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EPISTEMIC INTEGRATION OF THE EUROPEAN RESEARCH AREA: THE SHIFTING GEOGRAPHY OF THE KNOWLEDGE BASE OF FINNISH RESEARCH, 1995–2010

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Abstract

The integration of national research systems is one of the central objectives of European research policies. Yet, the epistemic objectives of this project have been poorly defined, and scant attention has been paid to whether political, social and financial integration of the ERA is accompanied by epistemic integration. We discuss the conceptual framework and methodological practices to monitor research integration, and conclude that most of them, such as research collaboration, are only partial indicators of it. To augment existing approaches with an analysis of epistemic integration, we analyse the geographical sources of knowledge of Finnish research 1995–2010. We show a broad shift towards a European knowledge base, demonstrating epistemic integration into the ERA, and that Finnish researchers are, paradoxically, sourcing knowledge from an increasingly distributed system of European knowledge hubs. As policy implications, we recommend clarifying ERA's epistemic objectives and to redefine its strategy of "reducing fragmentation".

1. Introduction

If policy makers introduce strong incentives for the integration of various research systems, in what ways does the knowledge production change at the level of individual scientists and research systems? What are the possible differences in behavioural changes with regard to social and epistemic practices of knowledge production? And, how can we distinguish the potential impact of different types of responses on the nature and properties of the new knowledge that is being created?

These questions lie at the heart of the process of research integration, and especially that of the European Research Area (ERA). It embodies an ambitious programme of research integration, often requiring European collaboration as a condition for research funding, and material in the Framework Programme for Research and Development, the European Research Council, the European Institute of Technology, to name a few of the policy instruments introduced for its advancement. The considerable political and financial investment in ERA has been justified by its contribution to the European Union competitiveness strategy – Lisbon Strategy for Growth and Jobs. As stated by the European Commission: "ERA is essential to making Europe a leading knowledge society and thus creating the conditions for long-term prosperity." (EC, 2007, pp. 5.) The strategy of ERA is to achieve this by reducing fragmentation in research policies and research. (EC, 2008)

As a project, the ERA faces the challenge of demonstrating that the instigated processes of research integration amount to changes that are genuine improvements in the quality and relevance of European research. However, the achievement and analysis of such changes is problematic. First, from the practical perspective, the objectives of the ERA need to be mediated by researchers when they select research partners, problems, objects and approaches (Laudel and Gläser, 2014). While research systems have been shown to shift organizational behaviour relatively quickly in response to new policy incentives, the literature often suggests short-term opportunism as a cause rather than genuine or desirable changes in the processes of production of new knowledge. (Butler 2003; Moed, 2008; Ingwersen and Larsen, 2013). Thus, to deliver on its central objectives, the ERA should be able to foster (healthy) changes in the epistemic practices of European scientists, and steer clear of cultivating opportunistic behaviour seeking financial (or other) rewards.

Secondly, the large-scale monitoring and evaluation of research integration presents both methodological and conceptual challenges. Although the literature on the subject has increased in tandem with the emergence of the ERA, the discussion of the nature of research integration has been overshadowed by empirical studies assessing the extent of social, economic, and political aspects of research integration. Indeed, the methods and literature for assessing the epistemic dimensions of research integration are relatively scarce and often limited to case studies. (Barré, Henriques, Pontikakis, and Weber, 2013; Frenken, Hardeman, and Hoekman, 2009; Luukkonen and Nedeva, 2010; Laudel and Gläser, 2014)

Nevertheless, in the case of research systems, whose central property is the creation and maintenance of scientifically valid knowledge, the key nexus of the processes of integration is that of epistemic orientation: Do researchers re-orient their epistemic practices, such as sources for knowledge, theoretical and conceptual frameworks, research questions, and so forth, as the different research systems are becoming intertwined through political, social, and cultural integration? This paper contributes to the literature on research integration by assessing the epistemic dimension in the processes of the integration of research systems, relates this to other dimensions of research integration, and by considering one methodological solution for large-scale evaluation of epistemic integration.

Our central argument is that the fundamental level of integration of different national research systems unfolds in the epistemic dimension of knowledge creation. Departing from the tradition that measures research integration predominantly through research co-authorship or alignment of research agendas and organizational structures, we make the case that epistemic integration – measured here as knowledge flows captured in citation behaviour – provides an important additional perspective on our understanding of the phenomenon.

Empirically, we analyse the process of integration in the ERA[1] by assessing geographical shifts in the knowledge bases of Finnish research between 1995 and 2010 using bibliometric methods. In practice, we analyse the geographical location of sources of knowledge for Finnish research by examining in what locations the scientific literature cited in Finnish publications has been written. The purpose of this exercise is to examine, through the prism of Finland, whether the evident social and political integration on a European level is accompanied by true epistemic integration at the level of knowledge creation.

Our empirical analysis enables a consideration of the current conceptual frameworks and methods in order to assess the integration of research systems. We seek to highlight the differences between analytic approaches by focussing on social, policy, or epistemic aspects of research integration, and develop perspectives on how to maintain critical methodological and conceptual differences. Finally, we provide brief policy considerations based on our empirical analysis as well as theoretical discussions.

The paper is organized as follows. The section that follows lays out our conceptual framework and develops our notion of epistemic integration in the context of the literature on integration and knowledge, also considering major perspectives on integration of the ERA. This section also reviews the previous literature on Finland's integration into the ERA. The third section details our approach, materials and methods, and is followed by a presentation of our results. Finally, we provide a discussion of our results and conclusions, as well as the present policy implications of the study.

2. Research Integration

The movement of national research systems towards and away from each other is one of the central phenomena characterizing their evolutionary trajectories. Such system level re-orientation is best

[1] In the empirical parts of this paper, we use the Member States of the EU-27 as a proxy for the ERA.

described as research integration, which usually occurs in response to a variety of factors, of which the most important include the search for new sources of knowledge, shifting political economy, changed social, cultural, and ethnic structures and dynamics, as well as many lesser ones.

The conceptual approach to study research integration is – or, we believe, should be – influenced by the broader shift in spatial scientometrics, which places enhanced emphasis on understanding the interactions between social actors across space. As Frenken et al. (2009) put it: "from 'the study of places' to the 'space of flows'." (pp. 43.) In the context of research integration, such 'flows' can include research mobility, collaborative practices, and, as we argue throughout this paper, also "knowledge flows' that bear essentially upon the epistemic aspects of knowledge creation.

Indeed, a particular challenge in the case of research systems is to demonstrate how the processes of integration influence the social and epistemic practices of creating new knowledge, as well as the content of resulting knowledge. Furthermore, , as we argue below in more detail, all too easily policy makers and scholars accept indicators of social, political, and financial integration as metrics for research integration.

