, such as new jobs created after public/private investment in R&D projects (cf., Beeson and Montgomery, 1990; Huggins and Cooke, 1997; Gagnol and Héraud, 2001; Cox and Taylor, 2006; Swenson and Eathington, 2007; Barrios et al., 2008), revenues, productivity, worker efficiency (cf., Love and McNicoll, 1988; Newlands, 2003; Harloe and Perry, 2004; Bilbao-Osorio and Rodríguez-Pose, 2004; Braunerhjelm, 2008), and, public health or environmental impact (cf., Hedrick et al., 1990; Simha, 2005). These types of studies assessed such impact mainly through this institution's influence on the evolution and composition of the Gross Domestic Product (GDP) and were usually associated with the need for backing or justifying public funds' allocation (cf., Martin, 1998; Bessette, 2003; Bilbao-Osorio, and Rodríguez-Pose, 2004; Barrios et al., 2008). Such studies are, in fact, largely related to a branch of neo-classical growth theory, or more generally, mainstream economics (e.g., Bayoumi et al., 1996).

In contrast with the economic dimension, the knowledge dimension of the influence and impact of R&D organisations is, in general, more poorly developed. Notwithstanding, several attempts have been made to study the combining backward expenditures-related linkages and the forward knowledge-related linkages of Universities and R&D organisations (e.g., Felsenstein, 1996; Huggins and Cooke, 1997; Newlands, 2003; Harloe and Perry, 2004; Buxton et al., 2004; Tavoletti, 2007). However, these attempts have failed to capture the whole nature of knowledge flows that goes beyond expenditures linkages.

Scientometric and bibliometric approaches are increasingly used by several authors to assess the evolution, productivity, and structure of scientific knowledge and R&D output (e.g., Meyer, 2004; Wagner and Leydesdorff, 2005; Dietz and Bozeman, 2005; Adams, 2006; Hussler and Ronde, 2007). Normally, studies within this research field (Meyer, 2000b; Meyer, 2004; Wagner and Leydesdorff, 2005) aim to appraise the scientific output of individuals, journals and even organisations (e.g., effective publication in internationally refereed journals, high citation scores) by surveying and analysing co-authorships and citation indexes. According to Wagner and Leydersdorff (2005), authors within this research field are interested in the increase of the interconnectedness of scientists (e.g., Okubo et al., 1992; Luukkonen et al., 1993; Zitt et al., 2000; Glänzel, 2001; Cantner and Graf, 2006), in figuring out patterns of collaboration in general (e.g., Chung and Cox, 1990; Gibbons et al., 1994; Katz and Martin, 1997; Dietz and Bozeman, 2005; Hussler and Ronde, 2007) and of international linkages in particular (e.g., Stichweh, 1996; Schott, 1998), and further analysing implications of linkages for funding and outcomes (e.g. Van den Berghe et al., 1998; Wagner et al., 2000; Advisory Council of Canada, 2001; Carmona et al., 2005; Adams, 2006). Although scientometric and bibliometric studies embrace a much wider perspective of the linkages/networks of R&D institutions in the regional, national and international context than standard economic studies, to the best of our knowledge, these studies did not make use of scientometric tools to analyse the influence and impact of R&D institutions. In the present work we aim to contribute towards filling this gap. As such, we use scientometric and bibliometric approaches to assess the influence and impact of an R&D organisation, therefore complementing traditional economic approaches, and providing a more embracing perspective of knowledge flows. To accomplish such endeavour we resort to multivariate logit models, addressing the main goal of our study which is to evaluate the organisation's international influence and impact.

We structure the present paper as follows. In the next section, we review the two main branches of literature in analysis: the standard economic approaches and the bibliometric and scientometric approaches. The methodology is further detailed in Section 3. Based on the most prolific units of INESC Porto in terms of scientific output, in Section 4, we use a logit model to assess the determinants of INESC Porto's international influence. Finally, in Conclusions, we address the main results and highlight the contributions of the methodology to the literature.

2. Assessing the Impact and Influence of R&D Organisations – a Literature Review

It is generally recognised (albeit less empirically proved) that R&D or knowledge producing organisations play a significant role in today's global economic development, by generating valuable returns in terms of economic growth and productivity (cf., Denison, 1968; Romer 1986: Steinnes, 1987; Dosi, 1988; Feller, 1990; Trajtenberg 1990; Lichtenberg, 1993; Felsenstein, 1996; Bilbao-Osorio and Rodríguez-Pose, 2004; Marginson and van der Wende, 2007).

Economic studies on the methods to measure the impact of a university (and less of a research organisation) at the national or regional economic level have proliferated. These studies usually present alternative models that best evaluate public and private support to R&D (Scherer, 1982; Felsenstein, 1996; Martin, 1998). Generally, instruments to measure the economic impact of R&D producers are mainly focused on the public funding directed for scientific research, in order to evaluate the usage of public money, i.e., the economic relevance of research (Bailetti and Callahan, 1992; Bozeman and Melkers, 1993; Felsenstein, 1996; Martin, 1998; Bessette, 2003). The focus is thus to evaluate the relevance of activities or outputs, undertaken by universities or R&D institutions, namely the production of skills, know-how, patents, technology transfer and licensing activities, consultancy and spin-offs, new job creation, new firms' creation, and so on (e.g., Smilor et al., 1990; Bozeman and Melkers, 1993; Goddard et al., 1994; Coe and Helpman, 1995; Felsenstein, 1996; Verspagen, 1997; Bessette, 2003).

Table 1: Summarising the main approaches on the economic impact of universities and R&D institutions

Approaches		Mechanisms / Methods	Results	Authors
Correlation between concentration of high-technology activities and various location factors which favour clustering		Empirical analysis of urban location factors, such as university presence, wage rates, amenity aspects, close firm-university links or metropolitan attractiveness	● Relationship between the presence of the university and the concentration of advanced technological production; ● Geographically localised effects of university research	Markusen et al., 1986; Steinnes, 1987; Malecki, 1987; Davelaar and Nijkamp, 1989; Bania et al., 1992; Audretsch and Feldman, 1996; Teixeira and Costa, 2006
The role of universities in the economic growth process	*The influence of universities on the local labour market*	Aggregate models using specific place-based data	Positive influence of the university presence	Beeson and Montgomery, 1990; Bluestone, 1993; Huggins and Cooke, 1997; Gagnol and Héraud, 2001; Rego, 2004; Bilbao-Osorio and Rodríguez-Pose, 2004; Simha, 2005; Cox and Taylor, 2006; Garlick et al., 2006; Swenson and Eathington, 2007; Barrios et al., 2008
	The influence of universities on the rate of creation of new firms			Bania et al., 1990; Schutte, 1999 ; Garlick et al., 2006
	The influence of universities on the development of the local service sector			Hedrick et al., 1990; Garlick et al., 2006
	The human capital effect over the investment patterns of local industry			Florax, 1992; Love and McNicoll, 1988; Huggins and Cooke, 1997; Helpman, 1997; Martin, 1998; Forrant, 2001; Gagnol and Héraud, 2001; Bessette, 2003; Newlands, 2003; Harloe and Perry, 2004; Bilbao-Osorio and Rodríguez-Pose, 2004; Simha, 2005; Steinacker, 2005; Cox and Taylor, 2006; MSTHE, 2006; Tavoletti, 2007; Braunerhjelm, 2008

Table 1:   Summarising the main approaches on the economic impact of universities and R&D institutions (continued)

Studies of impact in a strictly economic sense	*Accountability-type studies*	University-generated data for expenditure and payroll; surveys on staff and student spending patterns; derivation of income multiplier	Estimation of effects generated by the university on the components of the urban economy with which it has contact; namely, local businesses, local households and local government	Caffrey and Isaacs, 1971; Moore and Suffrin, 1974; Moore, 1979; Rosen *et al.*, 1985; Elliot and Meisel, 1987, Link, 1999; Bessette, 2003
	Regional economic impact studies	Stock regional economic analysis tools – mainly input-output and econometric modelling and imports/exports coefficients	University is viewed as a change-inducing factor; disturbance analysis of final demand connected to the university – for example, increased/decreased enrolment, employment or purchasing	Dorsett and Weiler, 1982; Rosen *et al.*, 1985; Elliot and Meisel, 1987; Goldstein, 1989-90; Zelder and Sichel, 1992; Beck *et al.*, 1993; Felsenstein, 1996, Helpman, 1997; Martin, 1998; Schutte, 1999 ; Simonyi, 1999; Silva *el al.*, 2000; Bilbao-Osorio and Rodríguez-Pose, 2004;
	Demand-side analysis by using Keynesian-type income-expenditure multipliers	Econometric models using Keynesian-type income-expenditure multipliers	Income, output and employment effects arising from the expenditure of faculty, staff and students	Brownrigg, 1973; Armstrong, 1993
Studies combining backward expenditure-related linkages and forward knowledge-related linkages		• Micro case study analysis; • Input and output econometric model; • Econometric and statistical descriptive analysis	• The university functioning as an export-base sector in the local economy; • Implications to the demand side and the know-how supplied	Felsenstein, 1996; Huggins and Cooke, 1997; Oosterlinck, 2001; Newlands, 2003; Harloe and Perry, 2004; Buxton *et al.*, 2004; Silva and Santos, 2006; Tavoletti, 2007

Source: Adapted from Felsenstein (1996)

Updating the survey of Felsenstein (1996) on the economic impact literature of universities and R&D institutions (cf. Table 1), we might distinguish four main approaches: (i) the proposition of correlation between concentrations of high-technology activities and various location factors that favour spatial clustering; (ii) the evaluation of the role of universities in the economic growth process; (iii) the studies of impact assessment in a strictly economic sense; and (iv) studies that introduce backward expenditure-related linkages combined with forward knowledge-related linkages of universities and R&D institutions.

