Mestrado em Economia e Gestão Internacional

Faculdade de Economia, Universidade do Porto

Assessing the influence of R&D institutions by mapping international scientific networks: the case of INESC Porto

José António Pacheco Sequeira

December 2008

Supervisor: Aurora A. C. Teixeira

Nota Biográfica

José António Pacheco Sequeira nasceu a 23 de Março de 1979, na freguesia de Mafamude, concelho de Vila Nova de Gaia, Portugal, o primeiro filho de Maria José de Lima Pacheco e de Henrique de Sousa Sequeira.

Em termos académicos, completou a licenciatura em Estudos Europeus em 2002, na Faculdade de Letras da Universidade do Porto, e, em 2004, decidiu especializar a sua formação na área de gestão internacional, prosseguindo os seus estudos com a inscrição na licenciatura em Negócios Internacionais, na Escola de Economia e Gestão da Universidade do Minho. Depois de obtido o diploma em Negócios Internacionais, inscreveu-se no Mestrado de Economia e Gestão Internacional, em 2006, na Faculdade de Economia da Universidade do Porto, onde procurou aprofundar os seus conhecimentos e competências em matéria de economia internacional, crescimento económico, comércio internacional, análise de mercados internacionais, gestão de inovação e gestão do conhecimento.

No âmbito profissional, encontra-se como investigador convidado na Unidade de Inovação e Transferência Tecnológica (UITT) do Instituto de Engenharia de Sistemas e Computadores do Porto (INESC Porto), desde Janeiro de 2008, tendo obtido uma bolsa de investigação por parte da mesma instituição e em conjunto com o Departamento de Engenharia Industrial e Gestão, da Faculdade de Engenharia da Universidade do Porto, entre Setembro e Novembro de 2008. Desde Dezembro de 2008, encontra-se ainda na Unidade de Planeamento do Investimento da empresa Porto Vivo, SRU – Sociedade de Reabilitação Urbana da Baixa Portuense S.A..

Biographical Note

José António Pacheco Sequeira was born at the 23rd March, 1979, in the parish of Mafamude, city of Vila Nova de Gaia, Portugal, the first child of Maria José de Lima Pacheco and Henrique de Sousa Sequeira.

Academically, he got the degree in European Studies in 2002, by the Faculty of Arts of the University of Porto, and, in 2004, he decided to specialise his training in the topic of international management, by following the university degree in International Business, at the Economics and Management School of the University of Minho. Afterwards, he joined the Master in International Economics and Management, in 2006, at the Faculty of Economics of the University of Porto, where he improved his knowledge and qualifications in subjects like international economics, economic growth, international trade, international market analysis, innovation management, and knowledge management.

Within the professional scope, he is an invited researcher in the Innovation and Technology Transfer Unit of the Instituto de Engenharia de Sistemas e Computadores of Porto, since January 2008, having received a research grant from this institution and the Department of Industrial Engineering and Management of the Faculty of Engineering of the University of Porto, between September and November 2008. Since December 2008, he is also at the Investment Planning Unit of the company Porto Vivo, SRU – Sociedade de Reabilitação Urbana da Baixa Portuense S.A..

Agradecimentos

Os meus agradecimentos dirigem-se, primeiro que tudo, à minha família; aos meus pais, aos meus avós, à minha irmã e cunhado, e à minha linda sobrinha, pessoas que eu amo e a quem devo tudo.

Uma outra palavra de profundo agradecimento é dirigida à Professora Doutora Aurora Teixeira, pela confiança depositada no meu trabalho, pela oportunidade e desafio que me lançou, pelo apoio constante, pelo incentivo permanente, por toda a paciência e dedicação e, sobretudo, pela sua preciosa amizade, pois fez possível a elaboração desta dissertação.

A Maria Madalena Domingues, pessoa que me influenciou a percorrer este caminho e a quem devo também o seu apoio e incentivo constantes, os seus preciosos comentários quanto a este trabalho, e a sua extraordinária paciência e disponibilidade, o meu muito obrigado pela sua grande amizade.

Não posso deixar ainda de agradecer especialmente o apoio e a grande amizade de Vitor Cardoso, uma pessoa que apenas conheci no âmbito do Mestrado, enquanto colega, mas que depressa se transformou num dos meus melhores amigos, com quem sei que posso sempre contar, e cujos comentários tomo-os sempre como preciosos; também a ele lhe presto aqui o meu profundo agradecimento.

A José Bruno Alves, Márcia Geração, Ana Margarida Catarino, e a Andreia Pereira, não posso deixar de dirigir também uma palavra de agradecimento pela amizade e pelo valioso apoio.

Por fim, um agradecimento especial à Professora Doutora Ana Teresa Tavares-Lehman, à Professora Doutora Ana Paula Africano e à Professora Ana Paula Delgado, bem como a Joana Taveira Almodovar, Mariana Mendes Baptista Lopes, a Marta Oliveira, e a todas as outras pessoas que aqui não posso enumerar, mas que também me apoiaram neste trabalho, por parte do INESC Porto e da Faculdade de Economia da Universidade do Porto.

Contudo, quero aqui expressar a minha inteira responsabilidade pelo conteúdo do presente trabalho.

Acknowledgments

I would like to thank, first of all, to my family; my parents, my grandparents, my sister and brother-in-law, and my lovely niece, people that I love and to whom I owe everything.

Another word of profound gratitude goes also to Professor Aurora Teixeira, for trusting on my work, for the opportunity and challenge that gave me, for her constant support, permanent encouragement, for all the patience and dedication, and, above all, for her precious friendship, because she made possible the making of this thesis.

To Maria Madalena Domingues, person that influenced me to take this pathway, and to whom I owe also her constant support and encouragement, because of her valuable comments to this work, and the extraordinary patience and availability, here I must state my gratitude for her amazing friendship.

I must also thank specially the support and marvelous friendship of Vitor Cardoso, a person that I only met as a colleague during the Master degree, but who soon became one of my dearest friends, with whom I know I can always rely on, and whose comments I recognise always as priceless; to him also goes my deepest gratitude.

To José Bruno Alves, Márcia Geração, Ana Margarida Catarino, and Andreia Pereira, I must also say thank you for their friendship and precious support.

Finally, I special recognition goes to Professor Ana Teresa Tavares-Lehman, to Professor Ana Paula Africano and to Professor Ana Paula Delgado, as well as to Joana Almodôvar, Mariana Mendes Baptista Lopes, and to Marta Oliveira, and to every other persons that I can not name here, but who have supported in some way this work, as far as INESC Porto and the Faculty of Economics of the University of Porto are concerned.

Nevertheless, I must declare my entire responsibility over the content of the present work.

Resumo

Os estudos que se debruçam sobre a influência e o impacto de organizações geradores de conhecimento (*e.g.*, universidades ou instituições de I&D) têm sido, normalmente, abordados por meio da análise estritamente económica, enfatizando o seu impacto económico no âmbito local, regional ou nacional. No presente estudo, avança-se com uma metodologia alternativa de modo a avaliar a influência e o impacto científico internacional de uma instituição geradora e difusora de conhecimento. São assim estudados dois ramos da literatura que tratam, por um lado, da mensurabilidade do impacto económico de organizações de I&D, e por outro lado, dos fluxos de conhecimento: nomeadamente, estudos económicos tradicionais e análises cienciométricas e bibliométricas. Consequentemente, apresentamos aqui uma metodologia complementar, baseada na cienciometria e bibliometria, por considerar a influência de uma instituição de I&D através da análise da produção científica desenvolvida e por via do reconhecimento da sua relevância pela comunidade científica internacional.

Concretamente, tendo como caso de estudo o INESC Porto, analisamos a dinâmica da sua produção científica durante os últimos doze anos, dando especial relevo à evolução das suas co-autorias científicas internacionais, delineando a arquitectura da sua *network* de conhecimento, bem como da sua estrutura (provavelmente) mutável. Adicionalmente, dando um enfoque especial às suas áreas científicas mais prolíficas, e atendendo ao trabalho científico registado no *Science Citation Index* (SCI), mapeamos as citações e inferimos sobre a sua influência e o seu impacto científico internacional. Desta forma, somos capazes de quantificar e mapear a rede científica internacional de uma organização produtora de conhecimento, através do uso de métodos estatísticos descritivos e geográficos, bem como por meio de modelos *logit*, que permitem a visualização do âmbito e a avaliação da importância da estrutura de influência internacional do INESC Porto.

Os resultados demonstram que o INESC Porto tem vindo a expandir a sua rede científica internacional. De facto, a sua rede de influência ao nível do conhecimento chega aos cinco continentes. Para além disso, as estimações econométricas levam-nos a concluir que a influência geográfica alargada da investigação científica do INESC Porto não é resultado do seu posicionamento internacional em termos de co-autorias, mas antes sim da qualidade intrínseca da sua produção científica.

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

Abstract

Normally studies about the influence and impact of knowledge-producing organisations (*e.g.*, universities or R&D institutions) have been addressed by means of strict economic analysis, stressing their economic impact in 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. Two main branches of the literature, dealing with the measurability of the economic impact of R&D organisations, on the one hand, and their knowledge flows, on the other, are surveyed: namely, standard economic studies, and scientometrics and bibliometrics analyses. Consequently, we introduce to the standard economic impact literature a new methodology, based on scientometrics and bibliometrics tools, which complement traditional assessments by considering the influence of a R&D institution when looking at the scientific production undertaken and to the recognition of its relevance by its international peer community.

Specifically, using INESC Porto as our case study, we analyse the dynamics of its scientific production over the last twelve years, attributing special attention to the international scientific co-authorships' evolution, outlining the architecture of the knowledge network and its (probable) changing pattern. Additionally, focusing on the most prolific scientific areas of INESC Porto, and resorting to published scientific work recorded in the *Science Citation Index* (SCI), we trace citations and infer over INESC Porto's international scientific influence and impact. Therefore, we are able to quantify and map the international scientific network of a knowledge-producing organisation through the use of geographical and descriptive statistical methods, as well as by logit models, which allow, respectively, the visualisation of the scope, and the assessment of the importance of INESC Porto's international influence framework.

The results show that INESC Porto has been enlarging its international scientific network. Actually, its knowledge influence network reaches the five continents. Moreover, the econometric estimations lead us to conclude 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

Index of Contents

Nota Biográfica ..... **i**

Biographical Note ..... **ii**

Agradecimentos ..... **iii**

Acknowledgments ..... **iv**

Resumo ..... **v**

Abstract ..... **vi**

Index of Contents ..... **vii**

Index of Tables ..... **ix**

Index of Figures ..... **x**

Abbreviations **1**

Introduction **2**

Chapter 1. Assessing the impact and influence of R&D organisations – a literature review **5**

1.1. Initial considerations 5

1.2. Assessing the influence and impact of knowledge-producing organisations – the standard approach of economic studies 5

1.3. Assessing the international influence of knowledge-diffusing organisations – the innovativeness of scientometrics approaches 9

1.4. Relationship between production/diffusion of scientific knowledge and the influence of R&D organisations 22

Chapter 2. Assessing the impact and influence of R&D organisations – methodological considerations **26**

2.1. Initial considerations 26

2.2. A brief description of INESC Porto 27

2.3. Data gathering considerations and some descriptive account 30

2.4. The best resource to trace knowledge-diffusion patterns – the Thomson Reuters database of INESC Porto's citations 38

Chapter 3. Assessing the impact and influence of R&D organisations – the case of INESC Porto 41

3.1. Initial considerations 41

3.2. INESC Porto's international scientific co-authorships' framework 42

3.3. The geographical scope and evolution of INESC Porto scientific production. Mapping the influence and impact through co-authorship networks 45

3.4. The geographical scope and evolution of INESC Porto scientific production. Mapping the influence and impact through citation networks 56

3.5. Explaining the (international) influence of INESC Porto. A logit model of the propensity for (international) citations of INESC Porto's scientific production 67

Conclusion 74

References 76

Appendix I 99

Index of Tables

Table 1: Summarising the main approaches on the economic impact of universities and R&D institutions 8

Table 2: Listing reasons given in the literature for the usage of citations 13

Table 3: Summarising the main approaches on scientometrics and bibliometrics literature 19

Table 4: Data synopsis of the three databases created (1996-2007).....33

Table 5: Foreign co-authored papers of INESC Porto.....42

Table 6: The most representative countries contributing to INESC Porto's scientific production.....46

Index of Figures

Figure 1: Synthesis of the commonly-used methodologies within economic impact literature and knowledge flows literature 24

Figure 2: The organigram of INESC Porto 29

Figure 3: Distribution of the scientific output of INESC Porto per four-year periods, and per working unit, in number of papers 36

Figure 4: Scientific output's percentage of INESC Porto and its working units by type of publication, per four-year periods 37

Figure 5: Percentage of papers with at least one foreign author 43

Figure 6: Evolution of scientific output by type of publication in INESC Porto 44

Figure 7: Country's affiliation of foreign co-authors (in % of total), 1996-2007 47

Figure 8: Country's affiliation of foreign co-authors (in % of total), for INESC Porto, per four-year periods 49

Figure 9: Country's affiliation of foreign co-authors (in % of total), for UOSE, per four-year periods 51

Figure 10: Country's affiliation of foreign co-authors (in % of total), for USE, per four-year periods 53

Figure 11: Country's affiliation of foreign co-authors (in % of total), for UTM, per four-year periods 55

Figure 12: Country's affiliation of authors citing INESC Porto's scientific production (in % of total), 1996-2007 58

Figure 13: Country's affiliation of authors citing INESC Porto's scientific production (in % of total), per four-year periods 60

Figure 14: Country's affiliation of authors citing UOSE scientific production (in % of total), per four-year periods 62

Figure 15: Country's affiliation of authors citing USE scientific production (in % of total), per four-year periods 64

Figure 16: Country's affiliation of authors citing UTM scientific production (in % of total), per four-year periods 66

Abbreviations

I&D – Investigação e Desenvolvimento

INESC Porto – Instituto de Engenharia de Sistemas e Computadores do Porto

R&D – Research and Development

UESP – Unidade de Engenharia de Sistemas de Produção

UITT – Unidade de Inovação e Transferência de Tecnologia

UK – United Kingdom

UOSE – Unidade de Optoelectrónica e Sistemas Electrónicos

USA – United States of America

USE – Unidade de Sistemas de Energia

USIC – Unidade de Sistemas de informação e Comunicação

UTM – Unidade de Telecomunicações e Multimédia

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 at the end have 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 has therefore profound consequences over several economic variables. The truth is that international economic activity is increasingly technology-driven and knowledge-based, and this has been forcing 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 the regional, national and international economic growth (Kuznets, 1966; Martin, 1998). These different-leveled 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 the 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 institutions' influence on the evolution and composition of the Gross Domestic Product (GDP) and were usually associated to 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 the 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, much poorly developed. Notwithstanding, several attempts were conducted 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 failed to capture the whole nature of knowledge flows that goes beyond expenditures linkages.

Scientometrics and bibliometrics 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 analyzing 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 scientometrics and bibliometrics studies embrace a much wider perspective of the linkages/networks of R&D institutions at the regional, national and international context than the 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 to fill this gap. As such, we use scientometrics and bibliometrics approaches to assess the influence and impact of an R&D organisation, complementing therefore traditional economic approaches, and providing a more embracing perspective of knowledge flows. To accomplish such endeavour we resort to geographical descriptive statistics and multivariate logit models, addressing the main goal of our study which is to map the scientific network of an R&D organisation and therefore to evaluate its international influence and impact. Essentially, the present work intends to give answer to the following research questions, namely:

1. Have the scientific production and international co-authorships' pattern of INESC Porto intensified over the last twelve years, within the period of 1996 to 2007?
2. Has the network of scientific production of INESC Porto been enlarging over time its geographical scope? Or putting it in other terms, has INESC Porto extended its international influence?
3. Does the international scientific influence of INESC Porto differ according to its most prolific areas of expertise (*i.e.*, Power Systems Unit, Telecommunications and Multimedia Unit, Optoelectronics and Electronics Systems Unit)? Have their network structure and boundaries evolved differently?

We structure the present dissertation as follows. In the next chapter, 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 Chapter 2. In Chapter 3, a comprehensive account of INESC Porto's scientific production by area of expertise is detailed and the net of international linkages is presented. Moreover, it will be analysed the most prolific units of INESC Porto in terms of scientific output, by employing descriptive geographical methods and logit models in order to assess the scope and importance of INESC Porto's international influence. Finally, we will address the main conclusions and highlight some limitations of the present study, as well as the contributions our methodology brings to the literature.

Chapter 1. Assessing the impact and influence of R&D organisations – a literature review

1.1. Initial considerations

The purpose of the present chapter is to review the two literature branches that fundament the goal pursued by our present work – to map the international scientific network of an R&D institution and therefore to evaluate its international influence. Thus, in a first section (Section 1.2.) we devote some attention to the traditional approach of economic studies. These studies evaluate the impact of knowledge-producing organisations, such as R&D institutions or universities. Further (Section 1.3.), we link this field of study with scientometrics and bibliometrics literature, which use measurability and relatedness tools to trace knowledge networks. These two sections are complemented by a third one (Section 1.4.), which synthesizes those two literature branches, reasoning how the analysis of the production and diffusion of scientific output may contribute to evaluate the international influence and impact of a R&D institution.

1.2. Assessing the influence and impact of knowledge-producing organisations – the standard approach of economic studies

It is generally recognised (albeit less empirically proved) that R&D or knowledge producing organisations have 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 jobs formation, new firms formation, 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).

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 expenditures-related linkages combined with forward knowledge-related linkages of universities and R&D institutions.

The first approach, suggested in the work of Felsenstein (1996), includes studies that assess the relationship between the presence of the university or R&D institution and the agglomeration of advanced technological production engines, depicting a 'seeding' effect of these organisations in the local economy, when, for instance, spillovers or spin-offs are produced (*e.g.*, Markusen *et al.*, 1986; Steinnes, 1987; Malecki, 1987; Davelaar and Nijkamp, 1989; Bania *et al.*, 1992). In these studies, the university is one of the most relevant location factors, such as wage rates, amenity aspects, close firms-universities links or metropolitan attractiveness, which contribute to suggest geographically localised effects of university research (Felsenstein, 1996).

As presented by Felsenstein (1996), the second approach – the role of universities in the economic growth process – deals specifically with issues of university-induced growth, *i.e.*, in local labour markets (*e.g.*, Beeson and Montgomery, 1990;

Bluestone, 1993; Bilbao-Osorio and Rodríguez-Pose, 2004; Swenson and Eathington, 2007; Barrios *et al.*, 2008), in new firm formation rates (*e.g.*, Bania *et al.*, 1990), in the development of the local service sector (*e.g.*, Hedrick *et al.*, 1990), or by influencing the human capital effect over the investment patterns of local industry (*e.g.*, Florax, 1992; Love and McNicoll, 1988; Huggins and Cooke, 1997; Newlands, 2003; Steinacker, 2005; Tavoletti, 2007; Braunerhjelm, 2008). In these cases, aggregate models are used from place-based data (cities, metropolitan areas, countries, regions), which find the presence of the university to have a positive effect (Felsenstein, 1996).

The third approach – studies of impact in a strictly economic sense – includes the case of studies that attempt to estimate local economic development impacts, ranging from specific, individual, organisational-centered reports or more academic-type contributions (Felsenstein, 1996). Within this approach, Felsenstein (1996) distinguish three variants: (i) accountability-type studies, which include thoroughly analysis of various kinds of direct impacts (in employment, income and sales) of the university in the economy (*e.g.*, Caffrey and Isaacs, 1971; Moore and Suffrin, 1974; Elliot and Meisel, 1987, Link, 1999; Bessette, 2003); (ii) the regional economic impact studies, which use input-output analysis instruments, econometric modelling and coefficients, focusing on regional change induced by the university presence; (iii) and, finally, demand-side analysis to university impact by using Keynesian-type income-expenditure multipliers, where the scale of this kind of approach is micro, depicting mainly the relationships of the university with the local economy.

Finally, the forth approach draws on the results of Felsenstein (1996), who conceptualises the university as an organisation that, on the one side, receives inputs from households, government and firms, paying its staff, equipments, services, and other kinds of costs (backward linkages of the university with the local economy), and, on the other side, produces outputs like human capital formation or knowledge production (forward linkages, knowledge-related impacts). Others, more recent authors (*e.g.*, Huggins and Cooke, 1997; Oosterlinck, 2001; Newlands, 2003;

Harloe and Perry, 2004; Buxton *et al.*, 2004; Tavoletti, 2007), adopt this approach in analyzing knowledge production activities, like consultancy, R&D, analytical and trouble-shooting services, or even non-market values' outputs, and the intangible assets, which result from the presence and influence of the university at the local and regional levels.

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 to urban location factors, such as university presence, wage rates, amenity aspects, close firms-universities 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 formation of new firm			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
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; disturbances analysis to 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,

Approaches		Mechanisms / Methods	Results	Authors
				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 expenditures-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)

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, descriptive, focusing on 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 organisations 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 and how this dimension of conductors and boosters of knowledge flows has also implications on R&D itself, and on economic progress at the limit. Section 1.3. specifically addresses this gap in the literature of the influence and impact of R&D organisations since it introduces a method commonly used to study knowledge output, namely by means of scientometrics statistical tools.