It is useful to assess the state of literature on research integration in the context of ERA, as it has been the single most important driver of research on the subject. (e.g. Georghiou, 2001; Luukkonen, Nedeva, and Barré, 2006; Luukkonen and Nedeva, 2010; Stein, 2004). Indeed, ERA's primary policy objective is to reduce fragmentation through integration of national research system, a process embodied, for example, in the organizational convergence of European research systems and alignment of research priorities.

The methodological framework to assess research integration remains relatively eclectic, and the integration of ERA continues to be evaluated from multiple perspectives. In their review of metrics for evaluating European research integration, Barré et al (2013) show that there are several approaches to conceptualizing integration

One line of research has focussed on the nature of the emerging ERA, mostly from governance and system perspectives. Political scientists have focussed on policy processes and institutions as giving rise to new European research systems, Kuhlmann and Edler, (2003) have focussed on emerging governance systems, and others (Borras, 2004; Stein, 2004) have conceptualized European integration as a process for building a European innovation or knowledge system.

Another line of research has considered methodological approaches and metrics to monitor and assess the nature and extent of research integration in the ERA. It is illustrative that the suggested approaches are sometimes conflicting, and combined embody an eclectic framework. Frenken (2002) introduces a new bibliometric indicator for the measurement of European integration, whereas Stein (2004) proposes that progress on the ERA can be tracked with traditional STI input and output indicators. Going beyond bibliometric and STI indicators, Barré et al (2013) have developed indicators focussing on policy integration (coordination and funding). Luukkonen and Nedeva (2010) have proposed a framework that distinguishes measurement and monitoring of research integration at the policy, social, and epistemic level, and provides a conceptual way of relating different methodological approaches to the measurement of research integration. Although informative on different dimensions of research integration, much of this literature omits the

discussion of inherent differences between governance studies, case studies, and large-scale quantitative monitoring of national research systems.

We argue that, in order to arrive at comprehensive understanding of the state of integration in the European Research Area, the analysis of collaborative structures and practices must be augmented with an analysis of epistemic structures and practices: Are European researchers relying increasingly on European sources of knowledge; do their theoretical and conceptual frameworks converge, and are their research questions being aligned?

While it is obvious that the quantitative study of knowledge is bound to satisfy by the use of proxies of knowledge, given its intangible nature, the issue here concerns whether practices of knowledge creation reflect the integration of the European Research Area? While policy coordination and greater international research collaboration are evident in the European Research Area (e.g. Barré et al., 2013; Glänzel and Schlemmer, 2007), the question remains to what extent the actual individual practices of knowledge creation may reflect "European integration".

In this paper, we present one empirical solution to measure epistemic integration in the ERA. By measuring the geographical dimension of the knowledge base (i.e. sources of knowledge) that researchers rely on when writing actual publications of new knowledge, we introduce epistemic metrics to assess Finland's orientation in the context of the ERA.

2.1. Policy integration

A necessary analytical distinction is to be made between the integration of research policies and research systems. Policies are primarily drivers and enablers of integration at a research level and, while their overall integration or alignment does play a role in the integration of research systems, one should not conflate the two.

Prior to the emergence of explicit policies to foster the integration of European research policies, the OECD advanced a convergence of science policies among its members since the early 1960s. This work included diffusion and the alignment of the social and economic aspects of research, such as policy coordination, planning and budgeting, resources allocation, administration, but it also touched on the epistemic dimension, as there were efforts to coordinate members' research priorities. However, priority-setting was controversial, and did not yield many results. (Henriques and Larédo, 2013)

Policy integration may also occur without bi- or multilateral cooperation, as Lemola (Lemola, 2002) has shown in the Finnish case. Since the late 1960s, Finland has imitated and adopted science and technology policy and governance models from countries with advanced models, and thereby gradually moved towards the Western European and OECD camp of innovation systems.

Obviously, the emergence of a common European policy framework since the early 1980s has given rise to a host of activities that can be described as efforts to integrate research policies. The progressive stages of integration of European research policies since the 1950s have been subject of an exhaustive list of studies (e.g. Borrás, 2003; Edler, Jakob; Kuhlmann, Stefan; Behrens, 2003; Georghiou, 2001; Guzzetti, 1995; Delanghe, Muldur, and Soete, 2009). In this literature, it is obvious that political investment in the ERA is justified because of the centrality of science and

technology for the broader European identity and economy, and because policymakers have employed policy integration (governance, funding, coordination of research priorities) so as to spearhead and trigger processes of research system level research integration.

Whereas policy integration is probably a necessary condition for broader and deeper integration at the level of research systems, it is not a plausible category for assessing to what degree national research systems really interact or are integrated, as it remains pre-occupied with coordination.

2.2. Research collaboration and co-authorship

Research collaboration constitutes one of the fundamental practices in which scientists concretely advance research integration. The literature on research collaboration maintains that research collaboration is a social convention, involving both formal and informal dimensions, making it difficult to define exactly where it starts and ends. Scientific collaboration is a broad umbrella concept covering several different types of formal and informal collaborative practices, and one can even argue that science itself is one huge collaborative endeavour, in which researchers collectively address common challenges. Scientific collaboration includes borrowing, sharing, and consideration of ideas, concepts, frameworks, data, and research problems through different means of communication and interaction. (Katz and Martin, 1997; Laudel, 2002; Duque, 2005)

For large scale empirical analysis of the integration of research systems, however, a broad conceptualization of research collaboration has little to offer when compared to bibliometric studies focussing on co-authorship. Although it enables relatively easily large-scale quantitative studies of research collaboration, some (Katz and Martin, 1997; Laurel, 2002) have argued that co-authorship is only a partial indicator of collaborative activity, possibly under-representing the true extent of collaboration. On the other hand, Melin (2000) has maintained the validity of co-authorship studies to analyse collaborative patterns. Evidently, one should avoid conflating research collaboration and co-authorship, but, we believe, that statistically sufficiently large bibliometric co-authorship studies are useful for large-scale analysis when one considers the limitations of the approach, which include: not all authors listed in a publication are necessarily responsible for the work (Katz and Martin, 1997); the reasons for co-authorship vary greatly, and cannot be inferred from the output (Melin, 2000); the outcome of collaboration is dependent on the seniority and role of the researcher (Bozeman and Corley, 2004); and, finally, co-authorship does not capture the full extent and scope of collaborative activities.

Nevertheless, research collaboration defined as co-authorship, is perhaps the most studied theme of research system integration, perhaps so much so that it is relatively commonplace, especially in large-scale statistical analysis, for interpreting increased co-publication activity as enhanced integration of different research systems. (For a useful overview, see Frenken, Hardeman, and Hoekman, 2009). Although research collaboration is a relatively credible and widely used nexus to measure research integration, its limitations have generated little if any discussion in that context.