To sum up, the traditional economic impact studies have this characteristic of estimating the impact of knowledge-producing organisations by using methods that rely essentially on economic variables, tested in econometric models and statistically analysed. These studies are, in brief, case studies, with a micro- or meso-level analysis length; they are descriptive and focus on the local, regional or national economic implications of the presence of a university or a R&D organisation. In specific cases, they attempt to analyse the knowledge-related impacts basically by suggesting the importance of this kind of organisation when offering knowledge-related services. Hence, these studies do not offer a clear picture of the relevance of R&D organisations as knowledge-diffusing actors or how the dimension of conductors and boosters of knowledge flows also has implications on R&D itself, and on economic progress at the limit.

There is a literature stream that has addressed the evaluation of the scientific production and diffusion resulting from R&D institutions in terms of publication, namely in international refereed journals, making use of bibliometric and scientometric instruments (*cf.*, Conroy and Dusansky, 1995; Scott and Mitias, 1996; Smith *et al.*, 1998; Kalaitzidakis *et al.*, 2003; Meyer, 2004). Despite mapping knowledge networks, and therefore serving part of our main goal in the present research work, generally, bibliometric and scientometric studies do not consider the economic dimension of knowledge production and diffusion, which certainly substantiates itself in the medium-, long-term. That is why we find it relevant to address this literature branch and further explore its contribution to our study, by complementing traditional economic impact studies of R&D organisations.

According to Pritchard and Wittig (1981), bibliometric methods have been used for more than a century, while Sengupta (1992) specifies that Campbell (1896) was the first author to produce the first bibliometric work, making use of statistical methods to study subject diffusion in publications. In the literature review conducted by Hood and Wilson (2001), two definitions are recovered for bibliometrics that complement each other, one presented by Pritchard (1969: 348), who defines it as "the application of mathematical and statistical methods to books and other media of communication", and the other given by Fairthorne (1969: 341), who widens the notion of the "quantitative treatment of the properties of recorded discourse and behaviour appertaining to it". But White and McCain (1989: 119) also have their own definition, presenting bibliometrics as "the quantitative study of literatures as they are reflected in bibliographies [providing] evolutionary models of science, technology, and scholarship." Bibliometrics is therefore commonly associated with quantitative measurements of documentary materials, used to analyse the structures of scientific and research areas, and to appraise research activity and the usage of scientific information (Hood and Wilson, 2001; Persson, 2001). Bibliometrics has been specifically applied in a large number of contexts, which include science studies, research evaluation, knowledge management, environmental scanning, trend analysis, and the optimisation of library and information resources (Persson, 2001). Consequently, scientometric and bibliometric approaches have been increasingly used by several authors to assess the evolution and structure of scientific knowledge and R&D output (*e.g.*, Meyer, 2004; Dietz and Bozeman, 2005; Teixeira, 2006; Adams, 2006; Abramo and D'Angelo, 2007).

On the other hand, the term 'scientometrics' is more recent; according to Hood and Wilson (2001), it was first employed by Nalimov and Mulchenko (1969) in Russian (in which the equivalent term is '*naukometriya*') to describe the study of all aspects of the literature of science and technology, its growth, structure, interrelationships and productivity, and is closely related to bibliometrics. The term became more widespread with the foundation of the homonymous journal, *Scientometrics*, by Tibor Braun, in Hungary, in 1978 (Hood and Wilson, 2001). At present, bibliometrics and scientometrics refer to the study of the dynamics of disciplines as reflected in the production of their literature, terms used consequently to describe analogous and overlapping methodologies (Hood and Wilson, 2001). Hence, according to Leydesdorff (2001), scientometrics is the claim that scientific developments, when conducted through an organised knowledge production and control, are amenable to measurement. As a matter of fact, scientometrics is fairly indistinguishable from bibliometrics, with plenty of bibliometric research about literature output (Hood and Wilson, 2001), having been published in the journal *Scientometrics*, while it also comprehends research work dealing with quantitative aspects of the science of science, communication in science, science policy, practices of researchers, socio-organisational structures, research and development management, the role of science and technology in the national economy, governmental policies towards science and technology, and much more (Hood and Wilson, 2001; Wilson, 2001). Summing up, the definition given by Tague-Sutcliffe (1992: 1) can be recovered here:

Scientometrics is the study of the quantitative aspects of science as a discipline or economic activity. It is part of the sociology of science and has application to science policy-making. It involves quantitative studies of scientific activities, including, among others, publication, and so overlaps bibliometrics to some extent.

According to Archambault and Gagné (2004), the main kinds of indicator used within bibliometrics include publication count (i), citations and their impact factor (ii), and co-citation or co-word analysis (iii). Specifically, publication count (i), as an indicator of the productivity of a scientific field of study in terms of the output delivered in journals, that is to say, as the number of articles published, may clarify the output intensity or the degree of specialisation of a specific field (Archambault and Gagné, 2004), may be used for the evaluation and comparison of the research performance of individual researchers, departments, and research institutions (Garfield *et al.*, 1978; Adam, 2002; Bornmann *et al.*, 2008), as well as to assess at the limit the scientific impact of nations (May, 1997; King, 2004; Bornmann *et al.*, 2008). As far as citations and impact factor are concerned

(ii), these indicators purposely address the assessment of the scientific impact of research, through the number of citations spread in internationally learned journals and, for instance, recorded and compiled in Thomson Reuters (Archambault and Gagné, 2004). Furthermore, co-citation-based indicators (iii) may be used to map research activity by means of bibliographic coupling, generating knowledge webs from the analysis of co-citations and/or co-words, which will create mappings (using time as a variable, and, as an example, depicting the evolution of scientific emerging fields), multifaceted representations of research fields, and related linkages of the fields of study themselves or of the actors performing within them (Archambault and Gagné, 2004). At present, the most commonly used gauge of the research impact of publications is the total number of citations attributed by articles to a scholar, institution or country, regardless of the unit of analysis, in a given period (Westney, 1998; van Leeuwen, 2001; van Raan, 2003; Archambault and Gagné, 2004), allowing citation rates to be an important indicator of scientific success because of their quantitativeness and objectiveness, therefore complementing qualitative methods of research evaluation, as for the case of peer review (Garfield and Welljamsdorof, 1992; Daniel, 2005; Bornmann *et al.*, 2008).

    As defined by Smith (1981: 83), "a citation implies a relationship between a part or the whole of the cited document and a part or the whole of the citing document", and bibliometrics uses citation analysis specifically to study these relationships. Smith (1981: 85) continues, interpreting citations as "signposts left behind after information has been utilised and as such provide data by which one may build pictures of user behaviour without ever confronting the user himself." Citation convention is actually a matter of controversy, as Cozzens (1989) points out, since their application may be due to the need to sustain the persuasive argument of the knowledge claims in the citing document, but may also be interpreted as some kind of reward or acknowledgement instrument. Self-citations, within this framework, may cause even more controversy, if one interprets them as biases of indicators to research evaluation studies (Smith, 1981; Schwarz *et al.*, 1998). Nonetheless, as defended by Glänzel and Schoepflin (1999), the application of citation-based indicators by the scientific community of a country or organisation will give a symptomatic picture of the research performance of the community under consideration.

    Several authors (*cf.*, Weinstock, 1971; Smith, 1981; Garfield and Welljamsdorof, 1992) present reasons for the convention of citations in scientific documents, which can be confirmed in Table 2, according to the relevance or to more positive or negative acknowledgement conduct.