1.3. Assessing the international influence of knowledge-diffusing organisations – the innovativeness of scientometrics approaches

There exists a literature stream that has addressed the evaluation of the scientific production and diffusion resulted from R&D institutions in terms of publication, namely in international refereed journals, making use of bibliometrics and scientometrics instruments (*cf.*, Conroy and Dusansky, 1995; Scott and Mitias, 1996; Smith *et al.*, 1998; Kalaitzidakis *et al.*, 2003; Meyer, 2004). Though mapping

knowledge networks, and serving therefore to a part of our main goal in the present research work, generally, bibliometrics and scientometrics studies do not consider the economic dimension of knowledge production and diffusion, which certainly substantiates itself in a 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 revision 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 also White and McCain (1989: 119) 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 optimization of library and information resources (Persson, 2001). Consequently, scientometrics and bibliometrics 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, being closely related to bibliometrics. The term was specially spread with the foundation of the homonymous journal, *Scientometrics*, by Tibor Braun, in Hungary, in 1978 (Hood and Wilson, 2001). Actually, 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. In a matter of fact, scientometrics is much indistinguishable from bibliometrics, having been published in the journal *Scientometrics* plenty of bibliometric research about literature output (Hood and Wilson, 2001), 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, it may be recovered here the definition given by Tague-Sutcliffe (1992: 1):

> 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 specialization 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 address purposely 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 the means of bibliographic coupling, generating knowledge webs from the analysis of co-citations and/or co-words, that will create mappings (using time as a variable, and as for 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 those (Archambault and Gagné, 2004). Actually, 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, no matter 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, complementing therefore 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 utilized and as such provide data by which one may build pictures of user behaviour without ever confronting the user himself." Citations' convention is actually a matter of controversy, like Cozzens (1989) points out, since their application may be due to the necessity to sustain the persuasive arguing of the knowledge claims in the citing document, but may be also 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, like Glänzel and Schoepflin (1999) defend, 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 a 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 uncited work	• Identifying original publications in which an idea or concept was discussed • Identifying original publications or other work describing an eponymic concept or term
	neutral	• 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	• Alerting to forthcoming work
	negative	• Correcting the work of others	• Criticising previous work • 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 however, like Table 2 shows, and also Thorne (1977) has highlighted, documents can be cited for reasons irrelevant to their merit; (iii) citations are made to the best works, but accessibility of a document often is 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, in fact nothing guaranties a relationship between their contents through citations; (v) and, finally, the assumption that all citations are equal, but the fact is that, like it is 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, like Kochen (1974) points out, (iii) willful unawareness, that is to say, deliberated 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 of the citation impact is a reflection of obsolescence, an evolutionary process that substitutes cited work by more recent and more relevant findings (Garfield, 1977, 1986). However, in the case of a breakthrough, all cited knowledge is made at once superseded, and, in this case, the literature faces a revolutionary process (Garfield, 1977, 1986). But it can even come about a third type of obliteration in literature, when 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 influences 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 bibliometrics and scientometrics bring to our study, through the correlation between bibliometric data and scientific knowledge growth (Kuhn, 1962; Price, 1965; Leydesdorff, 2001), being the best tool to issue relevant topics like performance or hierarchies (*cf.*, Schubert and Braun, 1996; Bornmann *et al.*, 2008), tracing sciences mappings and their developments (*cf.*, Burt, 1983; Leydesdorff, 2001), or even knowledge / actor-networks (*cf.*, Leydesdorff, 2001),

limitations in its usage must also be highlighted. Bibliometrics and scientometrics have, actually, 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 use 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, citations count of a research group has also 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.

Like 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 have a comparative nature, in order to relate the outcomes of our case study with the ones of similar entities. In this perspective, the level of aggregation must be fully indentified 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 scope, the scientific impact of nations (*cf.*, May, 1997; King, 2004). Also Schwarz *et al.* (1998) 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. Yet, 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. On 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 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 may be the concepts of 'citation impact' and 'intellectual influence' (Moed, 2005a; Bornmann *et al.*, 2008). A reference may be purely interpreted 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 take also 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 to look 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).

Actually, numerous authors identify limitations to bibliometrics, which can be compiled in a list, as follows:

- Pinski and Narin (1976) point out, for instance, the fact that there is no normalization for reference practices in the different scientific disciplines;
- a bias favouring journals with large papers is also identified by Pinski and Narin (1976), since, for example, review journals tend to have higher impact factors;
- moreover, one can not clearly differentiate the nature and merits of the citing journals (Tomer, 1986);
- also citation frequency is a matter of age bias, as stressed by several authors (Asai, 1981; Glänzel and Schoepflin, 1995; Moed *et al.*, 1998);
- on another hand, there is no suggestion in literature of the deviations from the citation impact statistic instrument (*cf.*, Schubert and Glänzel, 1986);
- some authors (*cf.*, Glänzel and Schoepflin, 1995; Moed *et al.*, 1998) reveal that it is not that frequently that the average time for a scientific paper to reach peak in citations is of two years;
- for Moed *et al.* (1998), the description of citation patterns should no anchor only on one single measure;
- like Moed and van Leeuwen (1995, 1996) reveal, impact factors may be inaccurate in some cases, due to the fact that the concept of citable document is not operationalised adequately;
- and, finally, errors in the calculation of impact factors may be due to incorrect identification in references (Braun and Glänzel, 1995; van Leeuwen *et al.*, 1997).

Also Schwarz *et al.* (1998) emphasise problems of data coverage and consistency when interpreting statistical indicators from a general-purpose database like SCI (*Science Citation Index*), for instance, from Thomson Reuters, which can be listed as follows:

- firstly, Schwarz *et al.* (1998) refer the fact that the observation period may be too short, failing in depicting all the citations accumulated over the years;
- secondly, one have to consider the distorting Matthew effect in citations' behaviour (*cf.*, Merton, 1968, 1988, 1995), which infers that cited authors will continue being cited;

- moreover, low or none citation rates do not diminish a paper, since there are reasons, like it was pointed out previously, for not citing or delaying doing it;
- it is also highlighted how papers unfolding useful and new measurement techniques have higher citation scores compared to those presenting research results by using established and well-known methods;
- Schwarz *et al.* (1998) also recover the fact that self-citation (and/or friendship citation) practices vary between scientific fields of study;
- when scientific work gets to be considered as 'classic', then it may lose explicit citations;
- and finally, utterly disregarding works not published in indexed journals has its consequence over analysis.

Like stressed above, normally, 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 analyzing co-authorships and citation indexes. At this literature extent, research has been basically 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 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 present 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 synthesis, *i.e.*, the studies that address the implications of scientometrics' tools usage (*e.g.*, Aguillo *et al.*, 2006; Aksnes and Taxt, 2006; Abramo and D'Angelo, 2007; Blanchard, 2007).

The 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 the academic careers (*e.g.*, Bozeman *et al.*, 2001), or the impact the citations indicators may produce (*e.g.*, Smith *et al.*, 1998; Meyer, 2004; Verspagen and Werker, 2004; Wagner and Leydesdorff, 2005). Further, 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 specifically the flows of knowledge (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 on scientometrics and bibliometrics 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 scientometrics 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) that 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 loose their quality, though there has clearly been 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 citations 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). Like 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 now is 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 (issue further developed in Section 2.4.) and which is regarded in this context of citation analysis as one of the best research sources to analyse references' 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 Zit *et al.* (2000), when, instead, the dispersion of information and communications' 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), introducing even 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 neighborhood. Furthermore, Carayole and Roux (2003) also remember that a branch of the literature emerged in Physics, focusing on large networks' structures (*e.g.*, Barabási and Albert, 1999, 2000; Watts and Strogatz 1998; Newman *et al.*, 2001), which highlighted that though the large number of network agents, and taking into consideration the 'six degree of separation' of Milgram (1967), the distance between them is usually small.

Concluding, it should be stated that though scientometrics and bibliometrics studies embrace a wider perspective over the linkages/networks of R&D institutions at the regional, national and international context than the 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. Scientometrics and bibliometrics studies are devoted basically to the interconnectedness of scientists, networks formation, national and international collaboration patterns, and in the implications, development, and impact of scientometrics tools usage. Our goal in this work, therefore, is 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 obtaining the map of its influence at the international level.

1.4. Relationship between production/diffusion of scientific knowledge and the influence of R&D organisations

R&D organisations have been gaining a decisive entrepreneurial orientation in today's economy, leading or having a strong influence over certain technological areas, where innovation and knowledge transference's processes are critical (Stephan and Audretsch, 2000; Cowan and Jonard, 2001; Meyer, 2004; Cantwell, 2006; Casson and Della Giusta, 2008). The publication productivity, the patent productivity, the interconnectedness of scientists, the collaborative behaviours and the wider diversity of network ties and social capital have been analysed in a variety of ways, which solidifies the perception of the R&D organisations as being specific

enablers and boosters in the production and diffusion of scientific knowledge (*cf.*, Stephan and Audretsch, 2000; Cowan and Jonard, 2001; Dietz and Bozeman, 2005; Cantwell, 2006; Casson and Della Giusta, 2008). Universities, R&D organisations and firms, through partnerships and collaborations, create technological opportunities, foster additionally learning networks and facilitate progress (Stephan and Audretsch, 2000; Beaver, 2001; Cantwell, 2006; Adams, 2006; Casson and Della Giusta, 2008).

At this point, it becomes relevant to highlight, on the one hand, the boundaries that the methodology normally associated to the economic impact of knowledge-producing organisations' literature branch has, and, on the other hand, evidencing the contribution scientometrics and a social network analysis statistical method brings within the knowledge flows' literature branch. A thoroughly analysis of four scientific papers was performed (*cf.*, Appendix I) in order to better fundament the choice made in terms of the application of the methodology for the present study. Figure 1 presents a synthesis-scheme to the analysis of those four scientific papers, namely the works of Martin (1998), and from Cox and Taylor (2006), representing the economic impact of knowledge-producing organisations' literature, and the works of Cantner and Graf (2006), and by Hussler and Rondé (2007), which are within the knowledge flows' literature scope.

Succinctly, the first 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. As far as the knowledge flows' literature branch 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) deliver results ranging from the appraisement of network patterns, to the geography of knowledge flows, and the assertion of the scientific output's impact. Among this literature branch, to the best of our knowledge, no scientific

contribution was produced by exploring social network analysis statistical methods in order to infer over the international impact and influence of a knowledge-producing organisation, namely a university or a R&D institution. It is the aim of the present work to fill this gap and introduce this methodology to address the evaluation of international impact of knowledge-producing and -diffusing organisations.

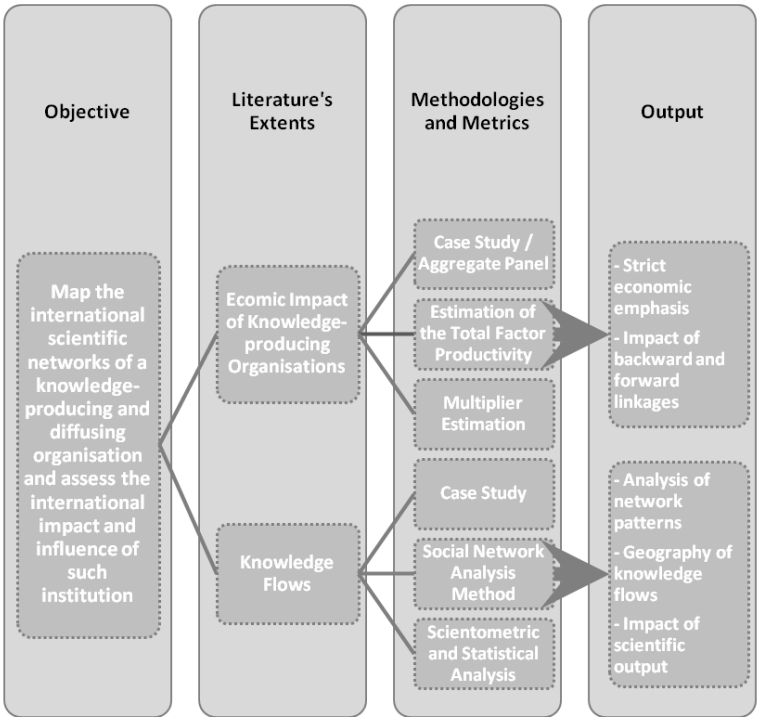


Figure 1: Synthesis of the commonly-used methodologies within economic impact literature and knowledge flows literature

Source: Adapted from Martin (1998), Cox and Taylor (2006), Cantner and Graf (2006), and Hussler and Rondé (2007)

In a matter of fact, the works from Cantner and Graf (2006) and from Hussler and Rondé (2007) present case studies about R&D hubs, namely Jena and the University Louis Pasteur, respectively, where it was intended to picture their learning networks and figure out their core competencies when tracing knowledge flows through the use of social network analysis' methods. However, despite this exercise, there was no direct inference over the influence this type of organisation has within the network it operates, nor even a special emphasis was traced to the international dimension of the relationships that form the network itself.

The present work aims exactly to bridge the economic impact literature's branch with the one devoted to scientometric analysis of knowledge flows using for its empirical implementation the case of INESC Porto and thus addressing the literature gap identified above. Hence, our goal in this work is to make use of the potential that scientometrics has to offer regarding the measurement of the production/diffusion of knowledge of an R&D organisation, and thus obtaining the map of INESC Porto's knowledge-producing and diffusing behaviour, its impact and influence over the international knowledge network it operates, methodology that is further explored in the next section.

Chapter 2. Assessing the impact and influence of R&D organisations – methodological considerations

2.1. Initial considerations

In the present study, we aim to analyse the international scientific impact and influence of a knowledge-producing organisation. Specifically, we seek to answer the following questions:

1. Have the scientific production and international co-authorships' pattern of INESC Porto intensified over the last twelve years, within the period of 1996 to 2007?
2. Has the network of scientific production of INESC Porto been enlarging over time its geographical scope? Or putting it in other terms, has INESC Porto extended its international influence?
3. Does the international scientific influence of INESC Porto differ according to its most prolific areas of expertise (*i.e.*, Power Systems Unit, Telecommunications and Multimedia Unit, Optoelectronics and Electronics Systems Unit)? Have their network structure and boundaries evolved differently?

Answering these questions call for an encompassing approach, requiring that we move beyond strict materialistic perspectives of organisations' impact and influence. INESC Porto will serve, for such a mission, as our study object, since it is, on a scientific point of view, an adequate representative of the R&D organisations, allowing therefore the development of a case study approach. INESC Porto's R&D pursuit combined with its fecund performance in several research areas, as we will expose further on (*cf.*, Section 2.2.), make this institution a solid means to respond to our research questions and an adequate receiver of the methodologies we wish to implement.

Straightforwardly, in order to carry out such endeavour, as stressed earlier, it is advisable to resort to a combination of statistical descriptive methods, scientometrics and exploratory social network analyses. Consequently, the research

work was conducted in two separated, though interrelated, stages, which roughly address our three main research questions. To begin with, we constructed a bibliographic database containing all the published and unpublished works (including both papers and communications in workshops and conferences) by INESC Porto's researchers, so that we could study their international co-authorships' patterns and scientific work publication, namely in international learned journals (*cf.*, Section 2.3.). Afterwards (Section 2.4.), we collected the citation data from the Science Citation Index (SCI) related to all the papers from INESC Porto's authors recorded in Thomson Reuters. This allows us, in Chapter 3, to geographically map the evolution of citations by foreign authors of works developed by INESC Porto's researchers during over a decade (*cf.*, Section 3.3. and Section 3.4.), and assess, consequently, at what extent the boundaries and the intensity of these international networks of scientific influence have changed both at INESC Porto as a whole and at the level of its most prolific units. Furthermore, through means of a multivariate logit model (*cf.*, Section 3.5), we are able to evaluate whether the influence of INESC Porto, proxied by the global and foreign citations of the internationally published works of its researchers, is dependent on foreign co-authorships.

2.2. A brief description of INESC Porto

The Institute for Systems and Computer Engineering of Porto (*Instituto de Engenharia de Sistemas e Computadores do Porto* – INESC Porto) was established on the 18th December, 1998, after a restructuring of INESC, which had several centres spread through Portugal, and one specifically in Porto, since May 1985 (INESC Porto, 2008b). This reform was a result of the local specialization of each centre, and their growing autonomy, which has lead to the rising of new institutions (as for instance, INESC Porto), centrally connected to INESC, and now with the responsibility to coordinate national strategic progress of each of those new born institutions (INESC Porto, 2008b).

INESC Porto was then constituted as a private non-profit association by two founders, the University of Porto and the Faculty of Engineering of the University of Porto, to whom joined afterwards, in 2006, the Faculty of Sciences of the University of Porto and the Polytechnic Institute of Porto (INESC Porto, 2008b). Regarded as a Public Interest Institution, INESC Porto was appointed, in 2002, as Associated Laboratory by the Ministry of Science and Technology (INESC Porto, 2008b, 2008c). This later distinction may be understood as an expression of the importance this institution has 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).

Presently (December, 2008), INESC Porto integrates six working units (*cf.*, Figure 2), with a common support services infrastructure, which pursue, in an overall scope, innovation and internationalisation by means of strategic partnerships, reassuring institutional and economic sustainability (INESC Porto, 2008b, 2008c), and which are identified as follows:[1]

- Information and Communication Systems Unit (*Unidade de Sistemas de informação e Comunicação* – USIC)
- Telecommunications and Multimedia Unit (*Unidade de Telecomunicações e Multimédia* – UTM)
- Innovation and Technology Transfer Unit (*Unidade de Inovação e Transferência de Tecnologia* – UITT)
- Manufacturing Systems Engineering Unit (*Unidade de Engenharia de Sistemas de Produção* – UESP)
- Optoelectronic and Electronic Systems Unit (*Unidade de Optoelectrónica e Sistemas Electrónicos* – UOSE)
- Power Systems Unit (*Unidade de Sistemas de Energia* – USE)

[1] From here onwards, we will identify each working unit of INESC Porto by its acronyms in Portuguese, since these are the names by which they are most commonly identified and recognised.

INESC Porto promotes, therefore, scientific research and technological development in the following activity areas: Telecommunications and Multimedia, Information Systems, Power Systems, Manufacturing Systems, and Electronics and Optoelectronics, aiming at promoting innovation and internationalisation (INESC Porto, 2008c). The heterogeneity of scientific expertise is also expression of an independent development of each unit, grown in a bottom-up fashion, and giving rise, therefore, to very different profiles, goals and perspectives, which, in turn, enable each one to take advantage of the local and short-term niches in the Portuguese market, but possibly endanger a coherent, long-term plan to the institution as a all (INESC Porto, 2008c).

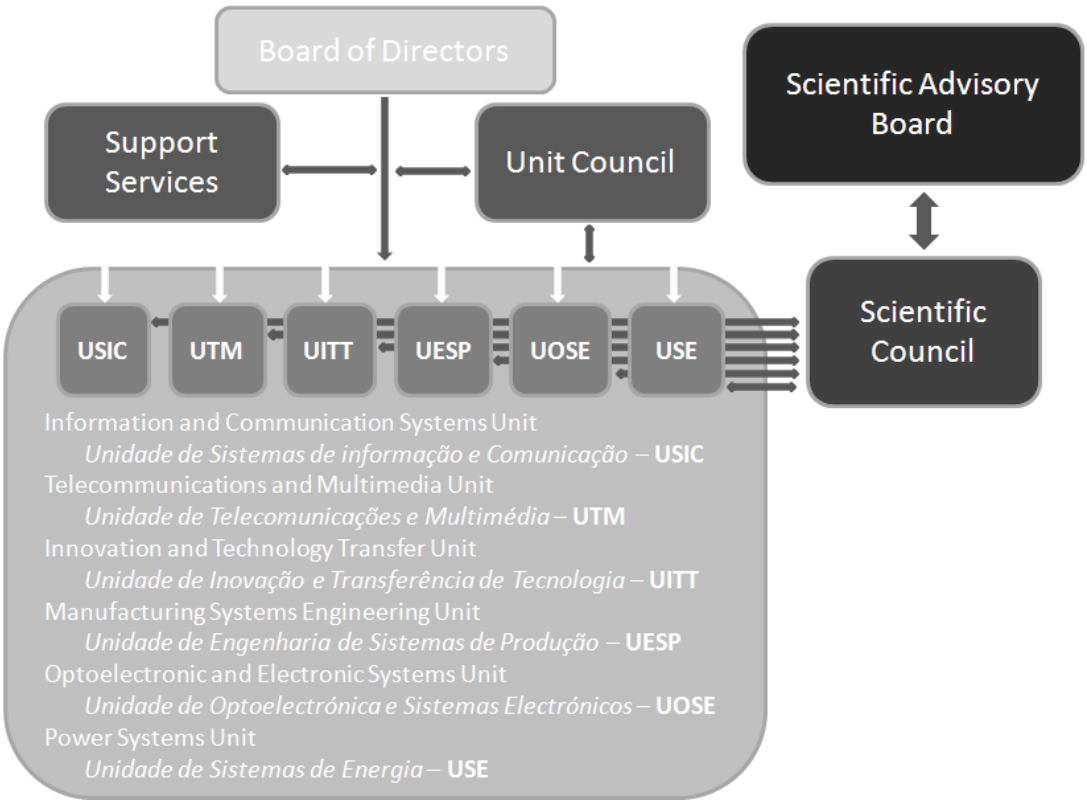


Figure 2: The organigram of INESC Porto

Source: Adapted from INESC Porto (2008b)

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 which are internal staff), according to

a report from INESC Porto's Human Resources Department, dated from the 30th September, 2008. INESC Porto's scientific capability has been recognised internationally in academic circles, becoming also a player in the international technology market (INESC Porto, 2008c). Its success has been proven by awards given, by the visible magnetism of international scholars and students, and by targeting even the world market with successful high-tech startups (INESC Porto, 2008c).