Large-scale quantitative studies typically employ bibliometric co-authorship or research programme participant data on research collaboration as a proxy so as to analyse the spatial behaviour of scientists producing new knowledge in collaboration. However, the analysis of the quality, depth, nature or usefulness of this collaboration usually remains opaque in such large-scale quantitative

studies, excluding well established tradition to correlate collaboration with citation performance or productivity.

In the context of ERA and the problems outlined in our introduction, it is particularly problematic that large-scale quantitative co-authorship studies easily by-pass the limitations of the methodology and data, and fail to consider: whether the collaboration is driven by a need to comply with funding or other reward criteria (Laudel, 2002), the balance of power (e.g. in terms of scientific excellence) between the partners, or to what extent the collaboration is having an impact on epistemic practices of the participating partners, such as sources of knowledge, theoretical and conceptual frameworks, and definition of central research problems.

With its acknowledged limitations, bibliometric analysis of co-authorship has particular potential to address epistemic dimensions of research integration, as co-publications are the tangible outcomes of (assumed) collaborative knowledge production. Another popular source of data for collaboration studies, research programme participant data, has even more limitations from the perspective of co-creation of new knowledge, because the data does not easily reveal what the collaboration involves apart from belonging to the same project.

Yet, given that European Framework Programmes (FP) one central aim is to advance research integration by networking European researchers, participant data has played pivotal role for large scale monitoring of integration in the ERA (Rietschel et al., 2009; EC, 2013a) The ex-post evaluation of FP6 and the interim evaluation of FP7 provide exhaustive details on the participation of researchers and organizations from individual countries, and draw policy conclusions on research integration based almost solely on participation and collaboration rates.

Although studies relying programme participant data have often shied away from addressing epistemic dimensions of the ERA's research integration, the European Commission's need to assess the state of integration in the ERA has produced studies analysing the evolution of research networks from more complex perspectives. The ex-post evaluation of FP6 included an analysis of networks in information society technology (Wagner et al 2005), which concluded that FP6 was integrating research project participants more effectively than previous FPs. European research networks, strengthened by explicit European policies, have also been shown to enhance knowledge diffusion between different regions. (Cassi, Corrocher, Malerba, and Vonortas, 2008)

Several studies of European integration and research collaboration have sought to go beyond the FP-participant data to explore the more complex aspects of ERA's integrative dynamics. Hoekman et al (Hoekman, Frenken, and Oort, 2009) analysed European scientific co-publication and co-patenting, and concluded that, when choosing collaborators, European researchers and inventors place a premium on proximity. Similarly, it appears that European academic researchers also continue to emphasize geographical proximity as important criteria when choosing co-authors, to the extent that proximity is more important than national borders. (Frenken et al., 2009) Several bibliometric studies of European research collaboration have consistently shown that there is a continuous increase in international research collaboration among European countries, but that no such threshold has been crossed that would signify the emergence of anything that is envisioned by European research policy makers. (Glänzel, Schubert, and Czerwon, 1999; Gusmão, 2001; Okubo and Zitt, 2004; Tijssen, 2008)

Research collaboration is the essential activity at the level of researchers, research groups, institutions, and research systems that advances research integration. Yet, as we have outlined above, research collaboration is such a complex and diffuse phenomenon that its conceptualization in in-depth case studies of research integration differs inherently from what is practical in large-scale quantitative analysis. Whereas case studies conceptualize research collaboration as a socially situated and relational process, involving informal and formal interactions, large-scale studies rely on stylized facts (e.g. co-authorship or project participation) to operationalize the concept useful for statistical analysis. The critical role played by collaborative creation of new knowledge for research integration necessitates, however, the development and experimentation of new approaches, which would serve to expand the conceptual framework of traditional bibliometric co-authorship studies. In particular, as we argue in this paper, the utility of bibliometric methods for analysis of research integration can be enhanced if augmented with approaches addressing epistemic aspects of knowledge creation.

2.3. Epistemic integration

Epistemic aspects are central, if not fundamental, for research integration, and for its large scale analysis and monitoring. As far as they are about creating new knowledge, research systems consist essentially of a number of epistemic communities, which share assumptions about bodies of knowledge as well as about the practices necessary to create new valid knowledge. They are both social and epistemic communities, whose proper holistic analysis requires one to address both aspects. Yet, as Laudel and Gläser (2014) have recently pointed out, the relationship between the content of research and its institutional framework has been little assessed in studies analysing the impact of changing governance of science in Europe. If we are to assess the emergence of the ERA from the vantage point of knowledge creation, there is a necessity for analytical strategies so as to discern relevant knowledge flows between different epistemic communities.

Knowledge flows, or circulation of knowledge, between research communities has been long-standing feature of qualitative studies of science, especially in the history and sociology of knowledge. One issue has been to develop the conceptual operationalization of “epistemic integration” suited for large scale quantitative studies. Emphasizing the importance of epistemic integration in the context of the ERA, Luukkonen and Nedeva (2010) have proposed “shared epistemic assumptions”, “shared methodologies and research methods”, “consensus regarding important research problems”, and “shared criteria for legitimization of knowledge” as useful measures of epistemic integration.

A further complication for the assessment of epistemic aspects of the ERA has been that its epistemic objectives have been poorly defined, especially when compared to its social, financial, and infrastructure targets. (see e.g. EC 2013b) The European Research Council (ERC) launched in 2007 provides an exception, however, as it aims exclusively to foster world-class “frontier”, “transformative”, or “break-through” research in Europe.

Investigating how the ERC is succeeding in changing the epistemic properties of European research, Laudel and Gläser (2014) pointed out the problem in the fit between the ERC’s institutional design and European research communities. ERC “is built after a blueprint derived from the biosciences” (Laudel and Gläser, 2014) and successfully promotes “transformative”

research in fields that share epistemic practices and properties with biosciences. Where no such fit exists, as is the case with the social sciences and humanities, the ERC appears to promote a type of research that is uncommon for the field.

The problem identified by Laudel and Gläser underlines the need to build evaluative frameworks of research integration that remain sensitive to the social and epistemic properties of research. As most studies analysing in-depth the epistemic aspects of research integration remain case studies, there is an apparent gap between the conceptual framework emphasizing the importance of epistemological aspects of research integration and the current ability of large-scale quantitative studies to take stock of this.

When it comes to direct analysis of *research integration*, there is an apparent contrast between analysis of epistemic properties in *case studies* and *large-scale quantitative studies.* Although useful for case studies or as analytical categories, the measures of epistemic integration proposed by Luukkonen and Nedeva lend themselves poorly to large-scale quantitative analysis of integration of national or supra-national research systems. Similarly, Laudel and Glänzel acknowledge the small number of cases as a limitation of their study. Indeed, presently, there hardly exists a clear-cut prescription for methodologies suitable for analysing epistemic integration with large-scale quantitative methods, yet there is a nascent literature on the subject.