Table 2:   Listing reasons given in the literature for the usage of citations

Attributing citations		by relevance		
		relevant	*less relevant*	*irrelevant*
by acknowledgment	*positive*	● Paying homage to pioneers ● Correcting one's own work	● Providing leads to poorly disseminated, poorly indexed, or non cited work	● Identifying original publications in which an idea or concept was discussed ● Identifying original publications or other work describing an eponymic concept or term
	neutralby	● Identifying methodology, equipment, etc. ● Substantiating claims ● Authenticating data and classes of facts – physical constants, etc.	● Giving credit for related work (homage to peer) ● Providing background reading ● Criticising previous work	● Alerting to forthcoming work
	negative	● Correcting the work of others	● Disclaiming work or ideas of others (negative claim)	● Disputing priority claims of others (negative homage)

Source: Adapted from Weinstock (1971), and Garfield and Welljamsdorof (1992)

    Smith (1981) also underlines assumptions as far as citation analysis is concerned, namely, (i) that citing a document implies using that document, but what is often proven is that only a small percentage of what is read and found useful is in fact cited; (ii) citing a document (from an author, a

journal, *etc.*) evidences merit given to that document, in terms of quality, significance or impact, but, as Table 2 shows, and Thorne (1977) has also highlighted, documents can be cited for reasons irrelevant to their merit; (iii) citations are made of the best works, but accessibility of a document is often a serious barrier, because of its format, place of origin, age or even language; (iv) though there is the assumption of content interrelationship between two bibliographically coupled documents, nothing in fact guarantees a relationship between their contents through citations; (v) and, finally, the assumption that all citations are equal, but the fact is that, as demonstrated in Table 2, there are several reasons sustaining the usage of citations.

Additionally, a similar listing may be identified in the works of Garfield (1977, 1986), and developed also by Smith (1981), when tracing reasons for not citing a scientific document, which may be related to (i) the lack of relevance of the topic, (ii) unawareness of relevant published works, suggesting here some kind of arbitrariness in the selection of the bibliography, as Kochen (1974) points out, (iii) wilful unawareness, that is to say, deliberate plagiarism, (iv) disregard for other scholars' researches, (v) obsolescence or 'natural' obliteration, (vi) or due to the disappearance of authors that use the specific cited information, contributing to the extinction of some topics. Furthermore, the decrease in the citation impact is a reflection of obsolescence, an evolutionary process that substitutes cited work with more recent and more relevant findings (Garfield, 1977, 1986). However, in the case of a breakthrough, all cited knowledge is immediately superseded, and, in this case, the literature faces a revolutionary process (Garfield, 1977, 1986). But a third type of obliteration in literature can also come about, in which relevant knowledge becomes current or common, which is the case of obliteration by incorporation, when literature absorbs the author's thought as eponymy (Garfield, 1977, 1986). Garfield (1977, 1986) still considers five main factors that directly influence citation impact, namely, (i) the subject matter and within the subject, the 'level of abstraction', (ii) the paper's age, (iii) the paper's 'social status' (because of the author(s) and/or the journal), (iv) the document type, and (v) the observation period.

Despite the benefits that bibliometrics and scientometrics bring to our study, through the correlation between bibliometric data and scientific knowledge growth (Kuhn, 1962; Price, 1965; Leydesdorff, 2001), by being the best tool to issue relevant topics like performance or hierarchies (*cf.*, Schubert and Braun, 1996; Bornmann *et al.*, 2008), tracing science mappings and their developments (*cf.*, Burt, 1983; Leydesdorff, 2001), or even knowledge / actor-networks (*cf.*, Leydesdorff, 2001), limitations in their usage must also be highlighted. Bibliometrics and scientometrics presently play a strong role in assessing and comparing the research performance and impact of scholars, research groups, R&D institutions and nations, but drawbacks are identified within this literature scope and alternative solutions are also presented. This is the case of Bornman *et al.* (2008), when evidencing that bibliometric analysis commonly uses an arithmetic mean value in the evaluation of research performance as a measure of central tendency (Kostoff, 2002; van Raan, 2004), but which has to be balanced by the recognition of the most prolific researchers, for instance (Daniel and Fisch, 1990; Bornman *et al.*, 2008). On the other hand, a citations' count of a research group also has its limitations (*cf.*, Schubert and Braun, 1996; Kostoff, 2002, Bornman *et al.*, 2008), which according to Schubert and Braun (1996) may be transposed by setting reference standards to the comparative appraisal of research performance, in terms of field of research, journals and related records. Lawani (1986), for instance, identified a strong relationship between the number of co-authors in a scientific paper and its citation counts, evidencing that the higher the number of co-authors, the higher the number of citations.

As Moed (2005a) argues, citation impact, for instance, is nothing less than a quantitative concept, with limited significance, which must be addressed taking into account the universe of citing publications, that is to say, the database that we operate on should be comparative in nature, in order to relate the outcomes of our case study with those of similar entities. In this perspective, the level of aggregation must be fully identified and comprehended (Moed, 2005a; Moed, 2005b; Bornmann *et al.*, 2008), because it is important whether we are evaluating and/or comparing the research performance of individual researchers, departments, research institutions (*cf.*, Garfield *et al.*, 1978; Adam, 2002) or

even, at another level, the scientific impact of nations (*cf.*, May, 1997; King, 2004). Schwarz *et al.* (1998) also recognise how citations deliver a reasonably valid measure at aggregate levels, and are a pragmatic way of tracing general characteristics of research structure, the visibility of results, and the positioning of a scholar, institution or country in the research community. However, Schwarz *et al.* (1998) highlight how the indicativeness of results from citation analysis should be further assessed by experts, for instance, through the means of peer review. From a quantitative and bibliometric point of view, the common usage of an arithmetic mean value as a measure of central tendency may erase or at least disguise the true importance, for instance, of the most prolific researchers, and this aspect must also be taken into account (Bornmann *et al.*, 2008).

Moreover, the concepts of 'intellectual influence' and 'contribution to scholarly progress', as Moed (2005a) evokes, could only be better assessed by analysing the cognitive contents of the data studied since those concepts are fundamentally of a theoretical and qualitative nature. Analysing citations from a reference list can also be misinterpreted, since their real influence over the scientific output may be vague or implicit (*cf.*, Schubert and Braun, 1996; Kostoff, 2002), merely acknowledgeable of a reverential author considered within a specific research field as producer of an influential work, remarking, therefore, how unrelated the concepts of 'citation impact' and 'intellectual influence' may be (Moed, 2005a; Bornmann *et al.*, 2008). A reference may be interpreted purely as the registration of the intellectual property of a knowledge claim, but does not necessarily reflect acceptance or rejection of such a claim, since it rather acknowledges by whom and in which work the claim was presented (Bornmann *et al.*, 2008). Citation analysis may also lead to the recognition of systematic biases that emerge naturally and commonly between authors and groups of authors, and which we must also take into consideration when interpreting (Bornmann *et al.*, 2008). Succinctly, when performing citation analysis, a constructive, qualitative, evaluative framework should be put into action in order to allow a substantive assessment of the contents of the data under analysis (Uren *et al.*, 2006), avoiding looking at it simply as a quantitative indicator (Garfield, 1972; Lawani, 1986; Garfield and Welljamsdorof, 1992; Daniel, 2005), to further comprehend and identify fully possible biases, distortions, or measurement 'errors' (Smith, 1981; Moed, 2005a; Bornmann *et al.*, 2008).

Studies within bibliometrics and scientometrics research field (*cf.*, Meyer, 2000b; Meyer, 2004; Wagner and Leydesdorff, 2005; Moed, 2005b) aim to appraise the scientific output of individuals, journals and even organisations (*e.g.*, effective publication in internationally refereed journals, high citation scores) by surveying and analysing co-authorships and citation indexes. At the extent of this literature, research has basically been conducted from three perspectives (*cf.*, Table 3), as Wagner and Leydersdorff (2005) have highlighted: on the one hand, scientometric analysis is concerned over the increase in the interconnectedness of scientists (*e.g.*, Okubo *et al.*, 1992; Luukkonen *et al.*, 1993; Zitt, *et al.*, 2000; Glänzel, 2001; Cantner and Graf, 2006); on the other hand, a literature branch is focused on a social sciences analysis of collaboration in general (*e.g.*, Chung and Cox, 1990; Gibbons *et al.*, 1994; Katz and Martin, 1997; Dietz and Bozeman, 2005; Hussler and Ronde, 2007) and international linkages in particular (*e.g.*, Stichweh, 1996; Schott, 1998; Jaffe and Trajtenberg, 1999; Hu and Jaffe, 2003; Verspagen and Werker, 2004); and finally, empirical research presents policy analysis of the implications of linkages for funding and outcomes (*e.g.* Van den Berghe *et al.*, 1998; Wagner *et al.*, 2000; Advisory Council of Canada, 2001; Carmona *et al.*, 2005; Adams, 2006). However, as a result of our literature analysis, a fourth type of approach can also be added to this summary, *i.e.*, the studies that address the implications of scientometric tools' usage (*e.g.*, Aguillo *et al.*, 2006; Aksnes and Taxt, 2006; Abramo and D'Angelo, 2007; Blanchard, 2007).