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

2.3. Data gathering considerations and some descriptive account

In order to conduct this research, we have firstly 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. By 14th April 2008, when 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, remaining therefore for further analysis 1426 papers (*cf.*, 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, 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 includes, specifically, 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-authorships' patterns of INESC Porto's scientific production.

During the process of assembling the information related to authors' affiliations, it was not possible to access 571 papers, since they were not available in SACA, nor in Thomson Reuters, or in 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 centralized 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 revealed to have different authors from the ones originally indentified 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.

As indicated previously, 845 papers were valid since it was possible to have access to their contents, whether through SACA search engine or through one online, like Google.com, Google Scholar or Thomson Reuters' Web of Knowledge. Furthermore, it should be added that 14 papers within these had authors with no written affiliation in INESC Porto, though that affiliation was confirmed by INESC Porto internally afterwards. Therefore, after this confirmation, it was decided to

accept these entries in our study. Entries where authors indentified in the paper did not correspond to the ones introduced in SACA were also accepted. In this later case, we corrected the information retrieved from SACA by using the authors as presented in the published paper.

As presented in Section 2.4., 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 in our database from INESC Porto's scientific production and work them in terms of co-authorships as well, given that they would be also considered in terms of citations' impact. We arrived then to a total number of 883 papers that cover a timeline, which begins in 1979[2] and ends in 2008. Since only after 1996 a significant number of papers are 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] At last, 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 we had access and papers that were not accessible for affiliation's handling) are distributed between the working units of INESC Porto, as shown in Figure 3. A note here must be highlighted since we recall that each paper may account 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 at our reach for the diffusion of that same

[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 have collected this data from SACA at the 14th April 2008, and therefore those 16 papers were the ones available at the time.

knowledge. This data is specifically important to address Research Question 1, which is thoroughly developed in Section 3.2..

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).

A descriptive analysis to our database indicates that, comparatively, UOSE is, undoubtedly, the most prolific unit, with 519 papers, from which communications in 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 total) and publications in book chapters and conferences proceedings (173 papers, 47,3% of total), while papers presented in international refereed journals account for 46 (representing 12,6% of the corresponding total). USE is the third most fecund 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. UESP has

190 papers in 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 other 2 published in international journals.

Globally, Figure 3 shows an increase of 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. In terms of proportions, Figure 4 shows us how INESC Porto has diminished publication in the overall, as far as international journals are concerned, from the period 1996-1999 to the period 2000-2003, but has doubled their share in the 2004-2007 phase, when this kind of publication accounted for 30,4% of all papers produced. Interesting to highlight also is the fact that book chapters have been declining their share through the years, while conference presentations keep representing around 40% of the overall INESC Porto's 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, loose importance in the case of UESP and UOSE, and gets stronger in USE, USIC, and more obviously in the case of UTM.

This analysis of the data permit 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.

Hence, in a first stage, we trace INESC Porto's knowledge production resorting to statistical analysis of the data we collected from SACA and afterwards the search we conducted for confirming the affiliations of every author (*cf.* Research Question 1., Section 3.2.). 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 1.239 connections resulted 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 collaborations' patterns and thus infer over INESC Porto's geographical influence scope, *i.e.*, its international interconnectedness and influence (*cf.* Research Question 2., Section 3.3.).

In a second stage, resorting to the information over citations available in the Thomson Reuters, namely in the Science Citation Index (SCI), we assessed the geographical pattern of the citations of INESC Porto's scientific production (*cf.*, Section 3.4.). For this purpose, we have 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 making correspondence also between every affiliation, in which resulted 13.035 citations' linkages (*cf.*, Table 4). This enables us to evaluate in what extent has INESC Porto scientific production 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 (*cf.*, Research Question 3., Section 3.4.), and assess the determinants of INESC Porto's international influence and impact (*cf.*, Research Question 3., Section 3.5.).

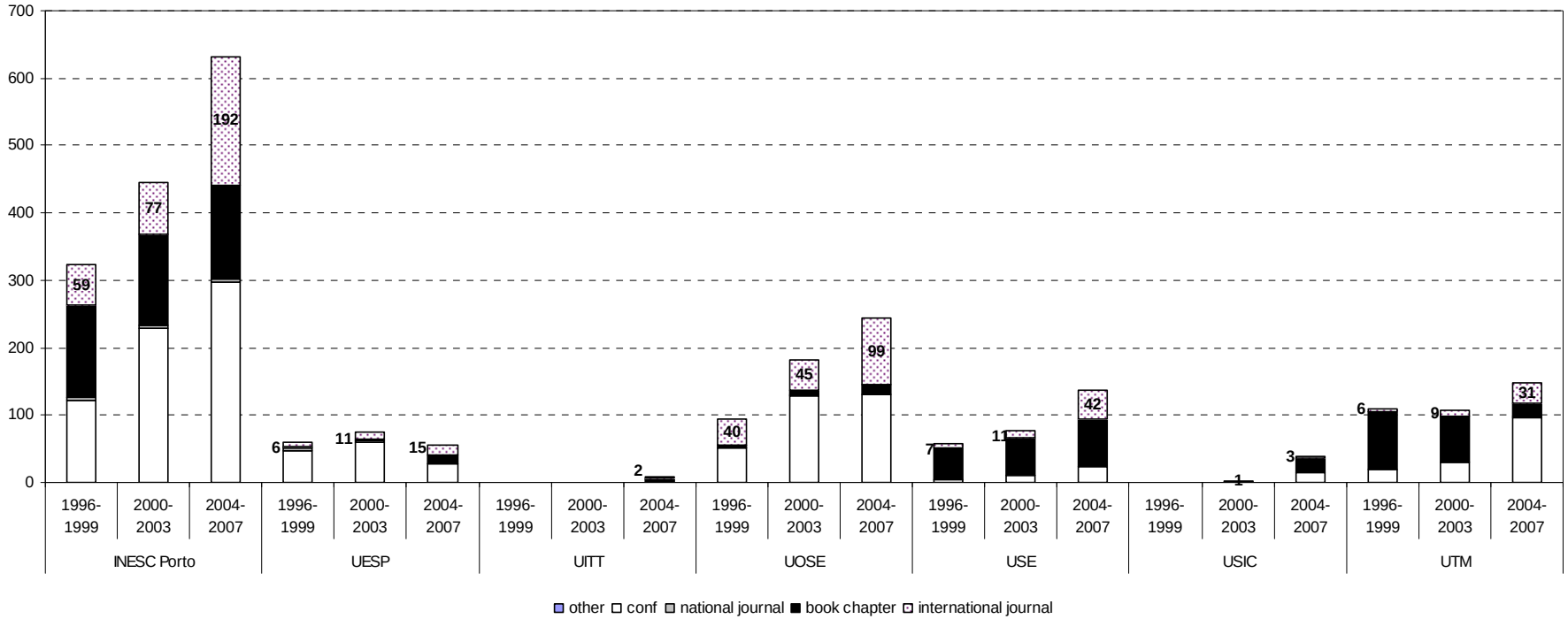


Figure 3: Distribution of the scientific output of INESC Porto per four-year periods, and per working unit, in number of papers

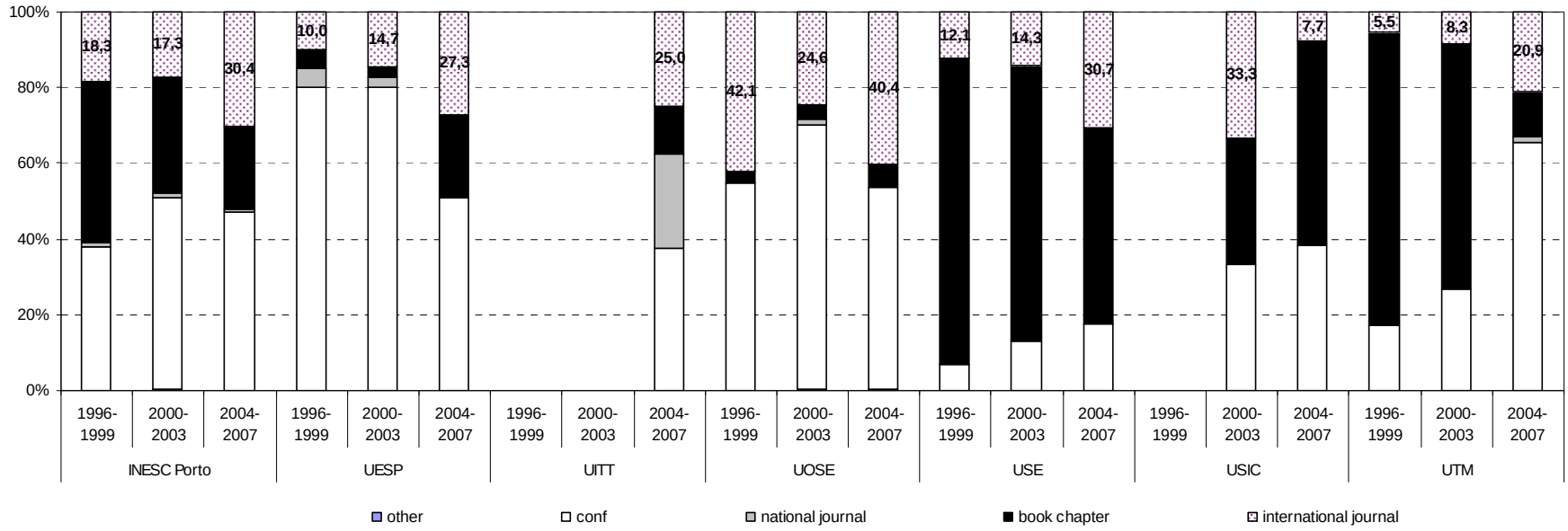


Figure 4: Scientific output's percentage of INESC Porto and its working units by type of publication, per four-year periods

2.4. The best resource to trace knowledge-diffusion patterns – the Thomson Reuters database of INESC Porto's citations

As mentioned before, on the 11th October 2008, a database was retrieved from Thomson Reuters' Web of Knowledge, specifically, references of an amount of 352 papers were downloaded, which presented authors that had INESC Porto in the address, since the online search was done under this specific affiliation's pre-condition. Hence, this database contains papers from which can be traced citations, enabling further analysis in order to map INESC Porto's influence scope (*cf.* Research Question 2. and Research Question 3.). A thoroughly revision of this database was conducted and 5 papers in duplicate were found, which demanded the correction of our sample to 347 papers (*cf.*, Table 4). Out of these, 125 papers revealed to be new when matching them with our primary dataset from SACA, which lead us to conclude that for some reason these papers were not recorded in the internal database from INESC Porto. Nevertheless, 38 papers out of these 125 new ones were included in the database of SACA since they were found relevant, because they were cited. Out of these 38, 29 papers were published in the period under analysis, namely from 1996 to 2007. Also 19 papers could not be dealt with since they were not accessible. Therefore, we were left with the remaining 246 papers that matched with SACA dataset, and from which citations could be traced (*cf.*, Table 4). They were then connected in a matrix format with the citing papers in order to assess the diffusion and influence of INESC Porto as a knowledge producing and diffusing organisation. Furthermore, 142 papers of INESC Porto were identified as having 754 citing papers, producing 13.035 connections between the authors of the cited papers and the authors citing them, which can be understood as the global network of INESC Porto's international influence.

We used Thomson Reuters database (Philadelphia, Pennsylvania, USA), inheritor of the Institute for Scientific Information (ISI), as evidenced above, since literature within bibliometrics range consider it as the main resource for citation analysis, which have therefore become the most broadly used in assessing research

performance (Archambault and Gagné, 2004; Bornmann *et al.*, 2008). Thomson Scientific organises, specifically, the *Arts and Humanities Citation Index* (A&HCI), the *Social Sciences Citation Index* (SSCI), and the *Science Citation Index* (SCI).

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 (CNER, 2002; 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 here acknowledged (Nederhof and Zwaan, 1991; Hicks, 1999; CNER, 2002; Archambault and Gagné, 2004; Neuhaus and Daniel, 2008), and several scientific fields are even neglected, like, for instance, 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, like it is the case of Scopus from Elsevier,[4] Google Scholar,[5] and Cite-Seer,[6] or even by discipline-oriented databases, such as Chemical Abstracts (Chemical Abstracts Services), MathSciNet (American Mathematical Society), and PsycINFO (American Psychological Association) (*cf.*, Neuhaus and Daniel, 2008). Actually, the main advantage of combining different data sources is coverage, since only Scopus account for 15,000 peer-reviewed journal titles (Neuhaus and Daniel, 2008). Nevertheless, Thomson Reuters databases nearly cover 10.000 learned journals (Katz and Hicks, 1998; Archambault and Gagné,

[4] http://www.scopus.com.
[5] http://scholar.google.com/.
[6] http://citeseer.ist.psu.edu/.

2004; Neuhaus and Daniel, 2008). In 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 to our study.

Chapter 3. Assessing the impact and influence of R&D organisations – the case of INESC Porto

3.1. Initial considerations

In this chapter, we aim to answer our three research questions. In the first two sections (*cf.*, Section 3.2. and Section 3.3.), we gathered and analysed empirical evidence for answering Research Question 1. and Research Question 2., that is to say, we describe INESC Porto's scientific output and assess its evolution over the last twelve years (*cf.*, Research Question 1.), as well as picture its international co-authorship pattern during the development of its R&D work, in order to infer over its geographical influence scope (*cf.*, Research Question 2.). Moreover, in Section 3.4., we consider the specific networks of influence of the most productive scientific fields of R&D of INESC Porto, targeting specifically Research Question 3., and explain, through a multivariate econometric model, the international influence and impact of INESC Porto on the basis of the citations made to its scientific research during the period in analysis (1996-2007) (*cf.*, Section 3.5.).

Therefore, recovering these three research goals, we ultimately aim to answer the following:

1. Have the scientific production and international co-authorships' pattern of INESC Porto intensified over the last twelve years, within the period of 1996 to 2007?
2. Has the network of scientific production of INESC Porto been enlarging over time its geographical scope? Or putting it in other terms, has INESC Porto extended its international influence?
3. Does the international scientific influence of INESC Porto differ according to its most prolific areas of expertise (*i.e.*, Power Systems Unit, Telecommunications and Multimedia Unit, Optoelectronics and Electronics Systems Unit)? Have their network structure and boundaries evolved differently?

3.2. INESC Porto's international scientific co-authorships' framework

The main goal of Research Question 1. is to assess whether INESC Porto's scientific production and international co-authorship's behaviour have intensified during the time frame between 1996 and 2007, since it this would indicate the progression into internationalisation of the organisation itself.

When analysing INESC Porto's dataset of papers accessed (*cf.*, Table 4), we may picture its scientific production in terms of international co-authorship behaviour, like it is synthesised in Table 5. From the 826 papers produced by INESC Porto's scientific collaborators, the proportion of internationally co-authored papers published in international learned journals represent 35,2%, which means that the majority of papers published in this type of publication (64,8%) are of Portuguese origin. Nonetheless, publications in international journals account for 50,2% of the total output of INESC Porto in terms of foreign co-authored papers (*cf.*, Table 5).

Table 5: Foreign co-authored papers of INESC Porto

	Proportion (%) of foreign co-authored papers in each type of paper	Distribution (%) of foreign co-authored papers by type
Conferences	19,7	21,0
National Journal	0,0	0,0
Book Chapter / Conferences' Proceedings	21,2	28,8
International Journal	35,2	50,2

By considering Figure 5, one can understand how the international collaboration in terms of publication has been increasing since 1996 in INESC Porto. In the last period of analysis, namely between 2004 and 2007, 27,4% of all scientific output produced had at least one foreign co-author, when in the first period of analysis (1996-1999) it represented just 21%. This positive outlook contrasts, however, with the reality of each working unit, like for instance UOSE, where the presence of a international co-author is stronger in the overall (32,1%), but which has been decreasing in the four-year period, starting at 1996-1999 with an amount of 41,7% of foreign co-authorships, and getting down to an amount of just 26,3% by 2004-2007. USE, in turn, stays along the global average of the period, at 26,8% of papers

with foreign co-authorships, while UTM has a much more impressive performance, jumping the share of papers with international co-authors from 11,5%, in the period of 1996-1999, to 38% in the more recent period of 2004-2007.

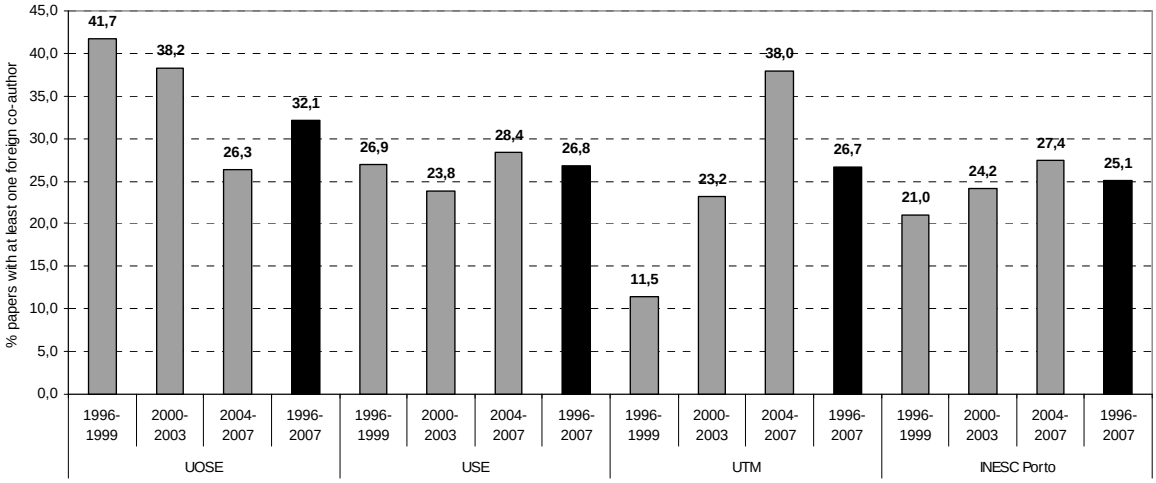


Figure 5: Percentage of papers with at least one foreign author

If we look at the evolution of the scientific publication of INESC Porto by type of publication, as showed in Figure 6, it is visible how the pattern is much different between its working units. Publications presented at conferences are the gross of the final output for UOSE and UTM, while USE has a big share of book chapters and conference proceedings, while in terms of publications in international academic journals, the figures are much positive in UOSE and USE, representing 32,8% and 22,9% of the overall output for the period 1996-2007 respectively, while UTM has a much timid record during the years, becoming more positive after 2004, and reaching a final 1996-2007 average of 12,9%.

We may conclude, therefore, that INESC Porto has been improving its success in publication when accounting more and more for an enlarging share in scientific output that gets to be published in international journals, namely from 2003 onwards (*cf.*, Figure 6). Internationalisation of the scientific production of INESC Porto is, consequently, a reality, for which contributes all working units, but with greater relevance, it should be highlighted, in UOSE and USE.

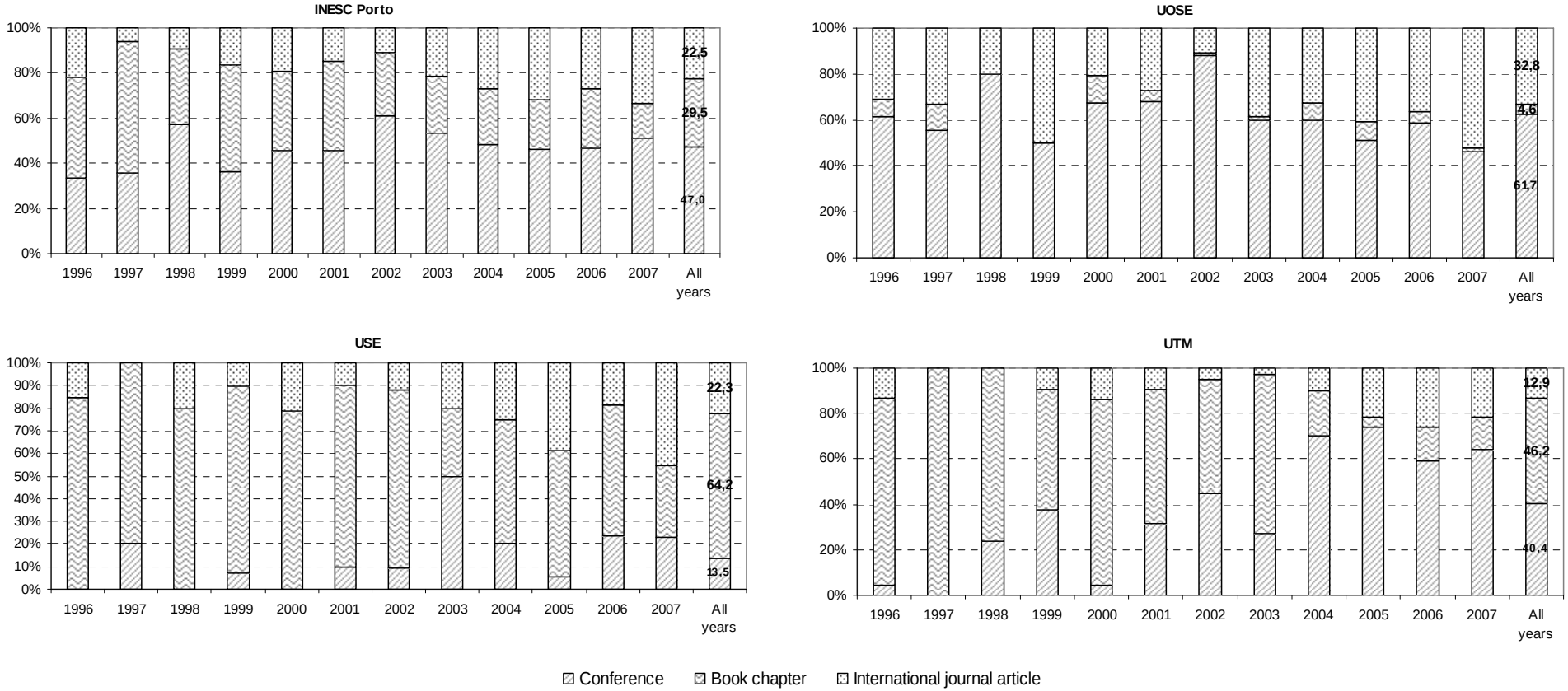


Figure 6: Evolution of scientific output by type of publication in INESC Porto

3.3. The geographical scope and evolution of INESC Porto scientific production. Mapping the influence and impact through co-authorship networks

In order to answer Research Question 2., we need to visualise INESC Porto's geographical network, depicting the main partner countries that contribute for its scientific production, the core contributors, and understand therefore whether INESC Porto positions itself in some kind of international R&D cluster. Moreover, we need to depict the overall dynamics of this international system which is ruled by INESC Porto, so that we may understand how this network has evolved and whether it has extended in fact its international range of influence.