If we turn from science policy studies to the literature on innovation systems, an alternative large-scale approach is apparent to relate the properties of knowledge to European innovation performance and firm behaviour. In an effort to explain how different regional innovation systems exchange knowledge and collaborate on innovation, students of geography and firms have analysed the nature and geography of knowledge flows. Analysing Scandinavian regional innovation systems, Asheim and Coenen (B. T. Asheim and Coenen, 2005) have pointed out that the nature of a local knowledge base depicts how innovative firms absorb and create knowledge. Depending on how much firms rely on an analytical (science-based) or synthetic (engineering-based) knowledge base, they follow a different mix of strategies of knowledge acquisition. Furthermore, Scandinavian firms select carefully when they rely on local knowledge and when they scout globally for knowledge critical for innovation, and they also deploy defensive methods to make “knowledge sticky”.(Asheim and Isaksen, 2002).

This literature gives rise to the suggestion that epistemic re-orientation, or integration, involves a range of (complex) cognitive choices by actors, yet the application of approaches developed for the use of firm and industry level quantitative data, such as Community Innovation Survey (CIS) and data on labour mobility, technology, investments, and production, lends itself poorly to available bibliometric data, and to an analysis of research integration, because of their inherent differences.

Students of research systems have employed citation practices – knowledge flows – as a proxy to assess the epistemic standing or orientation of research systems. Analysing where the most cited research originates, King (2004) argues that the global research system remains unequal. Citation analysis has also been used to compare the scientific performance of the United States and the European Union (Albarrán, Crespo, Ortuño, and Ruiz-Castillo, 2010), as well as to show that the emerging Brazilian research system is increasingly reliant on a domestic knowledge base. (Ponomariov and Toivanen, 2014) The point of these bibliometric studies – a view we share – is

that the large-scale analysis of the geography of citations awarded casts light on the epistemic aspects of research systems, and in particular enables us to examine in detail changes in the location of sources of knowledge.

In the context of the ERA, there are a number of studies that address the epistemic dimension by focussing on knowledge flows, especially using patent citation information. In analysing information society technologies in FP7, Brecshi et al (Breschi, Cassi, Malerba, and Vonortas, 2009) augmented participant data with patent citation information and demonstrated that central organizations for the FP7 IST networks were more effective than other participants in diffusing knowledge. An examination of patent citations awarded and received in European patents between 1990 and 1998 has shown moderately increased international knowledge flows within Europe. (Paci and Usai, 2008) In contrast to these results, using EU-level econometric data and methods, and not being confined to FP data, others (Rodríguez-Pose and Crescenzi, 2008) have argued that European regions have trouble in tapping into knowledge for innovation activities from neighbouring regions.

Research profiling of national research systems has embodied another method for analysing the epistemic impacts of EU membership, and Glänzel and Schlemmer (2007) have shown that joining the European Union does re-align a country's research profile with that of the rest of Europe, albeit slowly. Another possible approach to analysing the convergence of research systems, of whose application we are not aware, would be large-scale semantic text analysis (e.g. topic modelling), which would directly look at the content of scientific publications, not metadata (e.g. author information). While alignment of research agendas, frameworks, and questions probably can reveal one aspect of research integration, they do not directly address the issue of knowledge interaction between various research systems.

Other methodological attempts to focus on epistemic aspects of research integration often include the use of hybrid sources of data or a novel classification of data. For example, the nature of FP project participants has been used to assess to what degree they correspond with the EC's objective to integrate "science and society". (Rodríguez, Fisher, and Schuurbiers, 2013) Merging bibliometric, patent, as well as basic socio-economic statistical data is commonplace, and a novel approach has been the inclusion of internet data. In their analysis of European knowledge flows, Maggioni and Uberti (2008) added an analysis of university web-site links to data consisting of patents, the Erasmus student exchange programme, and FP5 participant data.

In conclusion, there are relatively few studies using bibliometric citation data to assess the integration of the ERA. A central point of this paper is to examine geographic patterns of knowledge flows within ERA, albeit through the case of Finland, in order to augment existing literature on integration of ERA with a perspective that focusses almost exclusively on one epistemic aspect of science, namely sources of knowledge.

2.4. The Finnish research system and ERA research collaboration

Finland's entry into the European Union in 1995 also marked an important change in the internationalization of Finnish science, rapidly bolstering earlier smaller steps to integrate more deeply into the European research system. Indeed, as Hakala et al (2002) have concluded, "internationalization has come to mean Europeanization" in Finland. Much previous research has

documented Finland's increasing social (research collaboration) and policy integration into the ERA, yet hardly any studies have attempted to map whether this political and social re-orientation is accompanied by epistemic shifts such as new geographical sources of knowledge or focus of research.

Policy integration has, moreover, been central to Finland's integration into the emerging ERA. Before Finland's membership of the EU and the break-up of the Soviet Union, a 1990 government report analysing Finland's position as regards the integration movement in Western Europe prioritized augmented Finnish participation in emerging European R&D programmes. (VNK, 1990) The same, almost enthusiastic, adoption of EU R&D and innovation policies and instruments, has characterized official Finnish EU policy to date. More recently, Finland's national innovation strategy in 2009 reviewed in detail the country's participation in different European R&D&I initiatives and their potential benefits to Finland, as well as declaring: "Drawn up during Finland's term of presidency, the EU's innovation strategy has provided a significant opening, harmonising innovation policy measures within the EU and promoting their determined utilisation in achieving the Lisbon objectives." (MEE, 2009)

Studies of research collaboration have emphasized that the increase of international research collaboration in Finnish research has been one of its key features since the early 1990s. Indeed, the share of internationally co-authored articles from all Finnish research publications has increased from 25% in 1990–1993 to 49% in 2006–2009. (Muhonen et al 2010)[2] Europe has featured prominently within this development, as research collaboration with European countries has grown faster than with the rest of the world, and participation in European research programmes has been a critical enabler of this. (Persson et al. 2000; Luukkonen and Hälikkä 2000; Kuitunen et al. 2008)

Of the few available bibliometric studies of internationalization of Finnish science between 1995 and 2010, the most relevant is a recent Ministry of Education analysis of Finnish international co-publication between 1990 and 2009. (Muhonen et al. 2012) Its key conclusion is that Finnish co-publication with European countries has increased steadily, whereas the share of collaboration with North American researchers has declined somewhat. The study reports that 40% of Finnish international co-publication in the years 1990–1994 involved collaboration with EU-15 member states and/or Switzerland, and that this share had increased to 54% in 2006–2009.

Evidently, the Finnish research system has re-orientated itself towards Europe in terms of research policy and research collaboration, yet we are not aware of any prior attempts to discover whether a similar re-orientation would have occurred at the epistemic level of Finnish research. Therefore, the central empirical issue for this article is to examine whether the political decision to align the Finnish research system with the ERA has been accompanied by epistemic re-orientation, conceptualized here as sources of knowledge. Moreover, the detailed analysis of the geographical re-orientation of the sources of knowledge of Finnish knowledge production should inform us about the nature of the broader integrative processes of ERA.