Studies in the area of scientometrics are undoubtedly becoming more and more frequent, and the interests moving investigation forward are several: the willingness to infer on the probability of national or international publications (*e.g.*, Teixeira, 2006), the studies of the paths of academic careers (*e.g.*, Bozeman *et al.*, 2001), or the impact the citation indicators may produce (*e.g.*, Smith *et al.*, 1998; Meyer, 2004; Verspagen and Werker, 2004; Wagner and Leydesdorff, 2005). Further to this, the pioneering work on the geography of knowledge flows by Jaffe *et al.* (1993) gave rise to a series of

studies that aimed to track the flows of knowledge specifically (Allen, 1977; Cantwell, 2006), like the case of the studies on international knowledge flows by Jaffe and Trajtenberg (1999), or the one by Hu and Jaffe (2003). Another perspective values the strands of knowledge not only because of their own inherent quality, but because their value is partially determined by a web of social relationships (Podolny and Stuart, 1995).

Table 3:   Summarising the main approaches in scientometric and bibliometric literature

Approaches	Scientometric analysis of the increase in the interconnectedness of scientists	Social sciences analysis of		Policy analysis of the implications of linkages for funding and outcomes	Implications of scientometric tools' usage
		collaboration	*international linkages*		
Authors	Okubo *et al.*, 1992; Luukkonen *et al.*, 1993; Zitt, *et al.*, 2000; Glänzel, 2001; Cantner and Graf, 2006	Chung and Cox, 1990; Cox and Chung, 1991; Gibbons *et al.*, 1994; Katz and Martin, 1997; Agrawal and Henderson, 2002; Carayol and Roux, 2003; Calvert and Patel, 2003; Bozeman and Corley, 2004; Meyer, 2004; Adams *et al.*, 2005; Dietz and Bozeman, 2005; Aksnes, 2006; Hussler and Ronde, 2007; Ramlogan *et al.*, 2007	Stichweh, 1996; Schott, 1998; Jaffe and Trajtenberg, 1999; Hu and Jaffe, 2003; Verspagen and Werker, 2004	Podolny and Stuart, 1995; Van den Berghe *et al.*, 1998; Henderson *et al.*, 1998; Wagner *et al.*, 2000; Advisory Council of Canada, 2001; Bozeman *et al.*, 2001; Leydesdorff and Meyer, 2003; Sampat *et al.*, 2003; Coronado *et al.*, 2004; MacGarvie, 2005; Moed, 2005b; Wagner and Leydesdorff, 2005; Carmona *et al.*, 2005; Adams, 2006; Marques *et al.*, 2006; Teixeira, 2006; Hong, 2008; Horta, 2008	Garfield *et al.*, 1978; May, 1997; Vincent and Ross, 2000; Leydesdorff, 2001; Adam, 2002; King, 2004; Moed, 2005; Aguillo *et al.*, 2006; Aksnes, and Taxt, 2006; Abramo and D'Angelo, 2007; Blanchard, 2007; Bornmann *et al.*, 2008

Source: Adapted from Wagner and Leydersdorff (2005)

The role of a research-intensive university in the knowledge transference process is also studied by Agrawal and Henderson (2002), recovering the work of Henderson *et al.* (1998), which suggested a decrease in the quality of patenting when an increase in university-based patenting was produced, but which is confronted with the findings of the study by Sampat *et al.* (2003). When replicating the same methodology but extending the time frame, Sampat *et al.* (2003) discovered that the university patents did not lose their quality, though there was clearly a longer time lag before they attracted a comparable number of citations and before they were valuable for continuing innovation. However, patenting has become progressively more important in recent years, and this tendency is likely to be fostered in years to come (Cantwell, 2006).

In the specific case of citation patterns (*cf.*, Cox and Chung, 1991; Coronado *et al.*, 2004; Meyer, 2004; Wagner and Leydesdorff, 2005; Aksnes, 2006; Abramo and D'Angelo, 2007), it is argued how important it is to measure patent and publication citations in order to better comprehend the linkages between science and technology pushers, and, at the limit, with firms (Meyer, 2000b; Stephan and Audretsch, 2000; Meyer, 2004). Actually, the method of patent citation analysis, a bibliometric instrument, was pioneered by Francis Narin and his research group, when tracking citations of patents from public funded research in scientific papers (*cf.*, Narin *et al.*, 1995; Narin *et al.*, 1997). This method has become useful when trying to clarify the scientific activity that may foster connection between firms and science (Godin, 1993; Godin, 1995; Stephan and Audretsch, 2000; Meyer, 2004). In fact, patent citations are a mixture of citations of scientific references and patents, motivated by a necessity to have science-related knowledge inputs in the new exploratory work or invention, forcing a stronger interaction between science and technology, and clarifying the main scientific contributions (Meyer, 2000b; Meyer, 2004). As Meyer stated, patent citations may be understood as information flows, a science and technology interplay, that is to say, reciprocal knowledge transfer (Meyer, 2000a; Meyer, 2000b; Stephan and Audretsch, 2000; Meyer, 2004).

The Institute for Scientific Information (ISI), which was launched in 1964 and is now part of Thomson Reuters business units, organises the *Arts and Humanities Citation Index* (A&HCI), the *Social Sciences Citation Index* (SSCI), and, specifically, the *Science Citation Index* (SCI), which has

long been the most common tool for measuring citations and which is regarded in this context of citation analysis as one of the best research sources to analyse reference patterns, international co-authorships, and interconnectedness of researchers that basically foster the diffusion of scientific capacity (Wagner and Leydesdorff, 2005; Bornmann *et al.*, 2008). According to Wagner and Leydesdorff (2005), international co-authorship occurs when a scientific output has more than one author, and at least two are from different countries. Price (1963), Stichweh (1996), and again Wagner and Leydesdorff (2005), actually address this phenomenon of increased international scientific interplay as a result of science's inner differentiation on specialised disciplines that naturally seek dynamic interactions to enrich scientific output of any kind (Bush and Hattery, 1956). But these authors also explain this phenomenon as a consequence of geographic proximity and historical determinants, as pointed out also by Zitt *et al.* (2000), when, instead, the dispersion of information and communication technologies is a relevant factor emphasised by Gibbons *et al.* (2004).
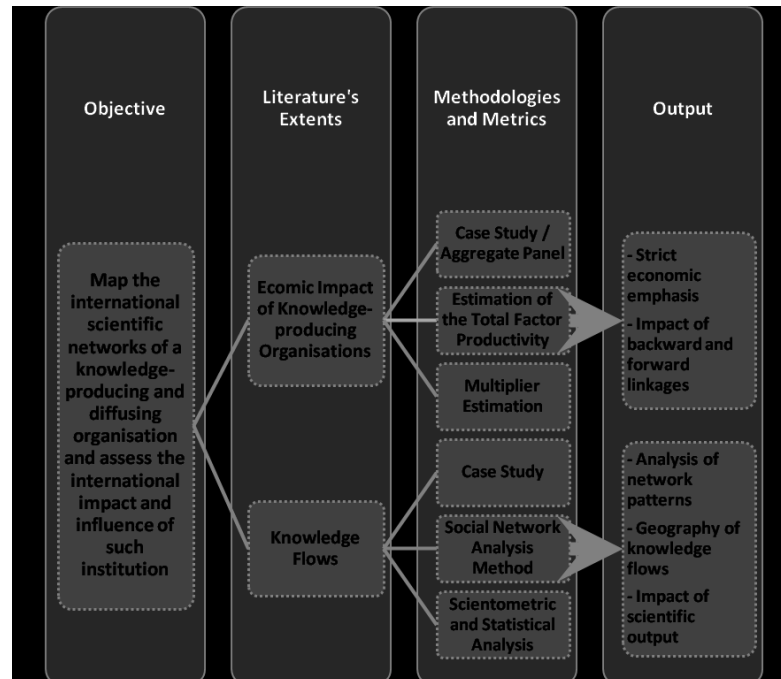
Undoubtedly, proximity and innovative-favourable local milieus, that is to say, innovative clusters, are considered by literature to support knowledge diffusion and knowledge spillovers (*cf.*, Feldman, 1994; Saxenian, 1994; Audretsch, 1998; Antonelli, 1999; Carayole and Roux, 2003; MacGarvie, 2005), thus stimulating the process of the network formation from this interrelationship milieu (Balconi *et al.*, 2002; Carayole and Roux, 2003; Casson and Della Giusta, 2008). Here the seminar work of Carayole and Roux (2003) is of relevance when studying the self-organising network formation and selection, following the previous theoretical suggestions that pointed out the importance of the role of information, knowledge and technology diffusion within issues of innovation dynamics (*e.g.*, David and Foray, 1994; Valente, 1996; Cowan and Jonard, 2001; Young, 2002), even introducing concepts of stability (*e.g.*, Watts, 2001; Jackson and Watts, 2002; Young, 1993; Kandori *et al.*, 1993) and efficiency that will model endogenously emerging structures (*cf.*, Jackson and Wolinski, 1996), but also enriching their contribution when using a preferential meeting process by reasons of neighbourhood. Furthermore, Carayole and Roux (2003) also remind us that a branch of the literature emerged in Physics, focusing on the structures of large networks (*e.g.*, Barabási and Albert, 1999, 2000; Watts and Strogatz 1998; Newman *et al.*, 2001), which highlighted that despite the large number of network agents, and taking into consideration the 'six degrees of separation' of Milgram (1967), the distance between them is usually small.