When analysing the presence of the foreign countries that contribute to the scientific achievements of INESC Porto (*cf.*, Table 6), it becomes evident that UK (14,1%), Spain (11,4%), USA (11,1%), Brazil (8,4%) and Germany (7,2%) are the core partners of INESC Porto's international network (*cf.*, Table 6, Figure 7). In a matter of fact, the existence of straight connections, as far as scientific production is concerned, with this group of countries, lead us to recall Bush and Hattery (1956), Price (1963), Stichweh (1996), Zit *et al.* (2000), and even Wagner and Leydesdorff (2005), authors that explained international scientific interplay because of geographic proximity and historical determinants, reasons that seems to be much adequate in the present case.

Nevertheless, the picture is slightly different when we focus on the most prolific working units. Recovering the work by Archambault and Gagné (2004), which highlights to the fact that evaluating the output intensity, that is to say, by counting the number of articles published by researchers, departments, and research institutions, this may indicate the degree of specialisation of a specific field and assess their research performance, consequently, we decided to conducted a refinement of our analysis, by focusing on the scientific output of UOSE, USE and UTM. As far as optoelectronics unit is concerned, 72,3% of its internationally co-authored papers are jointly produced with (co)authors affiliated in five core countries, namely USA (23,4%), UK (14,9%), Brazil (12,8%), Spain (12,8%) and Russia (8,5%). USE also develops 69,6% of its scientific R&D output in a hub formed by five countries, to be exact, Spain (19%), Brazil (15,2%), Greece

(15,2%), Venezuela (11,4%) and Macau (8,9%). UTM, on the other hand, has not such a high concentration in its five main partner countries, since these represent 55,7% of its overall production in international co-authorship. Regarding the telecommunications and multimedia unit, UK represents 18,1% of co-authorship, while Germany represents 13,4%, which are then followed by France (8,7%), Italy (8,1%) and Austria (7,4%).

Table 6: The most representative countries contributing to INESC Porto's scientific production

	UOSE	USE	UTM	INESC Porto
Austria				
Belgium				
Bosnia Herzegovina				
Brazil				
Canada				
Finland				
France				
Germany				
Greece				
Ireland				
Italy				
Macau				
Russia				
Spain				
Switzerland				
The Netherlands				
UK				
USA				
Venezuela				

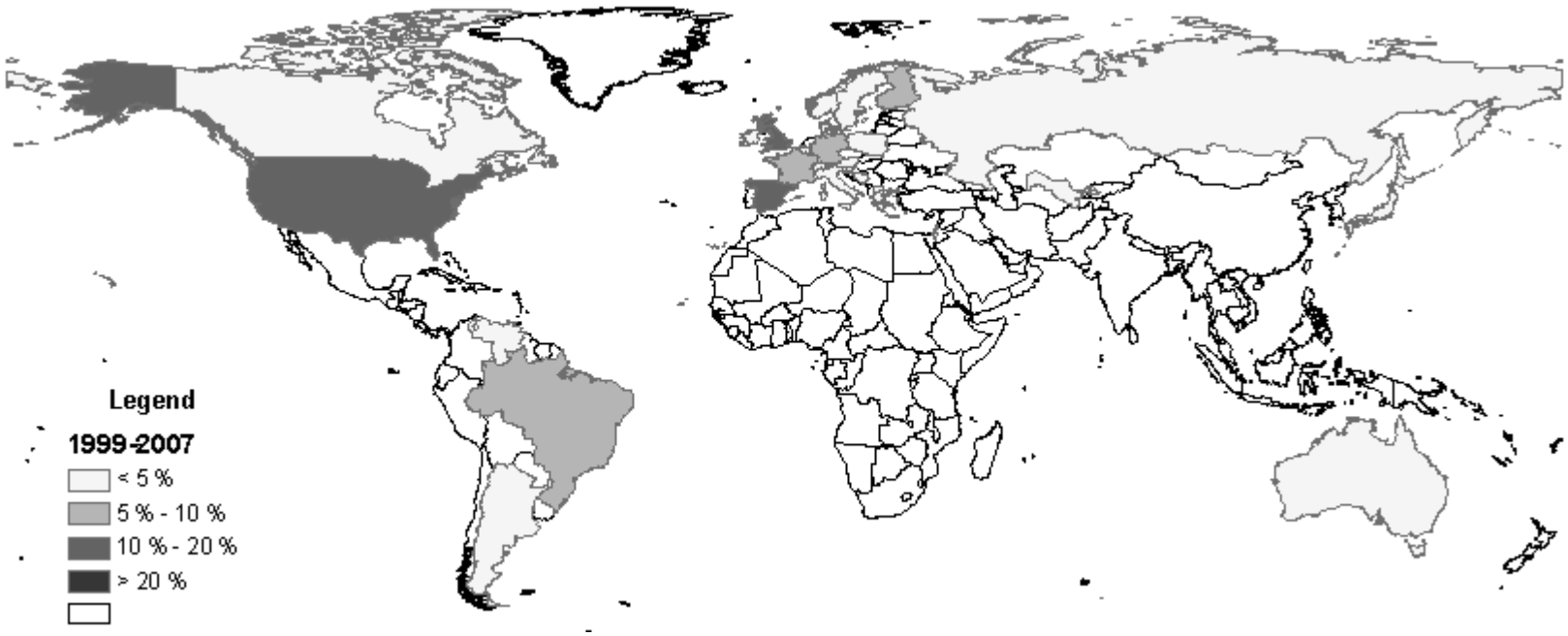
Legend:

>=10%

[5%; 9%]

< 5%

We may identify, as a result, some international scientific clusters with which INESC Porto directly interacts, one formed in Europe, where UK, Spain, Germany, Russia, France and Finland are the most important players at stake, and another one in America, where USA is of high relevance, following, in a significant degree of relevance, Brazil and Venezuela, in South America (*cf.*, Figure 7).



INESC Porto

UOSE

USE

UTM

Figure 7: Country's affiliation of foreign co-authors (in % of total), 1996-2007

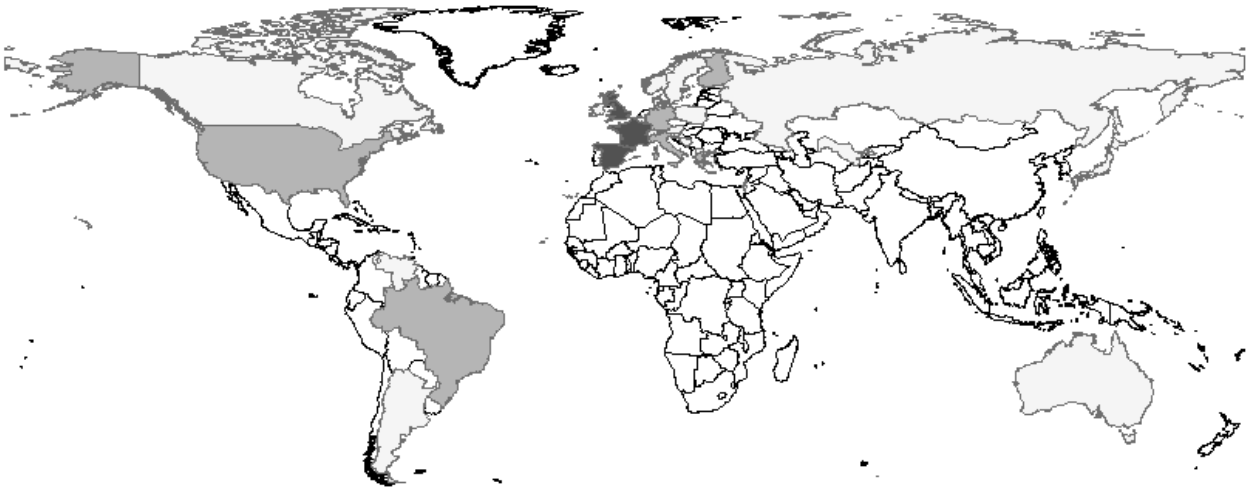
When analysing these foreign linkages through the time frame of 1996 to 2007, in blocks of four-year periods, this dynamic enrichment of the analysis reveals us how there are countries with which INESC Porto has been loosing connection, others that are entering its sphere of scientific collaboration, and even the specific case of Brazil, which maintains a stable collaborative pattern through the years (*cf.*, Figure 8). In a matter of fact, Brazil is not just a core player, as far as the overall scientific production of INESC Porto is regarded, but it is also a stable partner within its international scientific relationships, keeping a net contribution to co-authorship of *ca.* 5% to 10%, between 1996 and 2007 (*cf.*, Figure 8), stability reasoning that may be much anchored on previous works that have studied networks' dynamics (*e.g.*, Watts, 2001; Jackson and Watts, 2002; Young, 1993; Kandori *et al.*, 1993).

As far as the countries that are losing presence in INESC Porto's international network are concerned, we may highlight the cases of Greece (which comes from a share of participation in co-authorship of about 7%, in the period 1996-1999, down to a contribution of 4% in the period 2004-2007), UK (which progressively looses it share, coming from 18,6% in the first period of years, and reaching 2004-2007 with a collaboration of exactly 12,9%), and the USA (which falls drastically from the first position in terms of co-authorship in the first period of analysis, when it share was of 23,3%, and gets to 2004-2007 accounting for 9,5%). Macau, specifically, had a strong share of collaborative presence during the first period of analysis, amounting 16,3%, but it vanishes afterwards from records in the following periods.

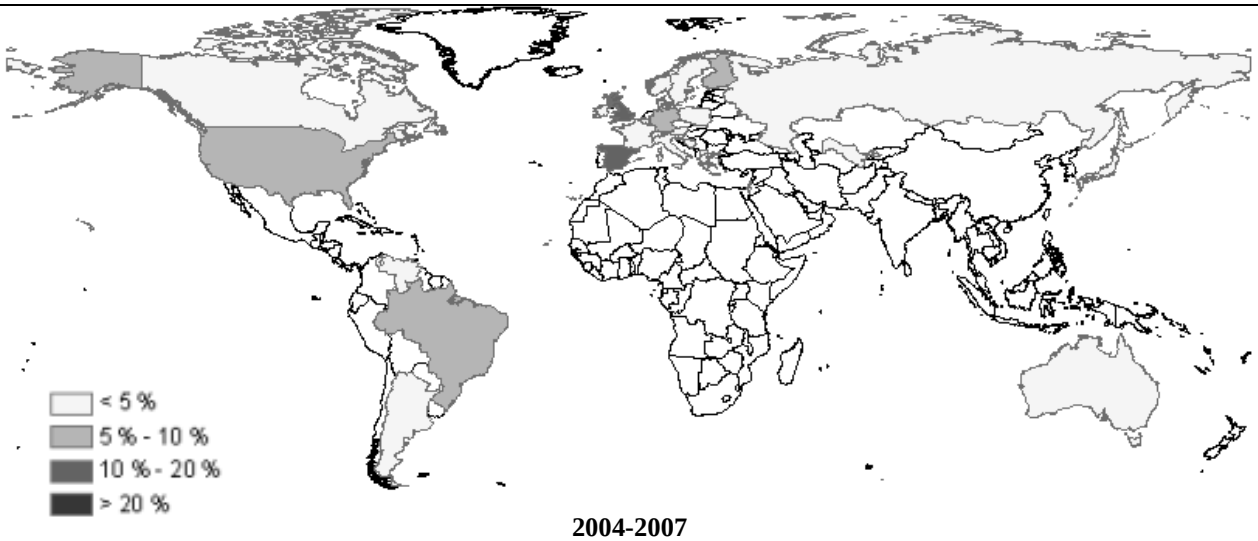
A much more positive outlook is delivered by Germany, Finland and Spain (*cf.*, Figure 8). Germany, specifically, has been moving positively inside INESC Porto's international network, coming from a share in co-authorships' participation of 2,3%, in the period 1996-1999, to steadily reach a collaborative rate of 9% at the end of the period under analysis. Also positive is the case of Finland, which enters the network in the period of 2000-2003, and gets to 2004-2007 with a share of 6% for the scientific collaboration of INESC Porto.

INESC Porto

1996-1999



2000-2003



2004-2007

Figure 8: Country's affiliation of foreign co-authors (in % of total), for INESC Porto, per four-year periods

The case of Spain is also of relevance, since it comes from a participation rate of 2,3% in the first period, and gets to become a partner with a stronger collaborative behaviour in the last two periods of analysis, though the figure, in 2000-2003, was about 16,7%, and, in 2004-2007, it has declined to 10,9%.

France is a case of a low contributor to the scientific production of INESC Porto, in the period of 1996-1999, but its input in this international network becomes stronger in the second period of analysis, reaching a share of 11,1% (the third place in the ranking of co-authorship for this period), and then declines in the last period, between 2003-2007, when its share falls back to a participation that amounts to 4% (*cf.*, Figure 8). With less relevance, but announcing a growing trend, are the cases of Austria and Canada, which only enter the network in the second period of analysis, and even Venezuela, which arrives at the network in the last period (*cf.*, Figure 8). These three countries present a participation in the co-authorship framework that almost reach 5% share, namely, Austria presents 4,5% in the last period, Canada gets 4%, and Venezuela also reaches 4,5% in 2004-2007.

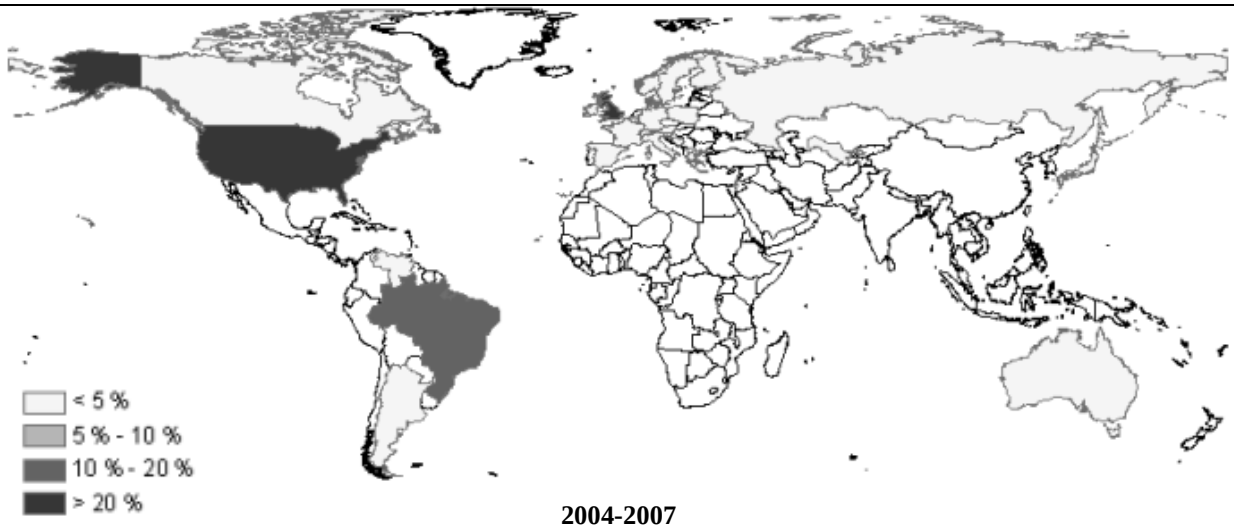
When considering the international co-authorship behaviour of the main scientific output deliverers of INESC Porto, namely UOSE, USE and UTM, it is evident how they all have specific evolution patterns of their own international network, strongly differentiated from the one identified as of INESC Porto as a whole (*cf.*, Figure 9, Figure 10, Figure 11).

Starting with UOSE, the USA is the most important partner country in its specific scientific network, though stronger in proportion in the first period (accounting then for about 36,8%), its co-authorships' share has declined to 15,6%, between 2000-2003, and has recovered afterwards to 23,3%, in the last period (*cf.*, Figure 9). Regarding Brazil, the second largest contributor in INESC Porto's co-authorship network, despite entering the network only in 2000-2003, its net input in this period reached an amount of 12,5%, and this figure has improved in the latest period when it summed 18,6%.

UOSE

1996-1999

2000-2003



2004-2007

Figure 9: Country's affiliation of foreign co-authors (in % of total), for UOSE, per four-year periods

In a lowest stage of relevance, but having still a positive outlook, is the case of Canada, which enters into the network in the period of 2000-2003, accounting for 3,1% of the total international co-authorship output, but increasing this proportion in the last years, reaching then to 7%. At a counter-tendency, we may find countries like UK, Switzerland, and Finland, which have decreased their participation in the international co-authorship network of UOSE. UK, in particular, had the largest fall, from 26,3%, in the first period, to 11,6% in the latest. Switzerland accounted for 10,5% of co-authorship share in the first period of analysis, disappears from records in the second period, and then reapers in UOSE international network, at 2004-2007, with a participation of 7%. Finland has also registered a strong decline in co-authorship, from 15,6%, in 2000-2003, to 2,3%, in 2004-2007.

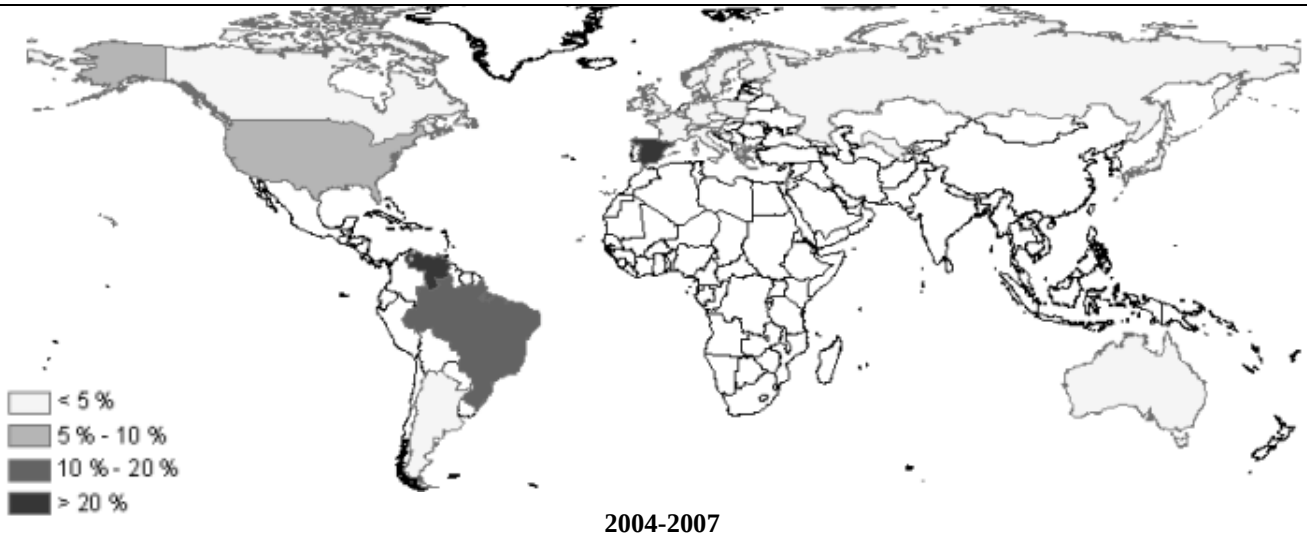
It must also be emphasised the collaborative rate of France and Russia, which present a steady co-authorships' participation, the first at the average level of 5% along the time frame of analysis, and the second reaching almost the 9% average rate for the three periods. A special note still has to be done to the case of Spain, which begins its participation in co-authorships with UOSE at a level of 5,3%, climbs afterwards to 28,1%, between 2000 and 2003, and then falls back to 4,7% in the latest period (*cf.*, Figure 9).