[2] One should note that the direct comparison between our results and Muhonen et al (2012) is undermined by the fact, that Muhonen et al (2012) have not fractionalized articles when crediting authorship, and that their analysis is limited to the publication types *Article, Letter* and *Review.* In addition, their analysis is limited to publications only involving international co-authorships, and applies whole counting in collaboration analysis.

3. Materials and methods

3.1. Approach

Above, we have argued that epistemological aspects need to be taken into account better when assessing research integration, and we have discussed the limitations and problems associated with some of the most common methodological approaches to evaluate research integration. We believe that plausible (large scale quantitative) analysis of research integration should include the assessment of such epistemic aspects, and propose below a method to do this by analysing the geographical location of sources of knowledge of Finnish researchers. Our approach embodies one (partial) solution, and does not attempt to claim to address all aspects of epistemic integration of research systems.

Large-scale analysis of citations of prior scientific literature in new scientific publications does open a window on analysing sources of knowledge, and thus one important epistemic dimension of research integration, but is constrained by the well-known limitations of citation analysis. (Leydesdorff, 1998) The most important of these include the built-in bias of bibliometric databases (e.g. the predominance of medical and natural sciences in ISI-WOS, to name one. Moed, 2005), the difficulty of interpreting correctly the meaning of citation (e.g. appreciative vs. critical), and so forth. (For a review of methodological issues related to citation analysis when applied to the analysis of knowledge flows, see Ponomariov and Toivanen, 2014). Nevertheless, when these limitations are considered sufficiently in analysis strategy and interpretation of results, we agree with Moed (2005) who has maintained that the main advantage of citation analysis is that it enables large-scale quantitative evaluation of knowledge flows.

Obviously, the epistemic integration of research systems unfolds across multiple levels, such as research agendas, central problems, and so forth, but whereas these continue only poorly to capture knowledge exchanges between national research systems, citation analysis enables us to track this aspect of knowledge flows. A central issue is what significance is ascribed to citations, and we propose a minimalistic interpretation, concluding only that the act of citing a paper signifies that the paper has had some relevance for the author of new scientific knowledge, thereby functioning as a "source of knowledge". (Ponomariov and Toivanen, 2014)

Analysis of the sources of knowledge of the Finnish research system with the above described citation analysis enables us to examine in what manner their geographical location shifts over a 15-year period, and casts new light on the way Finland has integrated into the ERA and how the integrative dynamics unfold altogether in the ERA. If Finnish researchers across major scientific fields shift increasingly to cite scientific literature authored by European located researchers, this provides evidence that the well-documented social and political integration of the ERA is accompanied by epistemic integration.

3.2. Data and methods

Our data consists of two sets of bibliometric data obtained from the Web of Science (ISI-WOS) index, which is maintained by the Institute for Scientific Information. The core data (Source) consists of publications with at least one author affiliated with Finland and indexed, and the second

data set (Cited) consists of all publications that have been cited in the Source data and indexed by the ISI. The data was delivered in tagged XML format, i.e. with full article-level information maintained in ISI-WOS, by Thomson Reuters in August 2012, and subsequently processed with text mining (e.g. VantagePoint TM), database management (MS Access) and other software at the individual article level.

The basic features of the data are described in Table 1. The Source data was limited to articles, conference proceedings, abstracts, and reviews, and totalled 153,572 records between 1995 and 2010. All document types are included in the Cited data, but it was limited to cited publications with a ten-year moving window – including only cited articles that are at most 10 years older than the citing publication. This serves two purposes. First, ISI-WOS coverage declines significantly the older the publication years, and thereby undermines the reliability of extended historical analysis. Secondly, our aim is to situate the analysis of geographical focus of knowledge bases in contemporary national research systems, and too long a time-window would cast little light on a country's current performance or its relevance to Finland. After these limitations, the Source data consisted of 1,671,950 records. (Table 1.)

[Table 1. here]

The Source and Cited data were linked by using a unique identifier, and we added into each Source record all the available instances of author countries from Cited records. Depending on year, we were able to assign references to about 67–85% of Source publications, with coverage improving for more recent years. (Table 1) The inclusion of references varies by document type, and as a rule the coverage is high for articles and reviews, and drops for proceedings, being lowest for abstracts. Evidently, references to publications not covered by ISI-WOS are not included in our analysis.

Given the frequency of international collaboration in Finnish science, there is a need to check for the number of Finnish and international authors when analysing knowledge bases. To this end, we have applied complete-normalized counting at the level of institutional authors[3] in the Source records. Complete-normalized counting refers to all institutional authors mentioned in the publication sharing with equal shares, 1 credit. (Gauffriau et al. 2008) We use institutional authors, institutions mentioned in the metafield of a publication, as ISI-WOS does not allow for individual author level fractional counting far back in time. For each Source record, we have developed the FI_AUTH variable, which gives the share of Finnish institutional authors among all institutional authors and whose value is by definition $0 < FI\_Auth \leq 1$. The *Fi_Auth* variable is reliant on the counting scheme used to be additive and normalized, thus supporting our selection of a complete-normalized counting scheme. (Gauffriau et al., 2007)

Finnish researchers' reliance on country-specific geographical knowledge bases for each Source record was estimated as:

$$SK_{ij} = FI_{Auth} \times I_{ij}$$

[3] Using institutional authors for a proxy for authors is subject to limitations such as being unable to control for possible double affiliations.

where SK_{ij} is the source of knowledge index for document i in regard to country j and I_{ij} times country j has been mentioned in Cited of document i.

A country's total share of the Finnish knowledge base would be its relative share of the total of instances of author countries listed in the record references. This method works especially to correct the probable noise caused by large international author teams, where Finnish researchers play minor roles, and overall it weights the importance of knowledge bases according to the Finnish contribution to the Source record.

A description of the geographical location of sources of knowledge for Finnish research is the theme of this paper. It is important to note that we are using the concept EU-27 as a proxy for the ERA, thereby excluding some minor countries that are officially part of the ERA. In our view, full membership in the EU, given the associated rights and responsibilities, must be used as a threshold to analyse research system level integration in the EU. Drawing geographical and political boundaries for scientific analysis always involves some compromises, and we believe that this definition is the most clear and watertight definition of the European level research system being analysed here.