Concluding, it should be stated that though scientometric and bibliometric studies embrace a wider perspective over the linkages/networks of R&D institutions in the regional, national and international context than standard economic studies, to the best of our knowledge, these studies did not make use of the bibliometric tools to analyse the influence and impact of R&D institutions/organisations. Scientometric and bibliometric studies are devoted basically to the interconnectedness of scientists, network formation, national and international collaboration patterns, and in the implications, development, and impact of scientometric tools' usage. Our goal in this work is therefore to make use of the potential that scientometrics has to offer when measuring the production/diffusion of knowledge of an R&D organisation, and thus understand the determinants of its influence at the international level.

Summarising, the traditional literature path brings us to methodologies that replicate case studies or present aggregate data, estimating, for instance, the Total Factor Productivity (*e.g.*, Martin, 1998), or the total impact by means of a multiplier formula (*e.g.*, Cox and Taylor, 2006). In this case, the scope of analysis is focused on strict economic effects, namely multiplier effects, evaluating the impact of backward-related and forward-related linkages of knowledge-producing organisations (Figure 1). As far as the literature branch of knowledge flows is concerned, the application of case studies' methodologies through the use of social network analysis methods and statistical analysis (*e.g.*, Cantner and Graf, 2006; Hussler and Rondé, 2007) delivers results ranging from the appraisement of network patterns, to the geography of knowledge flows, and the assertion of the scientific output's impact. Within this literature branch, to the best of our knowledge, no scientific contribution has been produced by exploring bibliometric tools in order to infer over the international impact and influence

distinction may be understood as an expression of the importance this institution holds within the Portuguese scientific community, placing it among a very selective group of Portuguese research institutions that develop valuable areas of expertise (INESC Porto, 2008c).

INESC Porto integrates six working units (Figure 2), with a common support services infrastructure, promoting scientific research and technological development in the following areas of activity: Telecommunications and Multimedia, Information Systems, Power Systems, Manufacturing Systems, and Electronics and Optoelectronics, aimed at promoting innovation and internationalisation (INESC Porto, 2008c). Considered to be a medium-size research and technology institution, INESC Porto runs with an annual budget of approximately 8 Million Euros (INESC Porto, 2008c) to support a structure of 318 members (72 of whom are internal staff), according to a report from INESC Porto's Human Resources Department, dated 30th September, 2008.

Figure 2: The organogram of INESC Porto
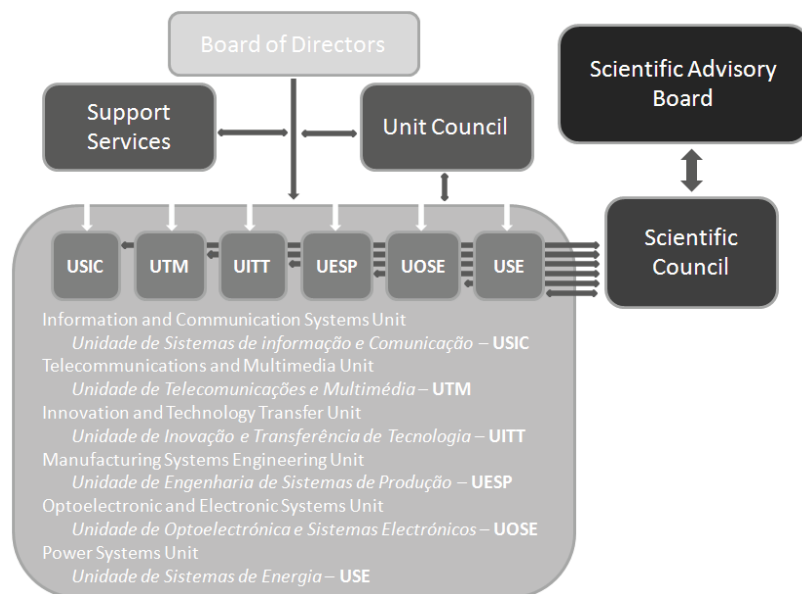
Source: Adapted from INESC Porto (2008b)

The recent analysis of the activities of INESC Porto made by an international Scientific Advisory Board (INESC Porto, 2008c) indicated that its strengths lie in its team of collaborators and in the strong research accomplishments it has made in key technology areas. Hence, we conclude that INESC Porto constitutes a pertinent and valuable unit of analysis for conducting a study on the international influence of R&D, knowledge-based institutions, since it combines fundamental preconditions for conducting the present research work, namely, outstanding scientific output developed during more than a decade, and within an international collaboration framework of co-authorship, integrating different research fields.

In order to conduct this research, we first collected and refined bibliographic data from a dataset named SACA (*Sistema de Arquivo e Controlo de Artigos* – Archive System of Articles Control), organised internally by INESC Porto. This dataset contains all published and unpublished scientific work, that is to say, internationally as well as nationally published papers, book chapters, international conference proceedings, and communications in workshops or at conferences. On 14th April 2008, when the data was gathered, 1488 entries were counted, but out of these, 62 papers were duplicated or triplicated, corresponding to the same paper but presented at different conference venues, and published again in an international journal, for instance, therefore leaving 1426 papers for further analysis (Table 4). Afterwards, the data collected from SACA was thoroughly reviewed and it constituted the basis for another database that was then built to register the affiliations of the authors

that teamed up, in a local, national or international framework, in order to deliver INESC Porto's scientific output. Since each paper is, to our study, a unit of research, all the information concerning it was gathered in the same worksheet line. This new database that we have built specifically,includes information regarding the number of authors of each paper or scientific output, the authors' affiliation and their country of origin, and, finally, the source of publication (*e.g.*, international or national journal, book, conference proceedings, *etc.*). Consequently, this dataset enables us to assess the main geographical trends and co-authorship patterns of INESC Porto's scientific production.[1] We obtained 845 valid papers which we were able to access, either through the SACA search engine or through an online one, such as Google.com, Google Scholar or Thomson Reuters' Web of Knowledge.

When compiling a dataset of citations from INESC Porto's publications in Thomson Reuters' Web of Knowledge, 352 papers with INESC Porto's affiliation were identified, but 125 did not match the records in SACA. Since 38 papers out of those 125 new papers identified were cited, we decided to add only these 38 to our database from INESC Porto's scientific production and work them in terms of co-authorships as well, given that they would also be considered in terms of citations' impact. We arrived, then, at a total number of 883 papers that cover a timeline, which begins in 1979[2] and ends in 2008. Since only after 1996 are a significant number of papers reported as being published or presented at conferences, we have decided to neglect 41 papers from the period 1979-1995, and 16 papers dating from 2008.[3] In the end, 826 documents constitute our final study sample from INESC Porto's scientific output, in terms of affiliation's mapping (*cf.*, Table 4).

In our dataset, we defined as relevant variables for each paper the authors and their affiliations, their countries of origin and the publishing information. All the 1397 papers (which include papers to which we had access and papers that were not accessible for affiliation's handling) are distributed among the working units of INESC Porto, as shown in Figure 3.[4]

A descriptive analysis of our database indicates that, comparatively, UOSE is, undoubtedly, the most prolific unit, with 519 papers, from which communications at conferences account for 309 (59.3%) presentations, and 184 (35.5%) papers were published in international refereed journals. UTM follows with 366 papers, distributed mainly between communications at conferences or workshops (145 papers, 36.6% of the total) and publications in book chapters and conference proceedings (173 papers, 47.3% of the total), while papers presented in international refereed journals account for 46 (representing 12.6% of the corresponding total). The USE is the third most fruitful unit in INESC Porto, with a total of 272 papers – 174 (64%) of which were included in book chapters or conference proceedings, and an amount of 60 papers (22.1%) were published in international journals. The UESP

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[1] During the process of assembling the information related to authors' affiliations, it was not possible to access 571 papers, since they were not available through SACA, or through Thomson Reuters, or through any other online search engine (like Google.com or Google Scholar). It was also not possible to access a printing copy since there is no material and centralised recording area of the papers produced in INESC Porto. Nevertheless, 845 entries were considered valid and thoroughly worked on, since 10 papers were also excluded. Specifically, as far as these 10 papers are concerned, in 5 cases none of their authors had written as belonging to INESC Porto and they were not recognised as having this affiliation. Two papers proved to have different authors from the ones originally identified in SACA, and one of these was from authors with no affiliation in INESC Porto whatsoever. The remaining three papers had no record in the journals that were identified in SACA and were, therefore, not accessible. It should be added that 14 papers within the 845 had authors with no written affiliation in INESC Porto, though that affiliation was confirmed by INESC Porto internally afterwards. Therefore, after this confirmation, we decided to accept these entries into our study. Entries where authors identified in the paper did not correspond to the ones introduced in SACA were also accepted. In the latter case, we corrected the information retrieved from SACA by using the authors as presented in the published paper.