Regarding USE, this dynamic analysis also shows us a particular pattern in terms of co-authorships (*cf.*, Figure 10). Concerning the partners that are loosing collaborative share, one must highlight countries like Greece, Bosnia and Herzegovina, and the UK. Specifically, Greece has had a strong participation in the two first periods, accounting then for 13,3% and 22,7%, respectively, but has fallen in the last period down to 9,8%. Bosnia and Herzegovina have entered USE international scientific network during the period of 2000-2003, with a share of 13,6% (ranking the third position of international partners of USE), but have fallen their contribution to USE scientific production in the last four-year period to an amount of 4,9%

USE

1996-1999

2000-2003



2004-2007

Figure 10: Country's affiliation of foreign co-authors (in % of total), for USE, per four-year periods

Finally, the UK had a share of scientific collaboration of 6,7% and 9,1% in the first two periods, but has shrunken this share down to 4,9%. The cases of France and Macau are different, but also vey important to highlight, namely because these countries have disappeared from USE's international collaborative network. France vanishes from record in the last four-year period of analysis, after being a partner country at a 5% to 10% level. Brazil is an important country in USE's network, having a share in co-authorship of 20% in the first period, losing in the second period to 4,5%, but recovering again in the last four-year period to 19,5%. Countries that gradually have been gaining weight, as far as USE's international relationships are concerned, are the USA and Spain. The USA enter the network in the second period of analysis, with 4,5%, and gets to 2004-2007 with 7,3%, while Spain also accounted in the second period for 18,2% of co-authorships, and in 2004-2007 this figure was already of 26,8%.

As far as the telecommunications and multimedia unit is concerned (*cf.*, Figure 11), we must emphasise the growth in terms of scientific contribution of Austria, which enters the network of UTM in 2000-2003 with 5,7%, and accounts in the last period for 8,4% of co-authorships, and the case of Germany, which also enters this international network in the second period, representing 11,4%, but grows to 15% between 2004-2007. With not such a good performance is the case of Brazil, for instance, strong in the first period of analysis, accounting then for a percentage of 14,3%, but declining drastically in the following periods. The same has happened with Denmark, which also had a share of contribution of 14,3% between 1996-1999, but finishes the time frame of analysis with just 2,8%. In the case of France, it had a strong collaborative behaviour in the second four-year period, of 20% of co-authorships, but declining then in the last period, to 5,6%. Also Italy represented 20% of co-authorships between 2000-2003, but ends the time frame of study accounting just for 4,7%. Much worse are the cases of UK and the USA, gradually decreasing their share of R&D collaboration with UTM along the years.

UTM

1996-1999

2000-2003

2004-2007

Figure 11: Country's affiliation of foreign co-authors (in % of total), for UTM, per four-year periods

UK represented 28,6 % of international co-authorships for UTM between 1996-1999, and then declines in the following period to 20%, and ends with an average figure of 16,8%. The USA had a stronger contribution in the first period, representing then 42,9% of international co-authorships, but afterwards drastically falls to 5,7% and 3,7% in the subsequent periods. Just a brief note also to the case of Spain, which enters into UTM's international scientific network in the second four-year period, with a share of 5,7%, and maintaining it around 5,6% in the last period, and finally Finland, which becomes only in the last four-year period a strong international partner, representing 10,3% of international co-authorships.

3.4. The geographical scope and evolution of INESC Porto scientific production. Mapping the influence and impact through citation networks

In the present section, we address Research Question 3. and attempt to understand whether the international scientific network of the particular R&D areas with higher level of scientific output in INESC Porto, namely, if UOSE, USE, and UTM, differ in their range of global knowledge influence from the average influence of INESC Porto, based on the patterns and evolution of global citations of INESC Porto's and its units' scientific production. Specifically, when analysing each scientific working unit of INESC Porto, we assess the extent to which there is a different network (citation) structure, as far as the knowledge influence and impact of each of their scientific production is concerned.

In order to answer such question, we resorted to the data collected from Thomson Reuters' Web of Knowledge search engine (*cf.*, Section 2.4.), and thoroughly worked out a new dataset where it was compiled information related to the affiliations of the authors citing INESC Porto's scientific publications. By analysing citation data, it was possible, to evaluate the degree of diffusion of the knowledge produced by INESC Porto and recognise the spreading of its international scientific influence network, by also comparing it to each international citation network of its most prolific expertise areas.

In a matter of fact, when looking to Figure 12, it becomes clear how INESC Porto's network is very different from the ones specific to each area of expertise of its most productive units. INESC Porto's authors have about 32,6% of their overall citations coming from authors affiliated in Portuguese R&D institutions, including here also self-citations, within the time frame period of analysis. This means that the majority of citations comes from abroad, which reveals, at least, a recognition of INESC Porto's scientific production from their international peer communities. Of course we can not, at this point, and regarding the information at our disposal, distinguish between the relevant or irrelevant citations, positive or negative ones, like suggested before, in Table 2, information that would certainly better our analysis and contribute to a more exact inference over the importance of INESC Porto's scientific output for the international scientific community. Nevertheless, our revision of the data concerning the affiliations of authors citing the scientific work of INESC Porto is instructive, to say the least, and revealing of the diffusion of its scientific knowledge produced.

Citations reveal, therefore, that authors citing INESC Porto output are affiliated in a total of 51 foreign countries, as distinctive as Argentina, Australia, Bulgaria, Colombia, Egypt, India, Iran, Israel, Malaysia, New Zealand, People's Republic of China, Saudi Arabia, South Africa, Thailand, Tunisia, Uruguay, and Viet Nam, just to name a few. To be exact, the large number of foreign authors citing INESC Porto are affiliated in People's Republic of China, which have a share of 12,8% of the total. China is followed by the UK, whose authors affiliated in its institutions account for 5,6% of the total authors citing INESC Porto's scientific output. In the third place of foreign citing countries is the USA, with 5,1%. Then Spain follows, with a share of 3,8%, Canada amounts 3,5% of citations, and Germany represent 3,4%. Italy has a share of 2,8%, South Korea comes next with 2,6%, and Switzerland has a percentage of 2,5%.

We conclude for this analysis on the wide diffusion of the knowledge produced by INESC Porto, and its influence in the scientific work developed in the five continents, with a higher emphasis on the knowledge hubs located in Southeast Asia, North America and Europe.

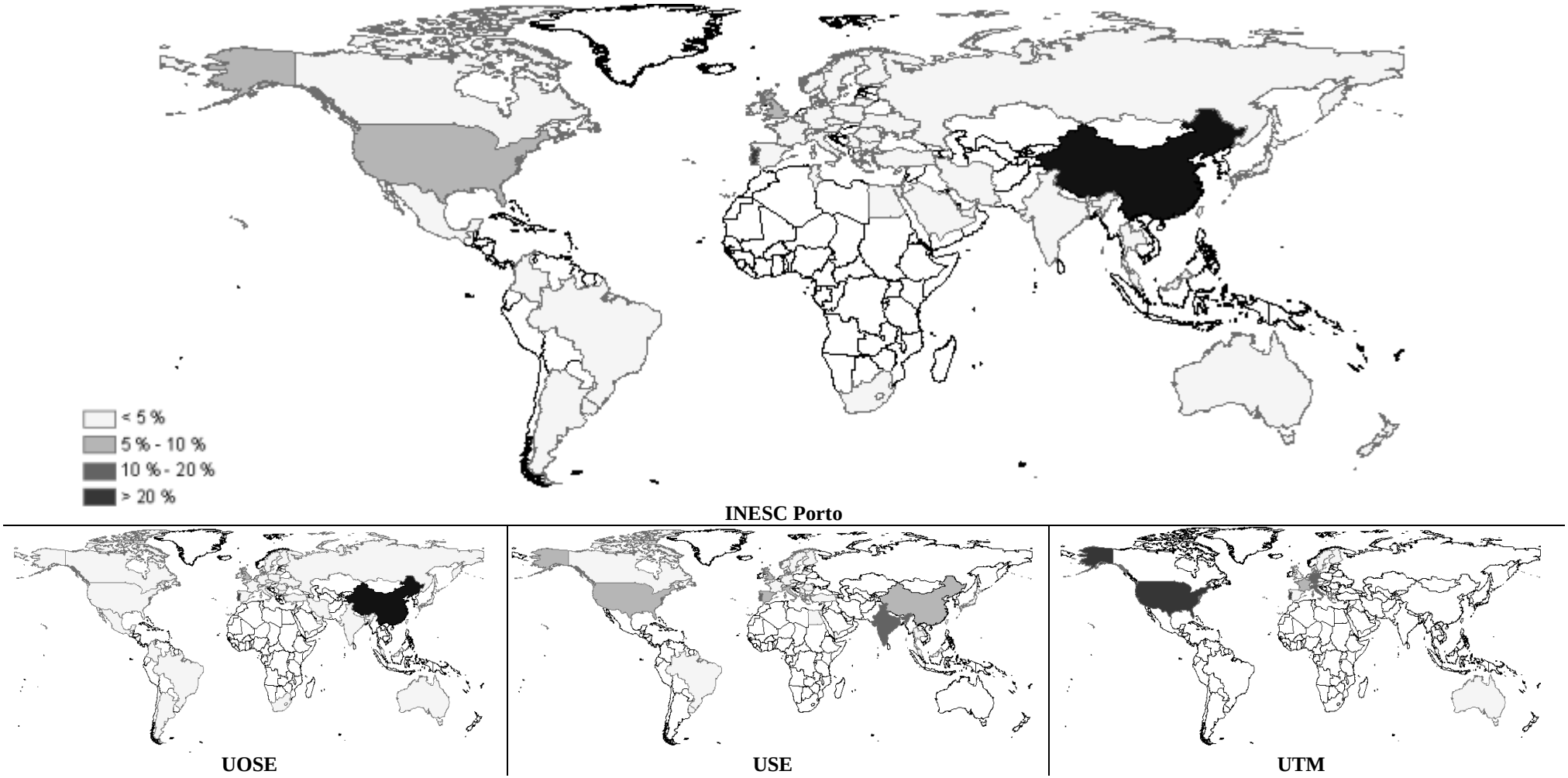


Figure 12: Country's affiliation of authors citing INESC Porto's scientific production (in % of total), 1996-2007

But looking carefully to Figure 12, it does also show us how different is the knowledge-diffusion network of each R&D working unit of INESC Porto.

UOSE, for instance, has, similarly to INESC Porto as a whole, 34,3% of its citations concentrated in Portugal, with the large majority still coming from abroad. More specifically, 13,5% of the citing authors are affiliated in organisations from the People's Republic of China, which leads by large margin, followed by the UK and the USA, whose author' affiliations account for 5,8% and 4,2%, respectively. Spain comes next, with 3,8% of the total citations, Canada has 3,5% and Germany 3,1%.

USE is the only case in which Portugal is not in the first place citing its scientific output, being India instead, accounting for 15,3% of the overall citations, while the Portuguese affiliated authors citing its works account for 10,6%. Spain has an average of 8,5%, as well as China, while Greece is also strong influenced by USE's knowledge, accounting for 8% of its total citations. The UK has about 6,1% of USE's citations, and the USA comes next, with 5,7%.

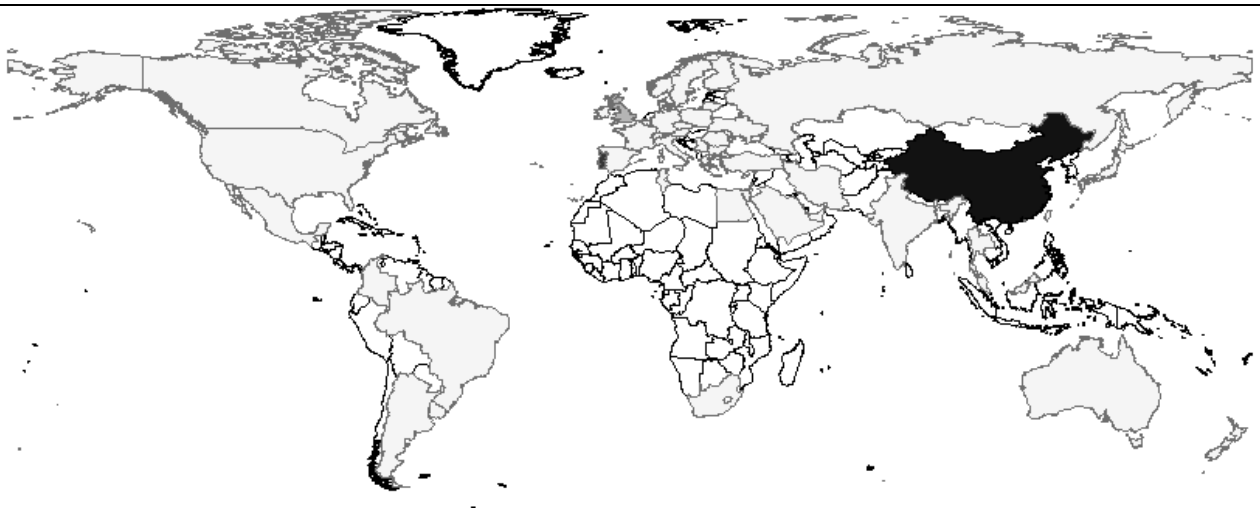
For UTM, Portuguese affiliated authors account for 28,6% of its total citations, and the USA comes in second place, with 21,1%. The ranking is completed with the significant contribution coming from Germany (12,9%), Italy (10,4%), and France (6,3%).

The previous static analysis produced by looking at the data covering the time frame 1996-2007 can be now complemented by a dynamic one that considers each four-year periods within that time interval, in order to visualise how has evolved the network of international influence of INESC Porto and of its areas of expertise.

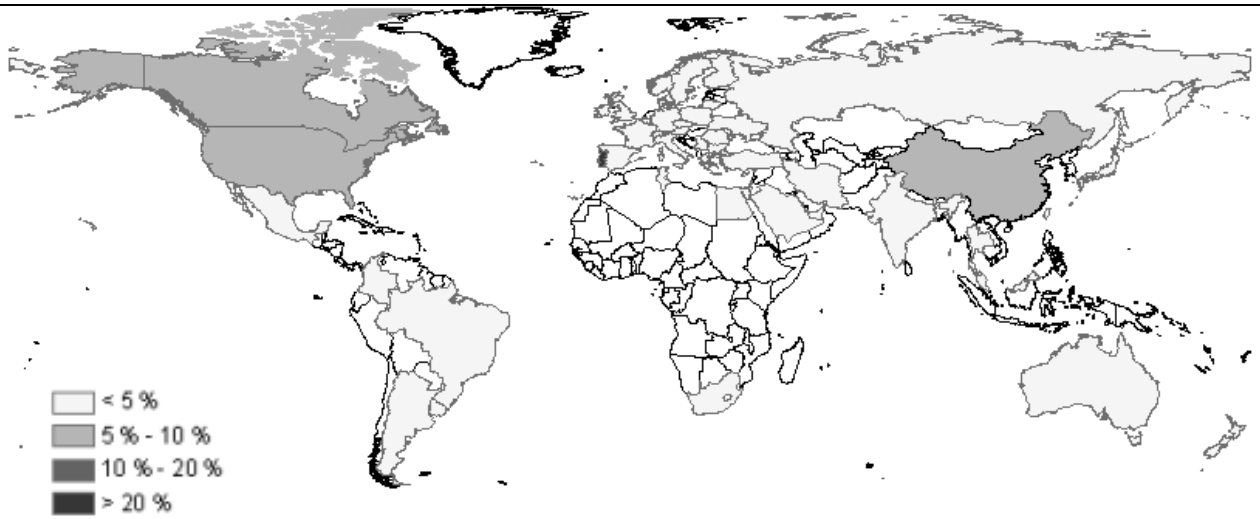
Starting with the broad impact network of INESC Porto (*cf.*, Figure 13), and having already in mind that around 32,6%, as stated previously, are citations that are originated from Portuguese affiliated authors, we realise, the huge importance of People's Republic of China as the most important international receiver of INESC Porto's scientific contributions. During the time period of 1996-1999, it already accounted for 11,7% of total citations, improving in the following four-year period to 19,7%, but decreasing in the latest period, to an amount of 7,9%.

INESC Porto

1996-1999



2000-2003



2004-2007

Figure 13: Country's affiliation of authors citing INESC Porto's scientific production (in % of total), per four-year periods

Also having a negative outlook, as far as citations are concerned, are countries like the UK, Russia and Switzerland. In the particular case of the UK, it has been steadily decreasing its citations of INESC Porto's scientific output from 7,2%, in the first period, to reach only 3,4% at the latest. Russia comes from a share of citations of 4,4% in the first period, to reach only 0,4% in 2004-2007, while also Switzerland had a percentage of 3,6% in the first time interval, but ends at the latest with 1,5%.

With a much fluctuating performance, concerning the citations of the scientific production of INESC Porto, are countries like the USA, Spain, South Korea, Germany, and France. As far as the USA are concerned, it starts in first period of analysis with a citations' share of 4,4%, which declines afterwards to 2,3%, and recovers in the latest time interval to 8,2%. Spain also starts with a citations' share that accounts for 4,5%, diminishes to 3,2% in the following period, and recovers slightly in 2004-2007 to 3,7%. Germany gets 5,2% of the total citations within 1996-1999, but falls to 1,2% in the next period, to recover in the latest one to 3,5%. Also France has the same behaviour, starting with 4,3%, but then citing poorly in the second four-year period, to recover to 2% in 2004-2007. South Korea, on the contrary, starts poorly, with 2,7% of the overall citations to INESC Porto scientific output, but amounts 3,6% in the second time interval, to fall back to 1,7% in the latest.

With a much better performance, as far as foreign citations of INESC Porto scientific production is regarded, are the cases of Italy and Canada, countries that increase their share of international citations. Italy starts with 0,9% in the first four-year period and gets up to 2004-2007 with a share of 4,2%, while Canada has a much promising performance, since it starts with 2,1% and ends by placing itself at the fourth place of the overall citations to INESC Porto output, with a share of 5,9%.

Focusing now on the broad international network of the optoelectronics unit (UOSE), as showed in Figure 14, we may realise how it has been changing through the years and how it is significantly different from the average picture given by INESC Porto, as presented previously. Countries like the USA, Germany, Australia, Poland and Finland, when taking a closer look, have been fluctuating inside the network of citations between 1996 and 2007.

UOSE

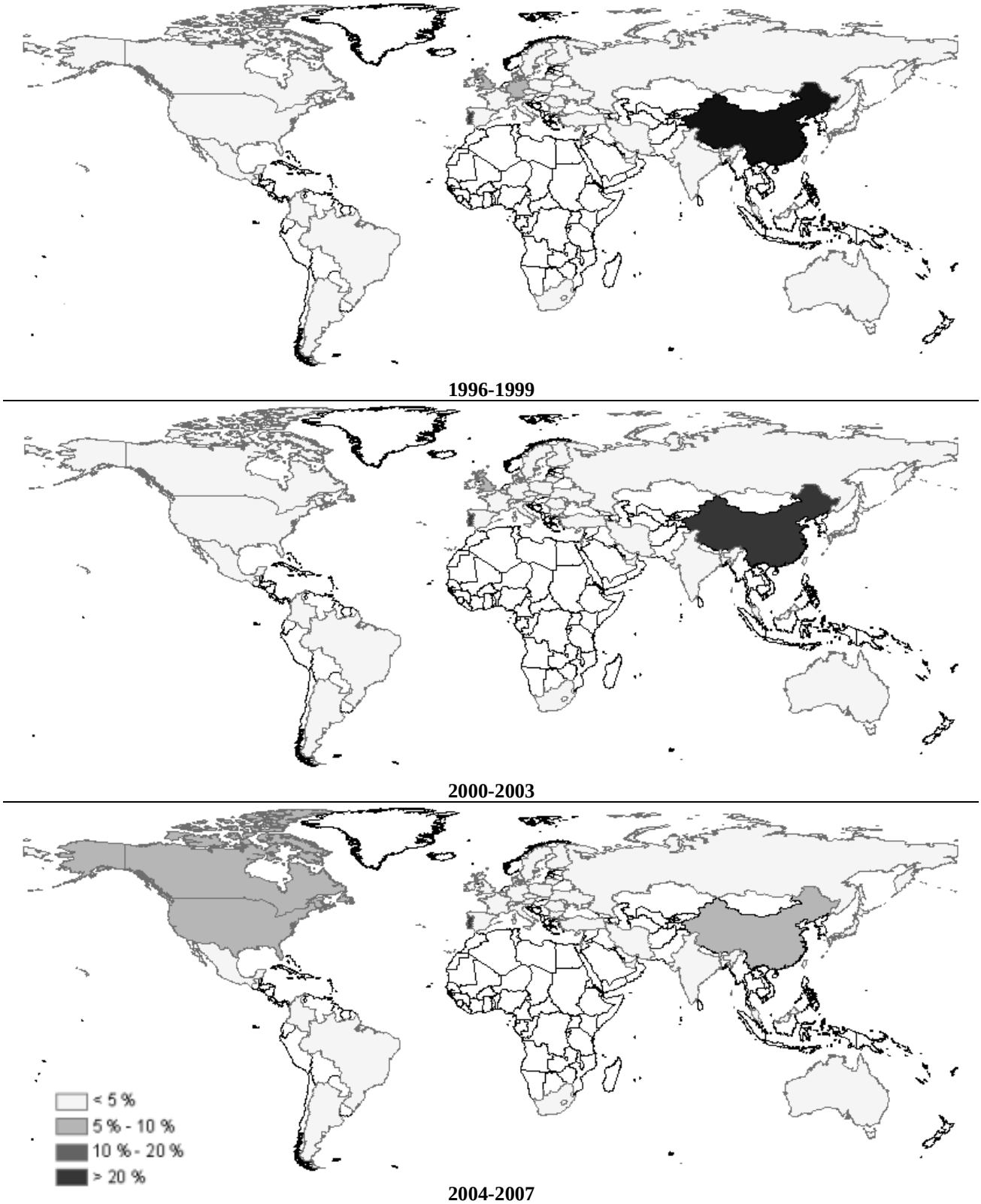


Figure 14: Country's affiliation of authors citing UOSE scientific production (in % of total), per four-year periods

As far as the USA is concerned, it has had a share of 4,4% in the first four-year time interval, but it has diminished by 2000-2003, recovering in the last period to 6,6%. Germany had also a better share of citations in the first time period, amounting to 5,3%, but then falls in the second period to 1,2%, and recovers slightly to 2,4% at the latest. A similar pattern happens in the case of Australia, which starts with a share of 2,5%, and diminishes down to 0,7% in the second four-year period, recovering nevertheless to 2,8% in 2004-2007. Evidencing a counter tendency are countries like China and South Korea, which start with shares of 11,9% and 2,8%, respectively, in the time period of 1996-1999, improving in the next period to, respectively, 20,7% and 3,3%, but then falling back to 8,5% and 2,1%, respectively, at the latest time interval. With much worsen figures are countries like Russia, Spain, Switzerland, and the UK, which have been decreasing their shares in the total UOSE's citations through the years, namely, the UK, which starts accounting for 6,9% and ends with 3,9%. On the other hand, Canada, for instance, has a much positive presence in the network of influence of UOSE, since it starts 1996-1999 with 2,1% and it arrives at 2004-2007 with a representation in terms of citations of 6%.