Apart from providing an overall assessment of the geographical orientation of the Finnish knowledge base, we also provide research field-specific analysis at the level of major research fields. In so doing, we rely on the ISI-assigned record level subject categories, currently totalling over 250, which are further consolidated into six major research fields (Natural sciences, Medical and Health sciences, Engineering and Technology research, Social sciences, Agricultural sciences, and Humanities) defined by the OECD (2007)

There is a considerable literature discussing the problems and advantages associated with the use of these subject categories (Boyack, Klavans, and Börner 2005; Leydesdorff and Rafols 2009; Zhang et al. 2010), and the debate has basically concluded that the subject categories can be used as "best-available proxies" for the research field, as long as the usual limiting factors are acknowledged. These include the fact that the subject categories are inter-connected and over-lapping, meaning that one record may be assigned to several categories. The subject categories cannot be applied to fractionalize articles (e.g. citations made or received); the subject categories are historical and do not recognize well emerging new research themes and fields; perhaps most importantly, they are in part based on human judgment and have been shown to be relatively prone to error. (Leydesdorff and Rafols, 2009) Consolidation of the individual fields into major research categories probably works to minimize this error, however. Thus, the study will only focus on results at an aggregate OECD major research field level. Due to inherent differences in referencing behaviour and assignment of authorship, the different fields are not compared against each other; rather the temporal dynamics of each major field is studied separately.

Finally, one should note that the ISI-WOS has significantly expanded its index coverage during our analysis period, especially in Asia, Africa and Latin America. As none of these regions proliferate in our results, we estimate that, apart from considering this when interpreting results for those countries, there is no need to check for the expanded coverage in our study.

4. Results

4.1. Finnish research system level integration into the ERA

The increasing role of the emerging ERA as a source of knowledge for the Finnish research system between 1995 and 2010 is the key empirical result of our analysis, as detailed in Table 2. When we analyse all the research indexed in WOS-ISI, the share of citations awarded to publications that have originated in one of the EU-27 countries increases by 14.5%, moving from about a 44% share of all literature cited to a little over half. Most of this growth comes from citations awarded to other EU-27 countries than Finland, as Finnish researchers keep the share of national self-citations relatively stable and below one fifth. (Table 3.)

[Table 2 here.]

[Table 3 here.]

The growth of the ERA as a source of knowledge for Finnish research comes at the expense of North America, and especially that of the USA. North America's relative share as a source of knowledge for Finnish researchers declines about 28% from 47% in 1995 to 34% in 2010. The USA's share declines almost 30%, from 47% in 1995 to 31% in 2010. Strikingly, Canada maintains its share practically unchanged at around 3.5%. This shift away from US-based sources of knowledge is a steady phenomenon, which progressively deepens throughout the period studied here. (Tables 2 and 3.)

At the level of major global regions, EU-27 and North America combined originate about 90% of all literature cited by Finnish researchers in the mid-1990s, and this share declines only slightly to about 85% by 2010. All other major global regions remain relatively marginal sources of knowledge for Finland. Asia's share increases 74% but, as its share in the mid-1990s is only about 4%, this share amount to only about 7% in 2010. Non-EU Europe (of which Norway and Russia account for about half) and Oceania originate between 1% and 4% of cited literature throughout the period studied here. In Table 2, unreported regions produce only a negligible share of literature cited by Finnish researchers. The share of the Middle East in 1995 is 0.68% and in 2010 1.13%, South America 0.34% and 0,84%, respectively, Africa 0.24% and 0.36%, and Central America and the Caribbean 0.12% and 0.25%.

Finland's global knowledge base is highly concentrated at the level of global regions, as the ERA and North America generate the majority of knowledge that is relevant to Finnish researchers. Although we consider in our interpretation the overall changes in the global dynamics of science production, namely the diminishing global share of the US and the increasing share of the ERA and selected Asian countries (Zhou and Leydersdorff, 2006), our results show a clear shift in the Finnish sources of knowledge from the North America towards the ERA. The most important shift in the Finnish knowledge base occurs between these two regions, as the relative relevance of North American research for Finnish research declines significantly between 1995 and 2010, and the ERA's grows significantly.

4.2. Fragmentation as a key feature of ERA's integration process

Consideration of the nature of the ERA's integration process is a key theme of this paper, as we have argued that it is likely – paradoxically – also to involve increased fragmentation, as more and more countries and science hubs gain importance within the research system that constitutes the ERA. Becoming more integrated involves becoming more distributed.

Our analysis of Finland casts light on this, as we detail how between 1995 and 2010 Finland's increasing reliance on EU-27 countries as sources of knowledge actually unfolds. Table 3 gives the relative share of the 10 countries that in total originated most literature cited by Finnish researchers between 1995 and 2010. The largest EU-27 source of knowledge and one that ranks overall 4th, the UK, increases its share by 10%. Respective ranks and figures are for Germany 5th and 57%, France 7th and no change, Sweden 8th and -12%, Italy 9th and 45%, and the Netherlands 10th and 35%.

Outside the table, the rank, share in 2010, and change in share between 1995 and 2010 for other EU-27 countries is as follows: Spain 13th, 1.66%, 228%; Denmark 16th, 1.45%, 23%; Belgium 18th, 1.16%, 63%; Austria 20th, 0.66%, 54%; Poland 27th, 0.44%, 110%, Greece 30th 0.36%, 258%, and all other EU-27 countries combined: 12th, 1.78%, 171%. Their combined share of Finnish references in 2010 was over 8%, and their combined share between 1995 and 2010 more than doubled. To this list can be added Norway, a non-EU country but an active participant in the ERA, whose share of Finnish references increased by about 66% and totalled little more than 1% in 2010. (Table 3, Supplementary annex 1.)

Finland's deepened integration into the ERA between 1995 and 2010 has been characterized by an intensified search for sources of knowledge from an increasingly geographically distributed system. While some of the originally large sources of knowledge for Finland, such as the UK and Germany, are able to increase their shares, some show no change or a steep decline, such as France, Sweden, and Finland itself. However, what is significant is the Finnish researchers' increasing reliance on a greater number of small geographical sources of knowledge, such as Denmark, Belgium, Austria, Poland, Greece and other small EU-27 member states. It is exactly this development, the proliferation of small national research systems as relevant sources of knowledge for Finland, which makes increasing fragmentation an essential feature of ERA's integration.

4.3. Finland's knowledge base by major research fields process

In addition to the research system level analysis of the shift in Finland's sources of knowledge provided above, we examine the phenomena at the level of major research fields, as defined by the OECD (2007) of Natural Sciences, Medical and Health sciences, Engineering and Technology, Social Sciences, and Agricultural Sciences. The data is insufficient in sample size to publish credible results for the Humanities.

The point here is to demonstrate that, at the level of research fields, there are substantial differences in terms of geographical orientation of search for sources of knowledge, and therefore also in the processes integrating the Finnish research community into European and other research systems. The differences between the fields are so significant that it is possible to argue that they add another, epistemic, dimension of "fragmentation" into Finland's integration into the ERA, already imprinted by the geographical fragmentation discussed above.