[2] A paper from 1979 is the oldest record presented in SACA, though there is also a record dating from 1983, two years before the creation of INESC Porto's centre.

[3] We recall that we collected this data from SACA on 14th April 2008, and therefore these 16 papers were the ones available at the time.

[4] A note here must be highlighted since we recall that each paper may be counted in one, two or three conferences, and also the same paper can be published in conference proceedings or in an international refereed journal, for instance – therefore, we should emphasise how the production of knowledge may lead to the maximisation of the means within our reach for the diffusion of that same knowledge.

has 190 papers in the SACA database, from which 136 (71.6%) were presented at conferences and 32 (16.8%) were published in international refereed journals. USIC has 42 papers, 22 (52.5%) are part of book chapters or conference proceedings, and, finally, UITT, with 8 papers, had 3 presented at conferences and another 2 published in international journals.

Table 4: Data synopsis of the three databases created (1996-2007)

Source	Databases		
	INESC Porto's Database	**INESC Porto's International Co-authorships Database**	**INESC Porto's Citations Database**
	INESC Porto/SACA Thomson Reuters	**INESC Porto/SACA Thomson Reuters**	**Thomson Reuters**
Total Records (nr. papers)	1.488	246	352
Total Records Revised (nr. papers)	1.397	246	347
Workable Sample (nr. papers)	826	246	246
INESC Porto's Cited Papers (nr. papers)	-	-	142 (120 papers are cited by at least one foreign affiliated author)
Total Citations (nr. papers)	-	-	754
Networking Linkages (nr. connections)	-	1.239	13.035
International Share[1] (%)	29,8%	100%	48,8%[2]
First Accessed	2008.04.14	2008.11.30	2008.10.11
Last Accessed	2008.10.01	2008.11.30	2008.11.03

Note: [1]The denominator is the 'workable sample'; [2] Ratio of the papers cited by at least one foreign affiliated author (120) to workable sample (246).

Globally, Figure 3 shows an increase in the overall scientific output of INESC Porto, which may be more positively perceived when considering the type of publication, namely in internationally refereed journals, which accounted for 59 scientific articles in the period of 1996-1999, reaching 77 papers during the time period of 2000-2003, and more than doubling in the period of 2004-2007, when the papers published in learned journals amounted to 192. This upward tendency for the publication in international refereed journals is actually followed by all INESC Porto's working units, when considering the time periods, though the reading of Figure 4 gives us another perception of the evolution of publication.

Figure 3: Distribution of the scientific output of INESC Porto per four-year periods, and per working unit, in number of papers
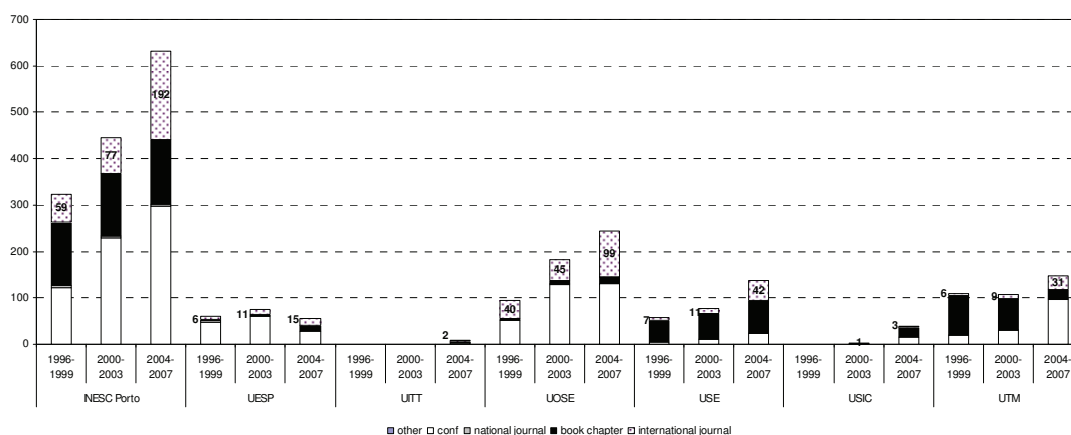
In terms of proportions, Figure 4 shows us how INESC Porto diminished publication overall, as far as international journals are concerned, from the period 1996-1999 to the period 2000-2003, but doubled its share in the 2004-2007 phase, when this kind of publication accounted for 30.4% of all papers produced. It is also interesting to highlight the fact that the share of book chapters has declined over the years, while conference presentations continue to represent around 40% of INESC Porto's overall output. Nevertheless, this pattern does not fit each INESC Porto's working unit, since, for instance, the weight of book chapters is higher in units like USE, USIC and UTM, though with different tendencies, getting weaker in USE and even weaker in UTM, but stronger in USIC. And as far as the percentage of papers published in international journals is concerned, here the increase in their relevance for units like UESP, USE and UTM is evident, while in UOSE the share lowers in the period 2000-2003 and recovers to 40% in the next four-year period, while it sinks in the case of USIC to 7.7%. Conferences, on the other hand, lose importance in the case of UESP and UOSE, and get stronger in USE, USIC, and more obviously in the case of UTM. This analysis of the data permits us to conclude that the relevance of UOSE, USE and UTM in terms of scientific production among INESC Porto's units is enormous in quantitative and qualitative terms and, at the limit, representative for the assessment of INESC Porto's scientific performance. This explains the closer analysis of these working units in terms of publication and diffusion of knowledge, depicting their evolution patterns, and on how they differentiate from one another.

Figure 4: Scientific output's percentage of INESC Porto and its working units by type of publication, per four-year periods
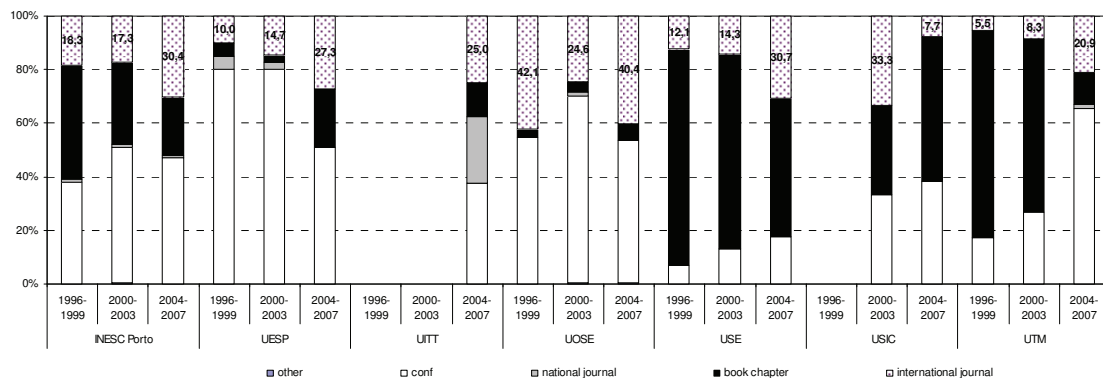
In a first stage, we trace INESC Porto's knowledge production resorting to statistical analysis of the data we collected from SACA and afterwards we conducted the search to confirm the affiliations of every author. With this data, it was possible to create another database linking each INESC Porto's author with a foreign co-author for all the papers that had international co-authorships. This new dataset grouped 1239 connections resulting from 246 papers with international collaborations (*cf.*, Table 4). Consequently, based on the dynamics of international co-authorships, we were able to map and trace international collaboration patterns and thus infer over INESC Porto's geographical scope of influence, *i.e.*, its international interconnectedness and influence. In a second stage, resorting to the information over citations available from Thomson Reuters, namely in the Science Citation Index (SCI), we assessed the geographical pattern of the citations of INESC Porto's scientific production. For this purpose, we also built a citations' dataset with the authors of each paper cited from INESC Porto (a total of 142 papers) in correlation to the papers and the authors citing them (a total of 754 papers), thus also creating a link between every affiliation, which resulted in 13,035 citations' linkages (*cf.*, Table 4). We used Thomson Reuters database, inheritor of the Institute for Scientific Information (ISI), since literature within the bibliometrics range consider it to be the main resource for citation analysis, which has therefore become the most broadly used in assessing research performance (Archambault

and Gagné, 2004; Bornmann *et al.*, 2008).[5] This enables us to evaluate to what extent INESC Porto scientific production has been increasingly cited at the world level. Combining citation matrixes and scientific areas, it was possible to depict the international scientific influence of INESC Porto according to its different areas of expertise, and assess the determinants of INESC Porto's international influence and impact.