As far as USE is concerned, its international knowledge diffusion is larger than for the other scientific units of INESC Porto, since citations coming from Portuguese affiliated authors account only for 10,6% (*cf.*, Figure 15). Within 28 countries, it must be highlighted the negative evolution within its network of countries like the UK, Greece, and France. The UK, as well as Greece, accounted in the first four-year period with a share of 24,3% each, but both decline this representation in citations drastically in the following periods, since the UK shrinks its share to 2,2% and 2,3% in the most recent periods, and Greece produces any citation in 2000-2003, but recovers it share to 6,2% in 2004-2007. France also had a significant share of citations to USE's knowledge production in the first period of analysis, namely of 16,2%, but vanishes itself from records in terms of citations in the following period, and gets 2,3% at the latest time interval. Also with a negative fluctuation of citations inside the network of knowledge diffusion of USE are countries like India, Thailand, Turkey, and Norway, since India, for instance, had ranked at the top of citations in the first two periods, with shares of 27% and 29,7%, respectively, but accounts only to 6,9% in the last period of analysis.

USE

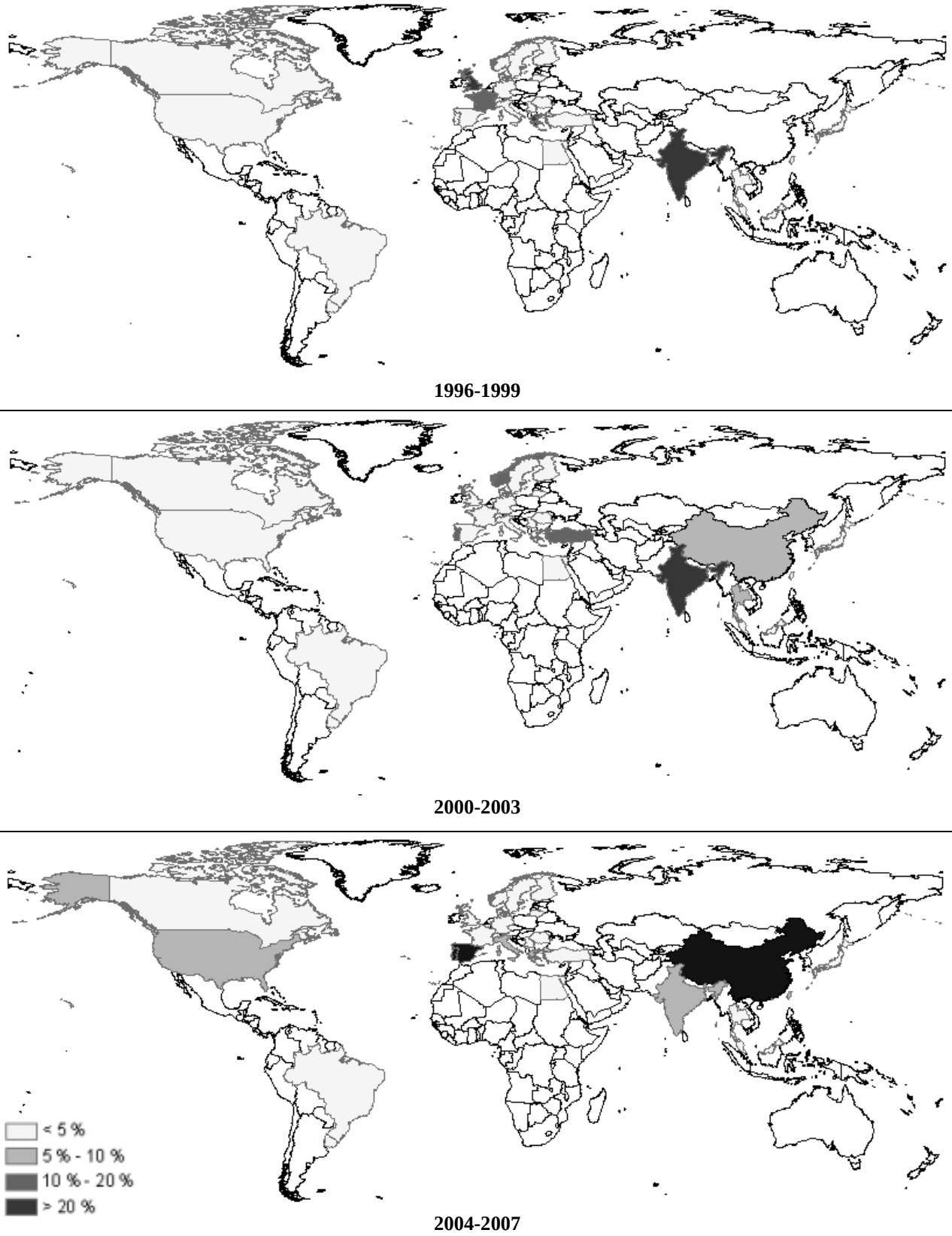


Figure 15: Country's affiliation of authors citing USE scientific production (in % of total), per four-year periods

Thailand, Turkey and Norway just appear within 2000-2003 time interval with shares of citations of 6,6% for the first country mentioned, and 11% for the other two. Countries that are steadily increasing their citations of USE output are the USA and the People's Republic of China, which enter into this network only at the second time period, accounting then for a share of 2,2% and 6,6%, respectively, but reach 2004-2007 with an amount of 8,5% and 11,6%. Entering lately into the network are countries like Spain and Taiwan, which gave citations to USE's scientific publications in a proportion of 13,9% and 7,7%, respectively, in the time period of 2004-2007.

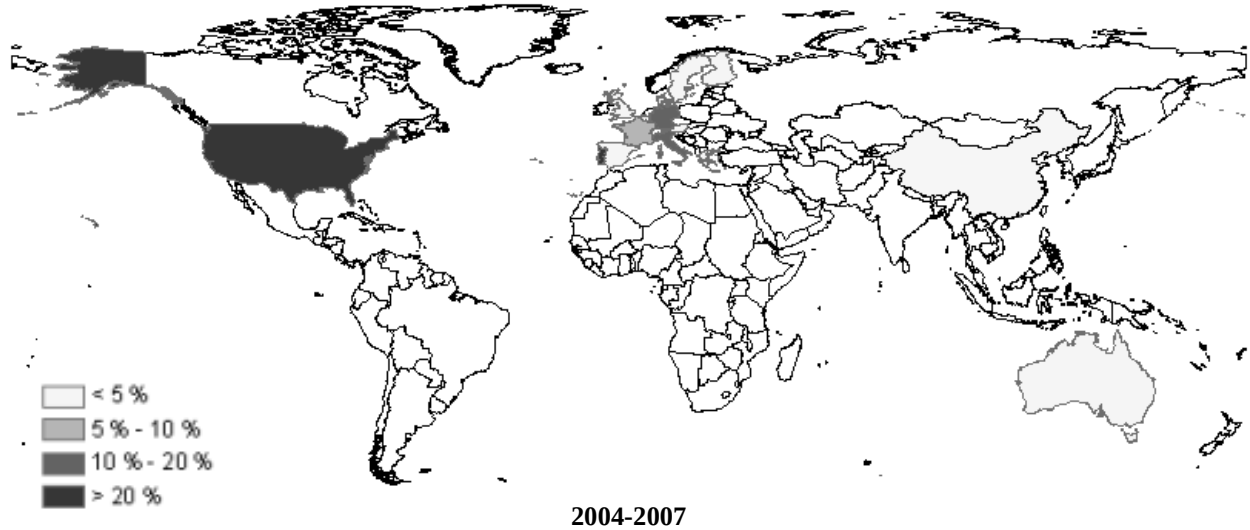
Again, the case of UTM, the telecommunications and multimedia unit, is much different, since it has only Portugal and the USA citing its scientific production in the first time interval, correspondingly, of about 25% and 75%, and still maintains two countries citing its scientific accomplishments between 2000 and 2003, namely Portugal (with a share of 42,9%) and Hong Kong (57,1%), but then widens its international knowledge-diffusing network, at the latest period of analysis, up to 17 countries (*cf.*, Figure 16). Between 2004 and 2007, Portugal still represents 27,6% of citations to this INESC Porto's unit, but to the USA corresponds a share of 22,1%, Germany takes a share of 13,8%, Italy gets 11,1% and France has 6,7% of total citations.

This dynamic analysis to the diffusion of knowledge of INESC Porto and its areas of scientific expertise shows us the widening and dynamics of INESC Porto geographical influence network, with different countries entering and exiting this network through the years. It is impressive the influence and impact of INESC Porto scientific production reflected in the range of countries associated to high technological and scientific accomplishments which have been citing and integrating INESC Porto's knowledge into their own R&D efforts.

UTM

1996-1999

2000-2003



2004-2007

Figure 16: Country's affiliation of authors citing UTM scientific production (in % of total), per four-year periods

3.5. 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. 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 for 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), on 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 such 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 an analysis of multiple regresses the predicted values cannot be interpreted as probabilities – they are not necessarily restricted 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, $\Pr ob(Y=1) = \dfrac{1}{1+e^{-\beta' X}}$, 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:

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

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 potential of international influence of the papers, and therefore, 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, *ceteris paribus*, it would present a higher probability to be cited in global terms or cited by foreign authors.

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:

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

$$+ \underbrace{\beta_4 Foreign_coauthor + \beta_5 Country_foreign_coauthor}_{International\ features} + \beta_6 Scientific_area + \varepsilon_i$$

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 another country, but not Portugal).

The estimates for the β*s* 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 includes citations by Portuguese (and INESC Porto's) 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 also be different.

Table 7: 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)			12.058 (0.149)	8.075 (0.426)	7.844 (0.449)
Nagelkerke R^2			0.383	0.450	0.293
Corrected			84.9	88.6	94.8

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

As presented in Table 7, 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 impact significantly on 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, negatively impacts 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 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 papers' 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 undertook 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 (USA, UK, Germany, to name a few). Quite unexpectedly, we observe that to have a paper which is co-authored with researchers affiliated in a foreign institution negatively and significantly impacts on INESC Porto's global influence, that is on the (log) odds of global citations, and have no impact whatsoever in 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's affiliated co-authors positively and significantly impacts 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 higher extent dependent on the intrinsic quality of the research produced than to be part of an international network of co-authorships. Although being capable of establishing (dense) networks with authors from other countries, which might reveal, *per se*, an indicator of the influence and impact of R&D institutions (as reported in Section 3.4.), the likelihood of these institution to constitute an effective source of international relevant scientific work for the area where it performs the corresponding activity does not depend from such networks, but rather from the quality itself of the scientific research it produces.

Conclusion

In the present study, we addressed the topic of assessment of 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 utmost, embraces rather intangible and wide ranging knowledge and information impacts, which frequently go beyond local or regional boundaries. We proposed a methodology, largely implemented within scientometrics and bibliometrics areas, which is based on the analyses of the patterns and evolution of an organisation's co-authorships and citations. Furthermore, our bibliometric-based method, instead of the local focus that characterizes 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 organization, 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 to the assessment of knowledge flows, which goes beyond useful but narrow economic outcomes, measuring the influence that an R&D organization (in this case, INESC Porto) has created among the global scientific area it operates.

More specifically, we described how INESC Porto knowledge network has evolved through 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 citations' patterns at a worldwide scale.

We gathered illuminating statistical evidence on how the geographical boundaries and dynamics of INESC Porto networks, as a whole, and its scientific working units, in

particular, have evolved in terms of co-authorships and citations. Moreover, we have demonstrated that the influence and impact of R&D organizations go beyond local boundaries, and evidenced a significant heterogeneity within the organization and its dynamics through time.

Notwithstanding the foreign collaborative pattern of INESC Porto's scientific production, and though the broad recognition of its scientific accomplishments, we showed, based on a multivariate econometric model, that the 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.

Although the exploratory statistical analysis, based on the mapping of geographical patterns and evolution of co-authorships and citations, provided interesting insights, the resort to more robust statistical tools, such as Social Network Analysis (SNA), would provide higher-level of qualitative results. Moreover, adding more knowledge producing and diffusing organisations to the analysis, by depicting network patterns of knowledge flows in a larger set of R&D institutions and universities, could permit to assess, for instance, the impact and influence of Portuguese or European R&D organisations. Triggering such topics would constitute, for sure, interesting and promising avenues for future research.

References

Abramo, Giovanni, and D'Angelo, Ciriaco Andrea (2007), Measuring science: Irresistible temptations, easy shortcuts and dangerous consequences, *Current Science*, Vol. 93, Nr. 6, pp. 762–766.

Adam, D. (2002), The counting house, *Nature*, Vol. 415, Nr. 6873, pp. 726–729.

Adams, J. D. (2006), Learning, internal research, and spillovers, *The Economics of Innovation and New Technology*, Vol. 15, Nr. 1, pp. 5-36.

Adams, James D., Black, Grant C., Clemmons, J. Roger, and Stephan, Paula E. (2005), Scientific teams and institutional collaborations: Evidence from U.S. universities, 1981–1999, *Research Policy*, Vol. 34, Nr. 3, pp. 259–285.

Agrawal, A., and Henderson, R. (2002), Putting Patents in Context: Exploring Knowledge Transfer from MIT, *Management Science*, Vol. 48, Nr. 1, pp. 44–60.

Aguillo, Isidro F., Granadino, Begoña, Ortega, José L., and Prieto, José A. (2006), Scientific Research Activity and Communication Measured With Cybermetrics Indicators, *Journal of the American Society for Information Science and Technology*, Vol. 57, Nr. 10, pp. 1296–1302.

Aksnes, Dag W. (2006), Citation Rates and Perceptions of Scientific Contribution, *Journal of the American Society for Information Science and Technology*, Vol. 57, Nr. 2, pp. 169–185.

Aksnes, Dag W., and Taxt, Randi Elisabeth (2006), Peer reviews and bibliometric indicators: a comparative study at a Norwegian university, *Research Evaluation*, Vol. 13, Nr. 1, pp. 33–41.

Allen, T. (1977), *Managing the Flow of Technology*, MIT Press, Cambridge, MA.

Antonelli, C. (1999), *The Microdynamics of Technological Change*, Routledge, London.

Archambault, Éric, and Gagné, Étienne Vignola (2004), *The Use of Bibliometrics in the Social Sciences and Humanities*, Final Report, Quebec, Canada: Science-Metrix.

Armstrong, H. W. (1993), The local income and employment impact of Lancaster University, *Urban Studies*, Vol. 30, Nr. 10, pp. 1653–1668.

Asai, Isao (1981), Adjusted Age Distribution and its Application to Impact Factor and Immediacy Index, *Journal of the American Society for Information Science*, Vol. 32, Nr. 3, pp. 172-174.

Audretsch, D. B. (1998), Agglomeration and the location of innovative activity, *Oxford Review of Economic Policy*, Vol. 14, Nr. 2, pp. 18-29.

Audretsch, D. B., and Feldman, M. P. (1996), R&D spillovers and the geography of innovation and production, *American Economic Review*, Vol. 86, Nr 3, pp. 630–640.

Bailetti, A., and Callahan, J. (1992), Assessing the Impact of University Interactions on an R&D Organisation, *R&D Management*, Vol. 22, Nr. 2, pp. 145–158.

Balconi, M., Breschi, S., and Lissoni, F. (2002), *Networks of inventors and the location of university research: an exploration of Italian data*, CESPRI, Working Paper nr. 127.

Bania, N., Clakins, L. N., and Dalenberg, D. R. (1992), The effects of regional science and technology policy on the geographical distribution of industrial R&D laboratories, *Journal of Regional Science*, Vol. 32, Nr. , pp. 209–228.

Bania, N., Eberts, R., and Fogarty, M. S. (1990), *Universities and the start-up of new companies: can we generalize from Route 128 and Silicon Valley?*, Working Paper Series, The Centre for Regional Economic Issues, Case Western Reserve University, Cleveland, Ohio.

Barabási, A. L., and Albert, R. (1999), Emergence of scaling in random networks, *Science*, Vol. 286, Nr. 5439, pp. 509-512.

Barabási, A. L., and Albert, R. (2000), Topology of evolving networks: Local events and universality, *Physical Review Letters*, Vol. 85, Nr. 24, pp. 5234-5237.

Barrios, Salvador, Mas, Matilde, Navajas, Elena, and Quesada, Javier (2008), Mapping the ICT in EU Regions: Location, Employment, Factors of Attractiveness and

Economic Impact, European Commission, *JRC Scientific and Technical Reports EU 23067*, pp. 1–113.

Bayoumi, T., Coe, D. T., and Helpman, E. (1996), R&D spillovers and global growth, *Working Paper no. 79*, The Canadian Institute for Advanced Research, Toronto.

Beaver, D. (2001), Reflections on scientific collaboration (and its study): past, present and future, *Scientometrics*, Vol. 52, Nr. 3, pp. 365–377.

Beck, R., Curry, P., Elliot, D., Levin, Meisel J., Vinson, R., and Wagner, M. (1993) *The economic impact of Southern Illinois University*, Revised Internal Report, Department of Economics, Southern Illinois University, Edwardsville, IL, USA.

Beeson, P., and Montgomery, E. (1990), The effects of colleges and universities on local labour markets, *NBER Working Paper Nr. 3280*, Cambridge MA, USA.

Bessette, Russell W. (2003), Measuring the Economic Impact of University-Based Research, *Journal of Technology Transfer*, Vol. 28, pp. 355–361.

Bilbao-Osorio, B., and Rodríguez-Pose, A. (2004), From R&D to Innovation and Economic Growth in the EU, *Growth and Change*, Vol. 35, Nr. 4, pp. 434–455.

Blanchard, Antoine (2007), Understanding and customizing stopword lists for enhanced patent mapping, *World Patent Information*, Vol. 29, pp. 308–316.

Bluestone, Barry (1993), UMASS / Boston, An Economic Impact Analysis, *Report 140*, University of Massachusets, Boston: USA.

Bornmann, Lutz, Mutz, Rüdiger, Neuhaus, Christoph, and Daniel, Hans-Dieter (2008), Citation counts for research evaluation: standards of good practice for analyzing bibliometric data and presenting and interpreting results, *Ethics in Science and Environmental Politics*, Vol. 8, Nr. 1, pp. 93–102.

Bozeman, Barry, and Melkers, J. (1993), *Evaluating R&D Impacts: Methods & Practice, Boston*, MA: Kluwer Academic Publishers.

Bozeman, Barry, Dietz, J., and Gaughan, M. (2001), Scientific and technical human capital: an alternative model for research evaluation, *International Journal of Technology Management*, Vol. 22, Nr. 7/8, pp. 636–655.

Bozeman, Barry, and Corley, Elizabeth (2004), Scientists' collaboration strategies: implications for scientific and technical human capital, *Research Policy*, Vol. 33, Nr. 4, pp. 599–616.

Bozeman, Barry, Dietz, James S., and Gaughan, Monica (2001), Scientific and Technical Human Capital: An Alternative Model for Research Evaluation, *International Journal of Technology Management*, Vol. 22, Nr. 7-8, pp. 716–740.

Braun, T., and Glänzel, W. (1995), On a Source of Error in Computing Journal Impact Factors, *Chemical Intelligencer*, Vol. 1, pp. 31-32.

Braun, T., Glänzel, W., and Schubert, A. (2000), How balanced is the Science Citation Index's journal coverage? A preliminary overview of macro level statistical data, In Cronin, B., Atkins, H. B. (eds), *The Web of Knowledge: A Festschrift in Honor of Eugene Garfield*, Medford, NJ: Information Today, pp. 251–277.

Braunerhjelm, Pontus (2008), Specialization of Regions and Universities: The New *Versus* the Old, *Industry & Innovation*, Vol. 15, Nr. 3, pp. 253–275.

Brownrigg, M. (1973), The economic impact of a new university, *Scottish Journal of Political Economy*, Vol. 20, Nr, 2, pp. 123–139.

Brusoni, S., Prencipe, A., and Pavitt, K. (2000), Knowledge Specialization and the Boundaries of the Firm: Why Do Firms Know More Than They Make?, *Administrative Science Quarterly*, Vol. 46, Nr. 4, pp. 597-621.