4.3.1. Natural science

Natural science is the largest Finnish major OECD research field, and therefore its dynamics do not radically deviate from the aggregated analysis provided above. Some minor differences do exist, of which the most important is that the sources of knowledge for Finnish Natural science research are more international than for Finnish research on average. Indeed, between 1995 and 2010 natural science research is in many respects responsible for the internationalization of sources of knowledge for the Finnish research system, as its reliance on domestic sources declines more than for any other major field. Finnish natural science researchers awarded about 17% of all citations to Finnish-originated research in 1995, but this share declined to a little less than 15% in 2010.

[Table 4 here.]

Table 4 details changes in the geographical location of sources of knowledge for Finnish natural science research. Whereas in 1995 North America is the largest source of knowledge, in the mid-1990s it is very quickly overtaken by the ERA. Indeed, North America's share declines by almost one third, whereas Asia doubles its share from 1995 to almost 9% in 2010, making it a substantial source of knowledge for Finnish natural science research. China, South Korea, and Taiwan are the major countries propelling Asia's rise, as Japan's share remains relatively unchanged. China, South Korea, and Taiwan show continued and sustained growth, and it is easy to believe that their role as sources of knowledge for Finland will continue to increase at a rapid pace. (Supplementary annex 2.)

Enhanced epistemic integration into the ERA is also obvious in Table 4. Overall, the ERA originates about 43% of cited publications in 1995, and about 49% in 2010. The ERA's rise in prominence occurs very rapidly in the mid-1990s, and it is important to note that, in the case of natural science research, the integration into the ERA is expounded by the substantially declining share of citations awarded to Finnish publications.

Finland's enhanced integration into the ERA in natural science research is also marked by increased fragmentation. Within the EU, the UK increases its share from 1995 by about 28% to 7.40% in 2010. The respective figures are for Germany a 42% increase to a 7.40% share; France declines by 9% to 4.05%; Sweden declines by 14% to 3.03%, and Italy increases its share by 60% to 3.30%. Evidently, Finland's natural sciences research system exhibits substantially different processes of epistemic integration towards individual ERA member states. (Supplementary annex 2.)

4.3.2. Medical and health sciences

Medical and health sciences constitute the second largest Finnish major research field. Their sources of knowledge are relatively international, as about 18% of all cited references in 2010 have originated in Finland. This share remains almost unchanged between 1995 and 2010, declining only a little over 1%. (Supplementary annex 2.)

[Table 5. here.]

At the level of major research regions, the ERA again displaces North America as the largest source of knowledge. This shift unfolds at a somewhat slower pace than in the case of the natural sciences,

but once the shift occurs definitively around 2000, the ERA accounts for more than half of all cited literature. Combined ERA and North America originate 86% of all cited references, making the rest of the world relatively marginal. Yet, the continued growth of China, South Korea, and Taiwan may transform Asia into a major source in the coming decade. (Table 5.)

Again, Finland's integration into the ERA varies greatly by country. Whereas the UK and France maintain their share almost unchanged, Germany shows an increase of 65%, Italy 45%, and the Netherlands 50%. Interestingly, Sweden, the third largest source of knowledge for medical and health science in 1995, declines by 14% and ranks 5th with a share of 3.50% in 2010. In the case of medical and health sciences, the same phenomenon of increased sourcing of knowledge from an increasing number of small European research systems is evident. (Supplementary annex 2.)

4.3.3. Engineering and technology

Engineering and technology research is perhaps the most significant growth component in the Finnish innovation system during its expansion from 1995 to 2010, and ranks overall as the third largest Finnish research field. It demonstrates a very different structure and dynamics from natural sciences or medical and health sciences, underlining the need to understand how epistemic factors bear upon the integration of research systems.

[Table 6. here.]

First, unlike most other major research fields, the share of domestic sources of knowledge of engineering and technology depicts an inverted V-shape between 1995 and 2010. Whereas domestic sources of knowledge in the mid-1990s average around 20%, they increase moderately up to 22% in the early 2000s, but decline to around 17% few years later. While it is beyond the remit of this paper to assess completely the reasons for this development, we assume that this is intimately linked with the relatively strong phase of expansion and upgrading of quality of research between 1995 and 2005, whereas the developments after 2005 might imply a retreat in those same aspects. (Supplementary annex 2.)

The second major difference is obvious at the level of major research systems, and detailed in Table 6. Even in 1995 the ERA is the largest source of knowledge for Finnish engineering and technology, originating more than half of all cited literature, and this share remains relatively stable throughout the period. North America's share declines from about 38% to around 30%, and Asia doubles its share from a little more than 6% in 1995 to 13% in 2010. In effect, Asia's increased share reflects a shift away from North American sources of knowledge. (Table 6.)

Individual countries again show very different trajectories. Within the EU, the UK maintains its share almost unchanged, whereas strong gainers are Germany (an increase of 12%), Italy (21%), Netherlands (48%), and Spain (53%), to name a few. Significant declines are showed by France (-33%) and Sweden (-29%). Outside Europe, the most important phenomenon is the rise of China, which climbs from relatively obscurity to become the 7th most important source of knowledge. Its growth in recent years is so strong that there are good reasons to assume that it will shortly rank as one of the most important sources of knowledge for Finnish engineering and technology. South

Korea and Taiwan show important gains too, whereas Japan's relative share declines by almost 10% to a share of little more than 4% in 2010. (Supplementary annex 2.)

4.3.4. Social sciences

Social sciences show distinct features. The share of domestic sources of knowledge remains unchanged at around 15% of all references, despite the fact that the field increases more than 10-fold between 1995 and 2010. The ERA's role as a source of knowledge increases, from 38% to 47%, but clearly less than in the natural sciences, medical and health sciences, or engineering and technology research. North America does lose its rank as the primary source of knowledge, declining from 54% to 41%. North America and the EU account for almost 90% of all cited literature throughout the period studied here, and other major regions remain marginal, despite their increased shares.

At the level of individual countries, the share of the USA declined between 1995 and 2010 from 24% to 36.19%, echoing a similar trend as in other major fields. The share of the UK, which in the case of social sciences features more prominently as a source of knowledge than in any other major field of research, increases from 1995 over 46% to over 12.21% in 2010. Respective figures for other major sources of knowledge are: the Netherlands 101% and 4.53%, Canada -32% and 4.51%, Germany 105% and 3.77%, Australia, 53% and 3.32%, Sweden -50% and 2,84%, and France 185% and 2.39%.

[Table 7. here.]

The country ranking of sources of knowledge in social sciences is clearly different from that of other major areas of research, and suggests that epistemic features play an important role when Finnish researchers choose where to turn for knowledge sources.

4.3.5. Agricultural sciences

The agricultural sciences demonstrate distinct features too. They rely strongly on domestic sources of knowledge. The share of Finnish originated references is about 20% in the mid-1990s, and this share increases by roughly one fifth by 2012 to a share of one quarter.

[Table 8. here.]