4. Explaining the (International) Influence of INESC Porto. a Logit Model of the Propensity for (International) Citations of INESC Porto's Scientific Production

The geographical mapping of co-authorships and citations showed some interesting patterns, both for INESC Porto as a whole and its most prolific units (Sequeira and Teixeira, 2009). It would be illuminating to evaluate which determinants affect the propensity of citations of INESC Porto's scientific work, that is, to understand which factors matter most in explaining the influence (global citations), in particular, the international influence (citations for authors with a foreign affiliation) of this knowledge based and producing institution.

One objective measure of the influence of a publication, and in a broader way, a scientific producing institution (*e.g.*, universities, R&D institutes), over future research is the frequency with which the study, or studies published/produced by such institutions, is/are cited in subsequent publications (Smith *et al.*, 1998; Sampat *et al.*, 2003; Meyer, 2004; Wagner and Leydesdorff, 2005; Filion and Pless, 2008). Previous studies (*e.g.*, Westney, 1998; van Leeuwen, 2001; van Raan, 2003; Archambault and Gagné, 2004) have demonstrated that the frequency with which a publication is cited varies greatly. Our objective in this section is to determine whether variables associated with an article's structural characteristics - namely number of authors, author, type of article (published in international journal *versus* published in book chapters, conference proceedings, *etc.*), year of publication -, the international features – presence of co-authors affiliated in foreign institutions, and country of origin of the foreign institution in which the co-author is affiliated -, and the scientific area of the papers – proxied by the INESC Porto's unit of the corresponding paper (UOSE – optoelectronics; USE – Energy; UTM – Multimedia; Others).

The nature of the data relative to the variable we aim to explain – cited (1) or not cited (0) – dictates the choice of estimation model. Conventional econometric techniques, in a context involving a discrete dependent variable, do not comprise a valid option. In fact, the premises that are necessary in the hypothesis testing of conventional regressions are necessarily violated – it is not reasonable to assume, for instance, that the error distribution will be regular. Furthermore, in a multiple regression analysis, the predicted values cannot be interpreted as probabilities – they are not necessarily restricted

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[5] The high *status quo* of Thomson Scientific among literature results from the selection criteria evoked to restrict its databases essentially to internationally oriented journals, and highly-cited book series and conference proceedings, which address preconditions like having a peer review committee, high publication frequency, the facilitation of an English abstract (*cf.*, Braun *et al.*, 2000), and citation count, since this is perceived, as evidenced above, as an indicator of usefulness, quality and/or impact of a journal (Archambault and Gagné, 2004; Bornmann *et al.*, 2008; Neuhaus and Daniel, 2008). Because of its tendency to have only the highest-impact peer-reviewed journals, this is also referenced as one of the biggest limitations in its usage, since only a fraction of the scientific work is acknowledged here (Nederhof and Zwaan, 1991; Hicks, 1999; Archambault and Gagné, 2004; Neuhaus and Daniel, 2008), and several scientific fields are even neglected, such as, computer science, engineering, and mathematics, where journal literature is less developed (Moed, 2005; Bornmann *et al.*, 2008). Therefore, several authors claim that Thomson Reuters databases, accessed in the Web of Knowledge, should be complemented by other datasets offered online, in the World Wide Web, as is the case of Scopus from Elsevier, Google Scholar, and Cite-Seer, or even by discipline-oriented databases, such as Chemical Abstracts, MathSciNet, and PsycINFO (*cf.*, Neuhaus and Daniel, 2008). Actually, the main advantage of combining different data sources is coverage, since only Scopus accounts for 15,000 peer-reviewed journal titles (Neuhaus and Daniel, 2008). Nevertheless, Thomson Reuters databases cover nearly 10,000 learned journals (Katz and Hicks, 1998; Archambault and Gagné, 2004; Neuhaus and Daniel, 2008). As a matter of fact, as suggested by Garfield (1996), around 2,000 journals account for roughly 85% of published articles and 95% of cited articles are included in the Science Citation Index. This is, therefore, a strong indicator of the validity of this data source for our study.

to the interval between 0 and 1. The approach adopted, therefore, falls within the general probabilistic models.

Prob (event j occurs) = Prob (Y=j) = F[relevant effects: parameters].

In the model of probability of (foreign) citation of the INESC Porto's papers, there is a set of factors, mentioned above, such as the characteristics of the article, its international features, and scientific area, included in vector X, that tend to explain the result (citation), such that:

$$\Pr ob(Y = 1) = F(X, \beta) \quad and \quad \Pr ob(Y = 0) = 1 - F(X, \beta).$$

The set of β parameters reflects the impact of the alterations operating on *X* on the probability of 'citation'. The problem at this stage is to build an appropriate model for the right-hand side of the equation. The base requisite is that the model should produce predictions that are consistent with the underlying theory. For a given vector of regressors, we expect that

$$\lim_{\beta'X \to +\infty} \Pr ob(Y = 1) = 1 \quad and \quad \lim_{\beta'X \to -\infty} \Pr ob(Y = 1) = 0.$$

Partially for reasons of mathematical convenience, the logistic distribution, $\Pr ob(Y = 1) = \frac{1}{1 + e^{-\beta'X}}$, has been used in many applications (Greene, 2000).

When rearranged according to *log odds*, or the probability ratio of an event occurring in contrast with the probability of non-occurrence of that same event, the expression is also called the *logit* model. The probabilistic model is a regression of the type:

$$E(Y \setminus X) = 0[1 - F(\beta'X)] + 1[F(\beta'X)] = F(\beta'X).$$

Whatever the distribution used, it should be noted that the model's parameters, like those of a non-linear model, are not necessarily the marginal effects. Generally speaking, $\frac{\partial E(Y \setminus X)}{\partial X} = \frac{dF(\beta'X)}{d(\beta'X)} \beta = f(\beta'X)\beta$, where *f(.)* is the density function which corresponds to the cumulative distribution function, *F(.)*.

For the logistic distribution, $\frac{d\Lambda(\beta'X)}{d(\beta'X)} = \frac{e^{\beta'X}}{(1 + e^{\beta'X})^2} = \Lambda(\beta'X)[1 - \Lambda(\beta'X)]$. Thus, in the *logit* model,

$$\frac{\partial E[Y \setminus X]}{\partial X} = \Lambda(\beta'X)[1 - \Lambda(\beta'X)]\beta.$$

It is obvious that these values vary in accordance with the values of *X*. In the interpretation of the estimated model, it is useful to calculate that value of the mean of the regressor and, when necessary, of other relevant values.

In logistic regression, the model's parameters are estimated using the maximum likelihood method (ML). That is, given the assumptions regarding the error distribution, the coefficients that make the observed results more 'probable' are selected.

According to the available literature (*e.g.*, Weinstock, 1971; Garfield and Welljamsdorof, 1992; Teixeira, 2006; Filion and Pless, 2008), the articles' characteristics, namely their size (number of authors), scientific area, tend to partially explain the corresponding propensity to be cited. Furthermore, we aim at assessing the importance of having foreign-affiliated co-authors and the country of affiliation of those co-authors in the propensity for being cited, and thus evaluate the the papers' potential for international influence, and therefore that of the research institution (INESC Porto). Thus, we can assume that, if the paper that is cited, namely cited by foreign affiliated authors, has foreign affiliated co-authors, all else constant, the probability of being cited in global terms or cited by foreign authors would be higher.

Thus, we propose that the empirical assessment of the propensity for INESC Porto's papers to be cited should be based on the estimation of the following general logistic regression:

$$P(cited) = \frac{1}{1 + e^{-Z}} ; with\ Z = \beta_0 + \underbrace{\beta_1 \ln nr\_authors + \beta_2 type\_paper + \beta_3 Period}_{structural\ characteristics\ of\ the\ paper} +$$

$$+ \underbrace{\beta_4 Foreign\_coauthor + \beta_5 Country\_foreign\_coauthor}_{International\ features} + \beta_6 Scientific\_area + \varepsilon_i$$

So as to obtain a more direct reading of the logistic coefficients, the equation of the logistic model should be rearranged, such that the logistic model is rewritten in terms of the odds of the event occurring.