Bush, G. P., and Hattery, L. H. (1956), Teamwork and creativity in research, *Science Quarterly*, Vol. 1, Nr. 3, Special Issue on the Administration of Research, pp. 361–372.

Buxton, Martin, Hanney, Steve, and Jones, Teri (2004), Estimating the economic value to societies of the impact of health research: a critical review, *Bulletin of the World Health Organisation*, Vol. 82, Nr. 10, pp. 733–739.

Caffrey, B., and Isaacs, P. (1971), *Estimating the Impact of a College or University on the Local Economy*, Washington, D.C., American Council on Education.

Calvert, J., and Patel, P. (2003), University-industry research collaborations in the UK: bibliometric trends, *Science and Public Policy*, Vol. 30, Nr. 2, pp. 85–96.

Campbell, F. B. F. (1896), *The Theory of the National and International Bibliography: with Special Reference to the Introduction of System in the Record of Modern Literature*, London, England: Library Bureau.

Cantner, Uwe, and Graf, Holger (2006), The network of innovators in Jena: An application of social network analysis, *Research Policy*, Vol. 35, Nr. 4, pp. 463–480.

Cantwell, John (Ed.) (2006), *The Economics of Patents. The Patent System and The Measurement of Invention*, The International Library of Critical Writings in Economics 197, Vol. I, Northampton, MA, USA: Elgar.

Carayole, Nicolas, and Roux, Pascale (2003), Self-Organizing Innovation Networks: When do Small Worlds Emerge?, *Working Papers of GRES - Cahiers du GRES*, Groupement de Recherches Economiques et Sociales, Nr. 2003-08.

Carmona, Salvador, García-Ferrer, Antonio, and Poncela, Pilar (2005), From Zero to Infinity: The Use of Impact Factors in the Evaluation of Economic Research in Spain, *Instituto de Empresa Business School Working Paper*, WP05-22.

Casson, Mark, and Della Giusta, Marina (Eds.) (2008), *The Economics of Networks*, The International Library of Critical Writings in Economics, Northampton, MA, USA: Elgar.

Chung, Kee H., and Cox, Raymond A. K. (1990), Patterns of Productivity in the Finance Literature: A Study of the Bibliometric Distributions, *The Journal of Finance*, Vol. 45, Nr. 1, pp. 301–309.

Coe, David T., and Helpman, Elhanan (1995), International R&D Spillovers, *European Economic Review*, Vol. 39, Nr. 5, pp. 859–887.

Comité national d'évaluation de la recherche – CNER (2002), *Évaluation de la recherche publique dans les établissements publics français*. Paris: CNER.

Conroy, M., and Dusansky, R. (1995), The productivity of economics departments in the U.S.: publications in the core journals, *Journal of Economic Literature*, Vol. 33, Nr. 4, pp. 1966–1971.

Coronado, Daniel, Acosta, Manuel, and León, Dolores (2004), Regional Planning of R&D and Science-Technology Interactions in Andalucia: A Bibliometric Analysis of Patent Documents, *European Planning Studies*, Vol. 12, Nr. 8, pp. 1075–1095.

Cowan, R., and Jonard, N. (2001), Knowledge creation, knowledge diffusion and network structure, in A. Kirman and J.B. Zimmermann (Eds.), *Economies with Heterogenous Interacting Agents*, Springer.

Cox, Raymond A. K., and Chung, Kee H. (1991), Patterns of Research Output and Author Concentration in the Economics Literature, *The Review of Economics and Statistics*, Vol. 73, Nr. 4, pp. 740-747.

Cox, Sue, and Taylor, Jim (2006), The Impact of a Business School on Regional Economic Development: a Case Study, *Local Economy*, Vol. 21, Nr. 2, pp. 117–135.

Cozzens, Susan E. (1989), What Do Citations Count? The Rhetoric-First Model, *Scientometrics*, Vol. 15, Nr. 5–6, pp. 437–447.

Daniel, Hans-Dieter (2005), Publications as a measure of scientific advancement and of scientists' productivity, *Learned Publishing*, Vol. 18, Nr. 2, pp. 143–148.

Daniel, Hans-Dieter, and Fisch, R. (1990), Research performance evaluation in the German university sector, *Scientometrics*, Vol. 19, Nr. 5–6, pp. 349–361.

Davelaar, E. J., and Nijkamp, P. (1989), The role of the metropolitan milieu as an incubation centre for technological innovations: a Dutch case study, *Urban Studies*, Vol. 26, Nr. 5, pp. 517–525.

David, P. A., and Foray, D. (1994), Percolation structures, Markov random fields and the economics of EDI standard diffusion, in Pogorel (Ed.), *Global Telecommunication Strategies and Technological Changes*, North-Holland, Amsterdam, pp. 135-170.

Denison, E. F. (1968), Measuring the economic contribution of education and the 'residual' to economic growth, in Bowman, M. J. (Eds.), *Readings in the Economics of Education*, Paris: UNESCO, pp. 315–317.

Dietz, James S., and Bozeman, Barry (2005), Academic careers, patents, and productivity: industry experience as scientific and technical human capital, *Research Policy*, Vol. 34, pp. 349–367.

Dorsett, R. A., and Weiler, W. C. (1982), The impact of an institution's federal research grants on the economy of its state, *Journal of Higher Education*, Vol. 53, Nr. 4, pp. 419–428.

Dosi, G. (1988), Sources, procedures and microeconomic effects of innovation, *Journal of Economic Literature*, Vol. 26, Nr. 3, pp. 1120–1171.

Elliot, D. S., and Meisel, J. B. (1987), *The economic impact study of Southern Illinois University at Edwardsville on the St Louis metropolitan area, 1986*, Department of Economics, Southern Illinois University at Edwardsville.

Evangelista, R., Iammarino, S., Mastrostefano, V., and Silvani, A. (2002), Looking for regional systems of innovation: Evidence from the Italian innovation survey, *Regional Studies*, Vol. 36, Nr. 2, pp. 173–186.

Fairthorne, R. A. (1969), Empirical hyperbolic distributions (Bradford-Zipf-Mandelbrot) for bibliometric description and prediction, *Journal of Documentation*, Vol. 25, Nr. 4, pp. 319–343.

Feldman, M. P. (1994), The university and economic development: the case of John Hopkins University and Baltimore, *Economic Development Quarterly*, Vol. 8, Nr. 1, pp. 67–76.

Feller, Irwin (1990), Universities as engines of R&D-based economic growth: they think they can, *Research Policy*, Vol. 19, Nr. 4, pp. 335–348.

Felsenstein, D. (1996), The university in the metropolitan arena: impacts and public policy implications, *Urban Studies*, Vol. 33, Nr. 9, pp. 1565–1580.

Filion, Kristian, and Pless, I. Barry (2008), Factors related to the frequency of citation of epidemiologic publications, *Epidemiologic Perspectives & Innovations*, Vol. 5, Nr. 3 (doi:10.1186/1742-5573-5-3).

Florax, R. (1992), *The University: A Regional Booster?*, Aldershot: Avebury.

Forrant, Robert (2001), Pulling Together in Lowell: The University and the Regional Development Process, *European Planning Studies*, Vol. 9, Nr. 5, pp. 613–628.

Gagnol, Laurent, and Héraud, Jean-Alain (2001), Impact Économique Régional d'un Pôle Universitaire: Application au Cas Strasbourgeois, *Working Paper BETA*, Université Louis Pasteur, Strasbourg.

Garfield, Eugene (1972), Citation analysis as a tool in journal evaluation: journals can be ranked by frequency and impact of citations for science policy studies, *Science*, Vol. 178, Nr. 4060, pp. 471–479.

Garfield, Eugene (1977), "The 'Obliteration Phenomenon' In Science – And the Advantage of Being Obliterated!", In *Essays Of An Information Scientist*, Chapter 2, Philadelphia, USA: ISI Press.

Garfield, Eugene (1979), *Citation Indexing-Its Theory and Application in Science, Technology, and Humanities*, New York, USA: Wiley.

Garfield, Eugene (1986), "Uses And Misuses of Citation Frequency", In *Essays of an Information Scientist*, Chapter 8, Philadelphia, USA: ISI Press.

Garfield, Eugene (1996), *SCI Journal Citation Reports: A Bibliometric Analysis of Science Journals in the ISI Database*, Philadelphia, Pennsylvania: Institute for Scientific Information, Inc.

Garfield, Eugene (1996), The significant scientific literature appears in a small core of journals, *The Scientist*, Vol. 10, Nr.17, pp. 13.

Garfield, Eugene, and Welljamsdorof, A. (1992), Citation data: their use as quantitative indicators for science and technology evaluation and policy-making, *Science & Public Policy*, Vol. 19, Nr, 5, pp. 321–327.

Garfield, Eugene, and Welljamsdorof, A. (1992), Citation data: their use as quantitative indicators for science and technology evaluation and policy-making, *Science & Public Policy*, Vol. 19, Nr. 5, pp. 321–327.

Garfield, Eugene, Malin, M. V., and Small, H. (1978), Citation data as science indicators, In: Elkana, Y., Lederberg, J., Merton, R. K., Thackray, A., and Zuckerman, H. (Eds), *Toward a metric of science: the advent of science indicators*, New York: John Wiley, pp. 179–207.

Garlick, Steve, Davies, Gordon, Polèse, Mario, and Kitagawa, Fumi (2006), *Supporting the Contribution of Higher Education Institutions to Regional Development - Peer Review Report: Atlantic Canada*, Paris: Organisation for Economic Co-operation and Development.

Gibbons, Michael, Limoges, Camille, and Nowotny, Helga (1994), *The new production of knowledge: The dynamics of science and research in contemporary societies*, Sage Publications, London.

Glänzel, W., and Schoepflin, U. (1995), A Bibliometric Study on Ageing and Reception Processes of Scientific Literature, *Journal Of Information Science*, Vol. 21, Nr. 1, pp. 37-53.

Glänzel, W., and Schoepflin, U. (1999), A Bibliometric Study of Reference Literature in the Sciences and Social Sciences, *Information Processing and Management*, Vol. 35, Nr. 1, pp. 31-44.

Glänzel, W., Schubert, A., and Czerwon, H.-J. (1999), A Bibliometric Analysis of International Scientific Cooperation of the European Union (1985-1995), *Scientometrics*, Vol. 45, Nr. 2, pp. 185–202.

Glänzel, Wolfgang (2001), National characteristics in international scientific co-authorship relations, *Scientometrics*, Vol. 51, Nr. 1, pp. 69-115.

Goddard, J., Charles, D., Pike, A., Potts, G., and Bradley, D. (1994), *Universities and Communities*, Committee of Vice Chancellors and Principals of the Universities of the United Kingdom, London, and Centre for Urban and Regional Development Studies, University of Newcastle.

Godin, B. (1993), *The relationship between science and technology: a bibliometric analysis of papers and patents in innovative firms*, unpublished D. Phil thesis, University of Sussex.

Godin, B. (1995), Research and the practice of publication in industries, R*esearch Policy*, Vol. 25, Nr. 4, pp. 587-606.

Goldstein, H. A. (1989–90), Estimating the regional economic impact of universities: an application of input-output analysis, *Planning for Higher Education*, Vol. 18, Nr. 1, pp. 51–64.

Grandstrand, O., Patel, P., and Pavitt, K. (1997), Multi-technology corporations: why they have 'distribute' rather than 'distinctive core' capabilities, *California Management Review*, Vol. 39, Nr. 4, pp. 8-25.

Greene, W. H. (2000), *Econometric Analysis*, 4th edition, New Jersey: Prentice Hall.

Harloe, Michael, and Perry, Beth (2004), Universities, Localities and Regional Development: The Emergence of the 'Mode 2' University ?, *International Journal of Urban and Regional Research*, Vol. 28, Nr. 1, pp. 212–223.

Hedrick, D. W, Henson, S. E., and Mack, R. S. (1990), The effects of universities on local retail, service and F.I.R.E. employment: some cross-sectional evidence, *Growth and Change*, Vol. 21, Nr. 3, pp. 9–20.

Helpman, Elhanan (1997), R&D and Productivity: the International Connection, *NBER Working Paper Series*, Working Paper 6101.

Henderson, R., Jaffe, A. B., and Trajtenberg, M. (1998), Universities as a source of commercial technology: a detailed analysis of university patenting, 1965-1988, *Review of Economics and Statistics*, Vol. 80, Nr. 1, pp. 119–127.

Hicks, D. (1999), The difficulty of achieving full coverage of international social science literature and the bibliometric consequences, *Scientometrics*, Vol. 44, Nr. 2, pp. 193–215.

Hong, Wei (2008), Decline of the centre: The decentralizing process of knowledge transfer of Chinese universities from 1985 to 2004, *Research Policy*, Vol. 37, Nr. 4, pp. 580–595.

Hood, William W., and Wilson, Concepción S. (2001), The literature of bibliometrics, scientometrics, and informetrics, *Scientometrics*, Vol. 52, Nr. 2, pp. 291–314.

Horta, Hugo (2008), On Improving the University Research Base: The Technical University of Lisbon Case in Perspective, *Higher Education Policy*, Vol. 21, pp. 123–146.

Hu, Albert G.Z., and Jaffe, Adam B. (2003), Patent citations and international knowledge flow: the cases of Korea and Taiwan, *International Journal of Industrial Organisation*, Vol. 21, Nr. 6, pp. 849–880.

Huggins, Robert, and Cooke, Philip (1997), The economic impact of Cardiff University: innovation, learning and job generation, *GeoJournal*, Vol. 41, Nr. 4, pp. 325–337.

Hussler, Caroline, and Rondé, Patrick (2007), The impact of cognitive communities on the diffusion of academic knowledge: Evidence from the networks of inventors of a French university, *Research Policy*, Vol. 36, Nr. 2, pp. 288–302.

INESC Porto (2008a), *Activity Plan of INESC Porto Units*, Porto, Portugal: INESC Porto.

INESC Porto (2008b), *Manual de Acolhimento do INESC Porto*, Porto, Portugal: INESC Porto.

INESC Porto (2008c), *Scientific Advisory Board Report*, Porto, Portugal: INESC Porto.

Jackson, M. O., and Watts, A. (2002), The evolution of social and economic networks, *Journal of Economic Theory*, Vol. 106, Nr. 2, pp. 265–295.

Jackson, M.O., and Wolinsky, A. (1996), A strategic model of social and economic networks, *Journal of Economic Theory*, Vol. 71, Nr. 1, pp. 44–74.

Jaffe, Adam B., Trajtenberg, M., and Henderson, R. (1993), Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations, *The Quarterly Journal of Economics*, Vol. 108, Nr. 3, pp. 577-98.

Jaffe, Adam B., and Trajtenberg, Manuel (1999), International Knowledge Flows: Evidence From Patent Citations, *Economics of Innovation and New Technology*, Vol. 8, Nr. 1, pp. 105–136.

Kalaitzidakis, P., Mamuneas, T. P. and Stengos, T. (2003), Rankings of academic journals and institutions in economics, *Journal of the European Economic Association*, Vol. 1, Nr. 6, pp. 1346–1366.

Kandori, M., Mailath, G., and Rob, R. (1993), Learning, mutation and long run equilibria in games, *Econometrica*, Vol. 61, Nr. 1, pp. 29–56.

Katz, J. S., and Hicks, D. (1998), Indicators for Systems of Innovation - a Bibliometrics-based Approach, Oslo: STEP Group, *IDEA Paper Series*, Vol. IV, Nr. 12, pp. 66.

Katz, Sylvan, and Martin, B. R. (1997), What is 'research collaboration'?, *Research Policy*, Vol. 26, Nr. 1, pp. 1–18.

King, David A. (2004), The scientific impact of nations: what different countries get for their research spending, *Nature*, Vol. 430, Nr. 6997, pp. 311–316.

Kochen, Manfred (1974), *Principles of Information Retrieval*, Los Angeles: Melville, pp. 74.

Kopcsa, Alexander, and Schiebel, Edgar (1998), Science And Technology Mapping: A New Iteration Model For Representing Multidimensional Relationships, *Journal of the American Society for Information Science*, Vol. 49, Nr. 1, pp. 7–17.

Kostoff, R. N. (2002), Citation analysis of research performer quality, *Scientometrics*, Vol. 53, Nr. 1, pp. 49–71.

Kuhn, Thomas Samuel (1962), *The Structure of Scientific Revolutions*, Chicago: University of Chicago Press.

Kuznets, Simon (1966), *Modern Economic Growth*, New Haven: Yale University Press.

Langlais, R. N. (1997), Transaction costs economics in real time, *Industrial and Corporate Change*, Vol. 1, Nr. 1, pp. 99–127.

Lawani, S. M. (1986), Some bibliometric correlates of quality in scientific research, *Scientometrics*, Vol. 9, Nr. 1–2, pp. 13–25.

Leydesdorff, Loet (2001), *The Challenge of Scientometrics: The Development, Measurement, and Self-Organisation os Scientific Communications*, Second Edition, USA: Universal Publishers.

Leydesdorff, Loet, and Meyer, Martin (2003), The Triple Helix of university-industry-government relations, *Scientometrics*, Vol. 58, Nr. 2, pp. 191–203.

Lichtenberg, F. R. (1993), R&D investment and international productivity differences, *NBER Working Paper N. 4161*.

Link, A. N. (1999), A Suggested Method for Assessing the Economic Impacts of University R&D: Including Identifying Roles for Technology Transfer Officers, *Journal of the Association of University Technology Managers*, Vol. 11, pp. 1–17.

Love, J. H., and McNicoll, I. H. (1988), The Regional Economic Impact of Overseas Students in the UK: A Case Study of Three Scottish Universities, *Regional Studies*, Vol. 22, Nr.1, pp. 11–18.

Luukkonen, Terttu, Tijssen, R. J. W., Persson, O., and Sivertsen, G. (1993), The measurement of international scientific collaboration, *Scientometrics*, Vol. 28, Nr. 1, pp. 15-36.

MacGarvie, Megan (2005), The determinants of international knowledge diffusion as measured by patent citations, *Economics Letters*, Vol. 87, Nr. 1, pp. 121–126.

Malecki, E. J. (1987), The R&D location decision of the firm and 'creative' regions, *Technovation*, Vol.6, Nr. 3, pp. 205–222.

Marginson, Simon, and van der Wende, Marijk (2007), *Globalisation and Higher Education*, Education Working Paper No. 8, Paris: Organisation for Economic Co-operation and Development.

Markusen, A. R., Hall, P., and Glasmeier, A. (1986), *High-tech America: The What, How, Where and Why of the Sunrise Industries*, Boston: Allen and Unwin.

Marques, J. P. C., Caraça, J. M. G., and Diz, H. (2006), How can university–industry–government interactions change the innovation scenario in Portugal?—the case of the University of Coimbra, *Technovation*, Vol. 26, Nr. 4, pp. 534–542.

Martin, Fernand (1998), The economic impact of Canadian university R&D, *Research Policy*, Vol. 27, pp. 677–687.

May, Robert M. (1997), The scientific wealth of nations, *Science*, Vol. 275, Nr. 5301, pp. 793–796.

Merton, Robert K. (1968), The Matthew Effect in Science, *Science*, Vol. 159, Nr. 3810, pp. 56-63.

Merton, Robert K. (1988), The Matthew Effect in Science, II: Cumulative advantage and the symbolism of intellectual property, *Isis*, Vol. 79, Nr. 4, pp. 606-623.

Merton, Robert K. (1995), The Thomas Theorem and the Matthew Effect, *Social Factors*, Vol. 74, Nr. 2, pp. 379-422.

Meyer, M. (2000a), Does science push technology? Patents citing scientific literature, *Research Policy*, Vol. 29, Nr. 3, pp. 409–434,

Meyer, M. (2000b), What is special about patent citations? Differences between scientific and parent citations. *Scientometrics*, Vol. 49, Nr. 1, pp. 93–123.

Meyer, M. (2004), Measuring the Impact of Science, *Engineering Management Conference, 2004. Proceedings, 2004 IEEE International*, Vol. 1, pp. 377–381.

Milgram, S. (1967), The small world problem, *Psychology Today*, Vol. 2, pp. 60–67.

Ministry of Science, Technology and Higher Education – MSTHE (2006), *Tertiary Education in Portugal – Background Report*, Lisbon: Organisation for Economic Co-operation and Development.

Moed, H. F., and Van Leeuwen, Th. N. (1995), Improving the Accuracy of the Institute for Scientific Information's Journal Impact Factor, *Journal of the American Society for Information Science*, Vol. 46, Nr. 6, pp. 461-467.

Moed, H. F., and Van Leeuwen, Th. N. (1996), Impact Factors Can Mislead, *Nature*, Vol. 381, Nr. 6579.

Moed, H. F., Van Leeuwen, Th. N., and Reedijk, J. (1998), A New Classification System to Describe the Ageing of Scientific Journals and their Impact Factors, *Journal of Documentation*, Vol. 54, Nr. 4, pp. 387-419.

Moed, Henk F. (2005a), *Citation Analysis in Research Evaluation*, Dordrecht, The Netherlands: Springer.

Moed, Henk F. (2005b), Citation analysis of scientific journals and journal impact measures, *Current Science*, Vol. 89, Nr. 12, pp. 1990–1996.

Moore, C. L., and Suffrin, S. C. (1974), Syracuse University : the impact of a nonprofit institution on regional income, *Growth and Change*, Vol. 51, Nr. 1, pp. 36–40.