Writing the logistic model in terms of the odds, we obtain the *logit* model

$$\log\left(\frac{\Pr ob(cited)}{\Pr ob(notcited)}\right) = \beta_0 + \underbrace{\beta_1 \ln nr\_authors + \beta_2 type\_paper + \beta_3 Period}_{structural\ characteristics\ of\ the\ paper} +$$

$$+ \underbrace{\beta_4 Foreign\_coauthor + \beta_5 Country\_foreign\_coauthor}_{International\ features} + \beta_6 Scientific\_area + \varepsilon_i$$

The logistic coefficient can be interpreted as a variation of the *log odds* associated with a unitary variation in the independent variable. Where e raised to the power β_i is the factor by which the *odds* are altered when the ith independent variable increases by a unit. If β_i is positive, this factor will be greater than 1, which means the *odds* have increased; if β_i is negative, the factor will be less than 1, which means that the *odds* have decreased. When β_i is 0, the factor is equal to 1, which leaves the *odds* unchanged. For example, if the estimate of β_4 shows up positive and significant for the conventional levels of statistical significance (that is, 1%, 5% or 10%), it will mean that, all else constant, the probability of citation ratio in contrast with the probability of non-citation increases when the affiliation of the papers' co-authors is foreign (that is from a country other than Portugal).

The estimates for the βs are presented in the next table, for the three alternative models which cover the different types of citation. The first model concerns global citations, which include citations by Portuguese (and INESC Porto) affiliated authors. The second model includes citations by at least one foreign affiliated author. The third and final model is only concerned with citations by exclusively foreign affiliated authors. It is to be expected, therefore, given the different degrees of international influence of scientific production – global; global excluding citations by exclusively national affiliated authors; and international (citations only by foreign affiliated authors) -, that the relative importance of the various potential determinants of citations will also be different.

Table 5: Assessing the (international) influence of INESC Porto - estimation of the logit model with the dependent variable being the ratio of the log odds of (foreign) citations

			Model 1: citations	**Model 2: at least one foreign**	**Model 3: cited only by foreign**
Article's structural characteristics	Number of authors (ln)		0.214	0.007	-0.086
	Type of article (dummy=1 if published in international journal; 0 otherwise)		2.227***	3.459***	3.342***
	Year of publication (ln)		-83.683	-188.048***	61.676
International features	Foreign co-authors (dummy=1 if at least one of the co-authors is affiliated in an international institution; 0 otherwise)		-0.689*	-0.597	0.300
	Country of origin of the foreign co author (default: other remaining countries)	Germany	-18.242	-17.766	-16.897
		Russia	0.524	-0.454	0.351
		Spain	0.156	0.168	-18.541
		UK	-0.224	0.063	0.778*
		USA	0.739	0.692	-1.308
Scientific area – Unit (default: UOSE)	USE		-1.263***	-0.978***	0.319
	UTM		-1.581***	-1.351***	-1.073*
	UESP, UITT, USIC		-1.045***	-0.713*	0.705
	Constant		663.861	1426.060***	-474.054
	N		883	883	883
	Cited		142	120	47
	Other		741	763	836
Goodness of fit Hosmer-Lemeshow Test (significance) Nagelkerke R² Corrected			12.058 (0.149) 0.383 84.9	8.075 (0.426) 0.450 88.6	7.844 (0.449) 0.293 94.8

***Note*:** Statistically significant at *** 1%; **5%; *10%

The models present a reasonable quality of adjustment. On the one hand, the percentage of correctly attributed estimated observations (between the categories 'cited' and 'not cited') is high, varying between 85% and 95%. Furthermore, the Hosmer and Lemeshow test indicates the *non-rejection* of the null hypothesis that the model predicts reality adequately.

It is interesting to report that the 'size' of the paper, proxied by the number of authors, does not significantly affect the odds of being cited, both in general terms (Model 1 and 2) and by exclusively internationally affiliated authors (Model 3). The newness of the paper, proxied by its year of publication, has a negative impact on the odds of citation when we exclude the citations made by authors affiliated in national (Portuguese) institutions (Model 2). As reported in previous similar studies on citation patterns/propensity (*e.g.*, Weinstock, 1971; Smith, 1981; Garfield and Welljamsdorof, 1992; Moed *et al.*, 1998; Teixeira, 2006; Filion and Pless, 2008), the scientific area is an important determinant of citations. In fact, being a paper from the Optoelectronic and Electronic Systems - UOSE (default unit) – means, on average, all the remaining factors being constant, a much higher degree of global and international influence (proxied by the odds of citations) than a paper published by Power Systems (USE), Telecommunications and Multimedia (UTM), Information and Communication (USIC), Innovation and Technology Transfer (UITT), or Manufacturing Systems Engineering (UESP). In the case of citations made exclusively by authors affiliated in foreign institutions (Model 3), Power Systems and the set of the remaining scientific areas cease to emerge with a degree of influence statistically different to that of the Optoelectronic and Electronic Systems.

Regardless of the degree of a paper's international influence when the paper is published in an international journal with referee, in comparison with papers published in book chapters or conference proceedings, the probability of citation ratio *versus* the probability of non-citation (the odds) is 9 ($e^{2,227}$) (global influence) to 32 ($e^{3,459}$) (international influence excluding citation exclusively from nationally affiliated authors) times higher. This indicates that the 'quality' of the paper published is a truly important predictor of the (international) influence of the scientific production undertaken at INESC Porto.

The literature (*e.g.*, Burt, 1983; Leydesdorff, 2001; Balconi *et al.*, 2002; Carayole and Roux, 2003; Casson and Della Giusta, 2008; Filion and Pless, 2008) usually gives a lot of credit to the importance of foreign networking, namely through the capability to produce scientific publishable papers in co-authorship with authors from institutions of other countries, in particular those highly ranked in scientific terms (the USA, the UK and Germany, to name but a few). Quite unexpectedly, we observe that to have a paper which is co-authored with researchers affiliated in a foreign institution has a negative and significant impact on INESC Porto's global influence, that is on the (log) odds of global citations, and has no impact whatsoever on international influence. Moreover, the country of affiliation of co-authors seems not to have any impact on the influence of INESC Porto. Notwithstanding, in the case of the strictly international influence (Model 3), we find that being a paper with UK affiliated co-authors has a positive and significant impact on the odds of citation by exclusively foreign affiliated authors.

The evidence gathered tends to imply that papers from INESC Porto which have foreign affiliated co-authors are not necessarily more cited, both in global terms and in strictly international terms. Interestingly, the same evidence seems to indicate that the scientific global and international influence of INESC Porto is to a greater extent dependent on the intrinsic quality of the research produced rather than on being part of an international network of co-authorships. Although being capable of establishing (dense) networks with authors from other countries might reveal, *per se*, an indicator of the influence and impact of R&D institutions (Sequeira and Teixeira, 2009), the likelihood of these institutions constituting an effective source of international relevant scientific work for the area in which it performs the corresponding activity does not depend on such networks but rather on the quality of the scientific research it produces.

5. Conclusion

In the present study, we addressed the topic of assessing the impact and international influence of a knowledge-producing and -diffusing institution. We moved away from (aiming at complementing) the standard economic impact literature and methods, as we argue that the impact and influence of knowledge-producing and -diffusing institutions are not restricted to economic related outcomes but, and more importantly, embrace rather intangible and wide ranging knowledge and information impacts, which frequently go beyond local or regional boundaries. We proposed a methodology, largely implemented within scientometric and bibliometric areas, which is based on the analyses of the patterns and evolution of an organisation's co-authorships and citations. Our bibliometric-based method, instead of the local focus that characterises traditional assessment methods, has an international scope.

Given the significant scientific output recorded, specifically in international refereed journals, and a broad collaborative group of co-authors, inclusively with foreign affiliations, we decided to use INESC Porto, a Portuguese research and development organisation, as our case study. Resorting to our bibliometric based methods, we assessed INESC Porto's international influence and impact.

Besides its international focus, standing therefore at a wider level of analysis, our methodology has presented a new insight into the assessment of knowledge flows, which goes beyond useful but narrow economic outcomes, measuring the influence that an R&D organisation (in this case, INESC Porto) has created within the global scientific area in which it operates.

More specifically, we described how INESC Porto's knowledge network has evolved over a time span of twelve years, focusing the analysis, on the one hand, on the organisation's co-authorship framework, and on the other, quantifying citation patterns on a worldwide scale. Notwithstanding the foreign collaborative pattern of INESC Porto's scientific production, and despite the broad recognition of its scientific accomplishments, we showed, based on a multivariate econometric model, that international peer acknowledgement derives not from those straight collaborative and clusterised patterns of international teamwork (co-authorships) but from the intrinsic quality of the scientific output produced.

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