Moore, G. A. (1979), Local income generation and regional income redistribution in a system of public higher education, *Journal of Higher Education*, Vol. 50, Nr. 3, pp. 334–348.

Nalimov, V. V., and Mulchenko, Z. M. (1969), *Naukometriya, Izuchenie Razvitiya Nauki kak Informatsionnogo Protsessa* [Scientometrics, Study of the Development of Science as an Information Process], Moscow: Nauka (English translation: 1971, Washington, D.C.: Foreign Technology Division, U.S. Air Force Systems Command, Wright-Patterson AFB, Ohio, NTIS Report Nr. AD735–634).

Narin, F., Hamilton, K. S., and Olivastro, D. (1995), Linkage between agency supported research and patented industrial technology, *Research Evaluation*, Vol. 5, Nr. 3, pp. 183–187.

Narin, F., Hamilton, K. S., and Olivastro, D. **(**1997), The increasing linkage between U.S. technology and public science, *Research Policy*, Vol. 26, Nr. 3, pp. 317-330.

Nederhof, A. J., and Zwaan R. A. (1991), Quality Judgments of Journals as Indicators of Research Performance in the Humanities and the Social and Behavioural Sciences, *Journal of the American Society for Information Science*, Vol. 42, Nr. 5, pp. 332–340.

Neuhaus, Christoph, and Daniel, Hans-Dieter (2008), Data sources for performing citation analysis: an overview, *Journal of Documentation*, Vol. 64, Nr. 2, pp. 193–210.

Newlands, David (2003), The Role of Universities in Learning Regions, Paper presented at the 43rd European Regional Science Association Congress, Paper Nr. 398.

Newman, M. E. J., Watts, D. J., and Strogatz, S. H. (2001), Random graphs models of social networks, *PNAS – Proceedings of the National Academy of Science*, Nr. 99, pp. 2566-2572.

Okubo, Y., Miquel, J. F., Frigoletto, L., and Doré, J.C. (1992), Structure of international collaboration in science: Typology of countries through multivariate techniques using a link indicator, *Scientometrics*, Vol. 25, Nr. 2, pp. 321-351.

Oosterlinck, A. (2001), *University/Industry Knowledge Management: A University Perspective*, Paris: Organisation for Economic Co-operation and Development.

Persson, Olle (2001), All author citations *versus* first author citations, *Scientometrics*, Vol. 50, Nr. 2, pp. 339-344.

Pinski, G., and Narin, F. (1976), Citation Influence for Journal Aggregates of Scientific Publications: Theory, with Application to the Literature of Physics, *Information Processing and Management*, Vol. 12, Nr. 5, pp. 297-312.

Podolny, Joel M., and Stuart, Toby E. (1995), A Role-Based Ecology of Technological Change, *The American Journal of Sociology*, Vol. 100, Nr. 5, pp. 1224–1260.

Price, Derek J. de Solla (1963), *Little Science, Big Science*, Columbia University Press, New York.

Price, Derek J. de Solla (1965), Networks of Scientific Papers, *Science*, Vol. 149, Nr. 3683, pp. 510–515.

Pritchard, A. (1969), Statistical bibliography or bibliometrics?, *Journal of Documentation*, Vol. 25, Nr. 4, pp. 348–349.

Pritchard, A., and Wittig, G. R. (1981)**,** *Bibliometrics: a bibliography and index*, Volume 1: 1874-1959, Watford, Hertfordshire, England: ALLM Books.

Ramlogan, Ronnie, Mina, Andrea, Tampubolon, Gindo, and Metcalfe, J. Stanley (2007), Networks of knowledge: The distributed nature of medical innovation, *Scientometrics*, Vol. 70, Nr. 2, pp. 459–489.

Rego, Maria (2004), Universities and economically depressed regions: how strong is the influence of the University of Évora on the human capital of the region?, Paper presented at the 44th European Regional Science Association Congress.

Romer, P. (1986), Increasing returns and long-run growth, *Journal of Political Economy*, Vol. 94, Nr. 5, pp. 1002–1037.

Rosen, M. I., Strang, W. A., and Kramer, J. (1985), The University of Wisconsin – Madison and the local and state economies: a second look, *Monograph Nr. 20*, Graduate School of Business, University of Wisconsin, Madison.

Sampat, Bhaven N., Mowery, David C., Ziedonis, Arvids A. (2003), Changes in university patent quality after the Bayh–Dole act: a re-examination, *International Journal of Industrial Organisation*, Vol. 21, Nr. 9, pp. 1371–1390.

Saxenian, A. (1994), *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*, Harvard University Press, Cambridge.

Scherer, F. M. (1982), Inter-industry technology flows in the United States, *Research Policy*, Vol. 11, Nr. 4, pp. 227–245.

Schildt, Henri A., and Mattsson, Juha T. (2006), A dense network sub-grouping algorithm for co-citation analysis and its implementation in the software tool *Sitkis*, *Scientometrics*, Vol. 67, Nr. 1, pp. 143–163.

Schott, Thomas (1998), Ties between centre and periphery in the scientific world system: accumulation of rewards, dominance and self-reliance in the centre, *Journal of World Systems Research*, Vol. 4.

Schubert, A., and Braun, T. (1996), Cross-field normalization of scientometric indicators, *Scientometrics*, Vol. 36, Nr. 3, pp. 311–324.

Schubert, A., and Glänzel, W. (1986), Mean Response Time – A New Indicator of Journal Citation Speed with Application to Physics Journals, *Czechoslovak Journal of Physics*, Vol. 36, Nr. 1, pp. 121-125.

Schutte, Frits (1999), The University-Industry Relations of an Entrepreneurial University: the Case of the University of Twente, *Higher Education in Europe*, Vol. 24, No. 1, pp. 47–65.

Schwarz, A. Winkel, Schwarz, S., Tijssen, R. J. W. (1998), Research and Research Impact of a Technical University – A Bibliometric Study, *Scientometrics*, Vol. 41, Nr. 3, pp. 371-388.

Scott, L., and Mitias, P. (1996), Trends in rankings of economics departments in the U.S.: an update, *Economic Inquiry*, Vol. 34, Nr. 2, pp. 378–400.

Sengupta, I. N. (1992), Bibliometrics, informetrics, scientometrics and librametrics: an overview, *Libri*, Vol. 42, Nr. 2, pp. 75–98.

Siegfried, John J., Sanderson, Allen R., and McHenry, Peter (2007), The economic impact of colleges and universities, *Economics of Education Review*, Vol. 26, pp. 546–558.

Silva, João Albino, and Santos, Sérgio (2006), Using Input-output Analysis to Estimate the Regional Economic Impact of Universities: A Case Study, *Proceedings of the Internacional EcoMod Conference: Regional and Urban Modelling*, Brussels, Belgium, 1-3 June.

Silva, João Albino, Santos, Sérgio, and Gomes, Luís (2000), *O Impacte do Ensino Superior Público na Região do Algarve 2000*, Faro: Fundação para o Desenvolvimento da Universidade do Algarve.

Simha, O. Robert (2005), The Economic Impact Of Eight Research Universities On The Boston Region, *Tertiary Education and Management*, Vol. 11, pp. 269–278.

Simonyi, Agnes (1999), The Evaluation of University-Region Relationships [1], *European Journal of Education*, Vol. 34, Nr. 3, pp. 335–341.

Smilor, R. W., Gibson, D. V. and Dietrich, G. B. (1990), University spin-out companies: technology start-ups from UT-Austin, *Journal of Business Venturing*, Vol. 5, Nr. 1, pp. 63–76.

Smith, K. (Ed.), Ekeland, A, Iversen, E, Kaloudis, A, Patel, P, and Narula, R (1998), Science, Technology and Innovation Indicators – A Guide for Policy-Makers, *IDEA Paper Series Nr. 5*, Oslo: STEP Group.

Smith, Linda C. (1981), Citation analysis, *Library Trends*, Vol. 30, Nr. 1, pp. 83–106.

Steinacker, Annette (2005), The Economic Effect of Urban Colleges on their Surrounding Communities, *Urban Studies*, Vol. 42, Nr. 7, pp. 1161–1175.

Steinnes, D. M. (1987), On understanding and evaluating the university's evolving economic development role, *Economic Development Quarterly*, Vol. 1, pp. 214–225.

Stephan, Paula E., and Audretsch, David B. (Eds.) (2000), *The Economics of Science and Innovation*, The International Library of Critical Writings in Economics, Vol. I, Northampton, MA, USA: Elgar.

Stichweh, Rudolf (1996), Science in the system of world society, Social Science Information, Vol. 35, Nr. 2, pp. 327–340.

Swenson, David, and Eathington, Liesl (2007), *The Economic Impacts of Iowa State University in Fiscal 2006*, Iowa State University.

Tague-Sutcliffe, J. M. (1992), An introduction to informetrics, *Information Processing and Management*, Vol. 28, Nr. 1, pp. 1–3.

Tavoletti, Ernesto (2007), Assessing the Regional Economic Impact of Higher Education Institutions: An Application to the University of Cardiff, *Transition Studies Review*, Vol. 14, Nr.3, pp. 507–522.

Teixeira, Aurora A. C. (2006), Vinte anos (1985-2005) dos *Working Papers* da FEP: um estudo sobre a respectiva probabilidade de publicação nacional e internacional, *Working Paper FEP*, CEMPRE, Faculdade de Economia, Universidade do Porto, Portugal.

Teixeira, Aurora A. C., and Costa, Joana (2006), What type of firm forges closer innovation linkages with Portuguese Universities?, *Notas Económicas*, Nr. 24, pp. 22–47.

Thorne, Frederick C. (1977), The Citation Index: Another Case of Spurious Validity, *Journal of Clinical Psychology*, Vol. 33, Nr. 4, pp. 1157–1161.

Tomer, C. (1986), A Statistical Assessment of Two Measures of Citation: The Impact Factor and the Immediacy Index, *Information Processing and Management*, Vol. 22, Nr. 3, pp. 251-258.

Trajtenberg, M. (1990), *Economic analysis of product innovation*, Cambridge: Cambridge University Press.

Uren, Victoria, Shum, Simon Buckingham, Bachler, Michelle, and Li, Gangmin (2006), Sensemaking tools for understanding research literatures: Design, implementation and user evaluation, *International Journal of Human-Computer Studies*, Vol. 64, Nr. 5, pp. 420–445.

Valente, T. (1996), Social network thresholds in the diffusion of innovations, *Social Networks*, Vol. 18, Nr. 1, pp. 69-89.

Van den Berghe, Herman, Houben, Josee A., de Bruin, Renger E., Moed, Henk F., Kint, Andre, Luwel, Marc, and Spruyt, Eric H. J. (1998), Bibliometric Indicators of University Research Performance in Flanders, *Journal of the American Society for Information Science*, Vol. 49, Nr. 1, pp. 59-67.

Van Leeuwen, Th. N., van der Wurff, L. J., and van Raan, A. F. J. (2001), The use of combined bibliometric methods in research funding policy, *Research Evaluation*, Vol. 10, Nr. 3, pp. 195–201.

Van Leeuwen, Th. N., Moed, H. F., and Reedijk, J. (1997), *JACS* Still Topping *Angewandte Chemie*: Beware Of Erroneous Impact Factors, *Chemical Intelligencer*, Vol. 3, pp. 32-36.

van Raan, A. F. J. (2003), The use of bibliometric analysis in research performance assessment and monitoring of interdisciplinary scientific developments, *Technikfolgenabschätzung*, Vol. 12, Nr. 1, pp. 20–29. English translation available on the 1st December, 2008, at: http://www.itas.fzk.de/tatup/031/raan03a.htm.

van Raan, A. F. J. (2004), Measuring science. Capita selecta of current main issues, In: Moed, H. F., Glänzel, W., and Schmoch, U. (eds), *Handbook of quantitative science and technology research. The use of publication and patent statistics in studies of S&T systems*, Dordrecht, The Netherlands: Kluwer, pp. 19–50.

Verspagen, Bart (1997), European 'Regional Clubs': Do they exist, and where are they heading? On economic and technological differences between european regions, *Maastricht Economic Research Institute on Innovation and Technology MERIT, mimeo.*

Verspagen, Bart, and Werker, Claudia (2004), Keith Pavitt and the Invisible College of the Economics of Technology and Innovation, *Research Policy*, Vol. 33, Nr. 9, pp. 1419–1431.

Vincent, Annette, and Ross, Dianne (2000), On Evaluation of Faculty Research Impact of Citation Analysis, *The Journal of Applied Business Research*, Vol. 16, Nr. 2, pp. 1–14.

Wagner, Caroline S., and Leydesdorff, Loet (2005), Mapping Global Science Using International Co-authorships: A Comparison of 1990 and 2000, *International Journal of Technology and Globalization*, Vol. 1, Nr. 2, pp. 185–208.

Wagner, Caroline S., Yezril, Allison, and Hassell, Scott (2000), *International Cooperation in Research and Development: An Update to an Inventory of U.S. Government Spending*, RAND, Santa Monica.

Wassermann, S., and Faust, K. (1994), *Social Network Analysis: Methods and Applications*, Cambridge University Press, Cambridge.

Watts, A. (2001), A dynamic model of network formation, *Games and Economic Behaviour*, Vol. 34, Nr. 2, pp. 331–341.

Watts, D. J., and Strogatz, S. H. (1998), Collective dynamics of 'small worlds' networks, *Nature*, Vol. 393, Nr. 6684, pp. 440–442.

Weinstock, N. (1971), Citation Indexes, In Kent A. (Ed.). *Encyclopedia of Library and Information Science*, New York: Marcel Dekker, Vol. 5, pp. 16-41.

Westney, L. C. H. (1998), Historical Rankings of Science and Technology: A Citationist Perspective, *The Journal of the Association for History and Computing*, Vol. 1, Nr. 1.

White, H. D., and McCain, K. W. (1989), Bibliometrics, In: M. E. Williams (Ed.), *Annual Review of Information Science and Technology*, Vol. 24, Amsterdam, The Netherlands: Elsevier Science Publishers B. V. for the American Society for Information Science, pp. 119-186.

Wilson, C. S. (2001), Informetrics, In: M. E. Williams (Ed.), *Annual Review of Information Science and Technology*, Vol. 34, Medford, NJ: Information Today, Inc. for the American Society for Information Science, pp. 3–143.

Young, H. P. (1993), The evolution of conventions, *Econometrica*, Vol. 61, Nr. 1, pp. 57–84.

Young, H. P. (2002), The diffusion of innovations in social networks, *Santa Fe Institute Working Paper*, Nr. 02-04-018, USA.

Zelder. R. E., and Sichel, W. (1992), *The impact of Western Michigan University on the Kalamazoo County Economy*, Department of Economics, Western Michigan University, MI.

Zitt, Michel, Bassecoulard, E., and Okubo, Y. (2000), Shadows of the past in international cooperation: Collaboration profiles of the top 5 producers of science, *Scientometrics*, Vol. 47, Nr. 3, pp. 627–657.

Appendix I

Synthesis of four papers sampling the economic impact of knowledge-producing organisations' literature branch and the knowledge flows' literature branch

Literature Branches	**Ecomic Impact of Knowledge-producing Organisations**		**Knowledge Flows**	
Authors, Year	Martin, 1998	Cox and Taylor, 2006	Cantner and Graf, 2006	Hussler and Rondé, 2007
Journal	Research Policy	Local Economy	Research Policy	Research Policy
Objective	Comparision of the gross impact with the net static impact, developing a practical method to measure the dynamic impact of university research	The impact of the Lancaster University's Management School (LUMS) on the regional economy. The estimated impact is not confined to backward linkage effects but focuses specifically on the forward linkage effects that will occur as a result of greater engagement with firms in the region's SME sector.	Description of the evolution of the innovator network of Jena, Germany in the period from 1995 to 2001	Analysis of the kind of cognitive relationships between researchers of a French science university and its influences over the geography of their collaborations
Methodology	R&D dynamic impact estimation based upon aggregate data	Case study of the Lancaster University's Management School	Application of social network analysis methods. The data on patents that were applied for at the German patent office and were disclosed between 1995 and 2001. To include all patents that were relevant for Jena as an innovation system it was filtered out all patents where at least one of the inventors named on the patent resided in Jena at the time of application, making altogether 334 distinct innovators on 1114 patent applications, employing 1827 inventors	Case study of the University Louis Pasteur; empirical investigation focusing on co-patenting teams, *i.e.* collaborative teams developing patented knowledge; use of data on physical co-inventors of patents as indicators of the geography of knowledge flows; the data set is constituted by 307 patents
Metrics	Estimation of the Total Factor Productivity: $\Delta\mathbf{TFP} = (\rho_y - 1)(\alpha l + \beta m + \delta k) + \theta_t + \mu r + \psi s$ ΔTFP – change in total factor productivity ρ – an index of returns to scale, *e.g.*, $\rho = 1$ means constant returns to scale α, β, δ – production elasticities of rates of growth of factors of	The total impact (J) of these different activities on regional income is estimated by applying the standard multiplier formula: $J = \sum_i J_i$ $J_i = k_i \times c_i \times l_i \times n_i \times y_i$	Network of innovators built up from a two-mode sociomatrix $\mathbf{X}_p$, where the rows are the innovators and the columns represents the inventors; the technological overlap is represented by $\mathbf{X}_t$, the rows being the innovators and the columns being the technological classes	Variables: • Degree of co-location (COLOC) of each patent: division of all Alsatian inventors by the total number of inventors *per* patent • The variable named MIXED TEAM, which scores 1 if the

	production *l, m, k* – factors of production: labour, intermediate inputs and physical capital *θ* – the time trend that represents the rate of technological change that is not immediately attributable to R&D capital and spillovers *r, s* – rates of growth of scientific capital and its spillovers *μ, ψ* – its production elasticities Function of the stock of knowledge: **R = *f* (*D,T,I*$_s$)** *R* – stock of knowledge available locally *D* – domestic stock of knowledge accumulated through previous R&D expenditures (contributors to this stock include private, government and university R&D) *T* – stock of knowledge obtained from abroad by international trade or multinational corporations I_s – e spillovers of international scientific capital (obtained by means other than trade)	*k* = regional multiplier *c* = propensity to consume out of income *l* = proportion of spending retained in region *n* = number of units affected (*e.g.* students, staff, businesses) *y* = additional income generated *per* unit *i* = type of injection	$\mathbf{X}_p = \begin{pmatrix} 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 \end{pmatrix}$ $\mathbf{X}_t = \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 1 \\ 1 & 1 \end{pmatrix}$ The density ***D*** of the network is defined as the number of all linkages divided by the number of possible linkages within the network: $D = \sum_{i=1}^{g} d_i/(g^2 - g)$ The network centralization is given by: $C = \sum_{i=1}^{g}(\max(C_i) - C_i)/(g-2)$	patent was invented by a private–public team, and 0 if we deal with purely academic teams • The variable E-COM scores 1 when the patent is the production of an epistemic community, and when E-COM scores 0, then the the patent title or IPC code refers to a tool or a process, meaning its a community of practice • Total of 12 independent variables. Econometric analysis: **COLOC$_i$ = *f* (*Z*$_i$)** *i* = 1–230 patents Z_i = {mixed team, e-com, sci-rep, sci-spe, tech-spe, team size, tech complex, tech-interdisc, S&T dist, lab size, ind-rep, CNRS} Estimation of the equation through an ordinary least square modelling: **COLOC$_i$ = *β*Z_i + *ε*** *ε* = indepently, identically and normally distributed *β* = parameter vector to be estimated
Units of Reference	Canadian Universities	Lancaster University's Management School	Jena	University Louis Pasteur
Results	With the average growth rate of GDP at 3.25% (in real terms) and TFP being 20% of DGDP (the rest being allocated to L and K), the contribution of TFP or knowledge to the Canadian GDP of 1993 is $73 billion. The total contribution of university R&D to	• The expansion of LUMS would result in 60 additional firms being assisted (*per* year) over and above the number that would have been assisted in the absence of the expansion; • The assistance provided to SMEs is estimated to	• The share of innovators that are part of the largest component of the cooperation network increases from 8.6 to 31.2% and the share of innovators connected by scientist mobility in the largest component increases from 25.2 to 32.3%; • 50% of all innovators	• Epistemic communities are less geographically spread than communities of practice; • Co-patenting teams involving corporate researchers do not exhibit specific locational features in comparison with purely academic

	the human is of 2.707302 billion Can$, and to other economic agents is of 12.808113 billion Can $, the total being 15.515415 billion Can$.	result in a steady-state increase in regional income of around £1.3 million *per annum*; • Taking into account he increased fee income from students, the forward linkage effect on regional income is estimated to be around £1.5 million; • The estimated total impact on regional income is around £3.6 million *per annum*.	are part of the largest component of the network; • The density of the cooperation network decreases (from 0.029 to 0.027) while it remains constant for the scientist mobility network (0.010); • While in the first period each actor had an average of 2.2 connections to other actors in the second period we observe an average of 2.8 connections via personal relationships; • The overall network becomes more centralized (from 0.109 to 0.184), which is also due to the development in formal cooperation (from 0.051 to 0.137) whereas centralization decreases in the scientist mobility network (from 0.102 to 0.057).	teams; • The larger the scientific reputation (SCI-REP)of Alsatian researchers, the lower the number of Alsatian team members; • Publishing a lot in a field (SCI-SPE) does not guarantee a widespread aura, whereas the quality of the publications (the number of citations, *i.e.* SCI-REP) is an effective attractor of nonregional partners; • Results present Alsace as a-typical in terms of academic spillovers: local scientific research does not mainly benefit local corporate research.