At the level of major research systems, EU-27 and North America are of almost equal size as sources of knowledge in the mid-1990s, both a little over 40%, and yet they evolve in a contrasting manner. The EU-27 share increases by almost 40% to account for 60% of all citations, whereas the North American share declines by 46% to 23%, respectively.

At the level of individual countries, significant differences exist. The USA's share declines by 50% to 18.54% in 2010, and Canada's share by 26% to 4.79% respectively. Agricultural research is the only major research field, where Finland's historical ally and geographically, politically, and culturally closest neighbour, Sweden, is able to increase its role as a source of knowledge. It originated 4.01% of references for Finnish agricultural research in 1995, and this share increased by 46% to 5.88% by 2010. Other major sources of knowledge that are increasing their share

significantly include Germany and France, whereas the UK's share declines by almost one quarter. (Supplementary annex 2.)

5. Discussion and conclusions

The integration of research systems is one of the key objectives for public policies in the age of globalization, as well as one of the central features characterizing the structural and organizational as well as epistemic evolution of research systems. While research integration unfolds in multiple dimensions such as social, political, cultural and so forth, we have sought to clarify and demonstrate the role of epistemic integration in measuring and monitoring research system integration with large-scale quantitative methods. Furthermore, we have argued that some of the most common approaches to monitor research evaluation, such as research collaboration, are only partial indicators of research integration and that they should be augmented with methods addressing epistemic integration.

We have maintained that it is important to distinguish between policy, social, and epistemic aspects of research when assessing research integration. Moreover, we argue that epistemic orientation, in this article measured as sources of knowledge, provides a more realistic and accurate perspective to assess the nature of research system integration than do policy or social aspects, because researchers are relatively free to choose whom they cite or where they obtain relevant knowledge from. An illustrative problem is the role of top-down policies prompting behavioural changes in the research systems. Often research funding stipulates not only the number of required international partners, but also where they must be from. However, a practical and feasible approach to the measurement and monitoring of research integration will probably involve hybrid methods, in which different approaches and methods augment each other.

The centrality of research integration for European research policies is the reason for much of the recent research interest in the topic. Indeed, the emerging ERA is essentially about the policymakers' drive to "reduce fragmentation" by enhancing coordination among research policies, funding, and researchers. Significant political and financial investments in the creation of an ERA have given rise to a series of evaluation, monitoring, and measurement studies tracking the European integration of various national research systems. While the consensus of these studies appears to be that there is an increasing and mildly accelerating movement towards an ERA, and that the EU policies and programmes are enhancing knowledge diffusion across Europe, the speed and scope of this integration falls short of research policy objectives. (Breschi et al., 2009; Wolfgang Glänzel and Schlemmer, 2007; Tijssen, 2008; Wagner and Leydesdorff, 2005; European Commission 2013; Rietschel et al. 2009)

The case of individual countries is often more striking. Indeed, "Europeanization" has encompassed practically all the internationalization efforts of the Finnish research policies, and since the mid-1990s the country has quickly oriented itself towards European research programmes and partners when measured as policy integration or co-authorship linkages. As our results confirm, this re-orientation has been accompanied by "Europeanization" of the sources of knowledge of Finnish research as well. The major shift in the knowledge base of Finnish research between 1995 and 2010

has been the wholesale shift away from North America as the primary source of knowledge, and its replacement by the EU-27 countries.

Overall, Finland's global knowledge base is highly concentrated, as it is in practice divided between the EU-27 and North America. This bipolarity also characterizes the shift in the geographical location of Finland's sources of knowledge, as Finnish researchers trade North America for EU-27. This movement also appears to be uniform in four of the five major fields studied in detail (natural sciences, medical and health sciences, social sciences and agricultural sciences), with only small differences in the timing of the shifts. In the case of engineering and technology, Europe has been the most important source of knowledge throughout the period studied here, and North America's declining share is mostly due to the rise of Asian research systems.

The break-down of aggregate results into major research fields underlines the importance of understanding the epistemic aspects of research integration in their proper context. Evidently, researchers from various disciplines apply different criteria when selecting relevant sources of knowledge, leading to relatively distinct profiles of the major research fields in our study.

However, a central point in this paper has been that one should not too easily conflate policy, social, and epistemic integration, as they do not (always) share the same incentive structures and dynamics. The comparison of analyses of Finnish international co-publication and our approach to the focus on sources of knowledge underlines the differences between social and epistemic aspects of research integration. In its analysis of Finnish international co-publication, the Academy of Finland (Lehvo and Nuutinen, 2006, p.18) concluded that Finnish co-publication with North America had increased by 42% between 1995 and 2004. A study commissioned by the Ministry of Culture and Education (Muhonen et al 2012, p.25) concluded, on the other hand, that the share of North American co-publication from all Finnish international co-publication declined moderately from 35% in 1990–1993 to 30% in 2006–2009. Conversely, we show that North America's share as a source for Finnish science has declined from being over 45% in the early 1990s to a little less than 35% by in the first decade of 2000s. Other such differences are easy to point out, such as, for example, the case of Sweden, whose share declines in our study but increases or remains stable in analyses focussing on co-authorship.

The broader policy implication here is that the ERA needs increasingly to be assessed in terms of its epistemic properties, including the epistemic integration of various national research systems, and that this approach needs to augment the existing methodologies currently dominated by social network analysis. This would be made easier and more credible, if the ERA's epistemic objectives were to be more clearly defined, alike it's political, financial, and social objectives have been spelled out.

Our results underline that the epistemic orientation towards the ERA has been an all-encompassing, system-level transition for the Finnish research system since the mid-1990s. In many respects, this suggests that – at least in in the case of Finland – the ERA is increasingly attractive and relevant as a source of knowledge.

From the vantage point of research policy, we have also highlighted the fact that Finland's increased integration into the ERA can be characterized as a process of fragmentation, raising

another conceptual problem with the strategy of ERA. As Finnish research looks increasingly for sources of knowledge within the EU-27 countries, the number of relevant knowledge hubs in fact increases. The nature of this process belies the concept that the ERA is about “reduction of fragmentation” as spelled out in European research policy, and calls for the development of a conceptual framework for the integration of the ERA that accommodates increasing policy coordination and increasing variety of international research teams, as well as an increasing number of relevant European sources of knowledge for European researchers.

Supplementary material

Supplementary annex 1. Share from all references in Finnish research by major countries and regions, 1995-2010

Supplementary annex 2. Major cited countries and regions 1995-2010 by OECD major fields

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Tables

Table 1. Finnish scientific publications and reference data coverage, 1995-2010.

Year	Source records	Cited records	Country coverage in references
1995	4693	44024	67 %
1996	5119	52500	75 %
1997	6041	58226	72 %
1998	8800	79538	70 %
1999	8867	86357	78 %
2000	9477	93164	78 %
2001	9353	94726	80 %
2002	9608	99638	80 %
2003	9972	109270	81 %
2004	10705	106490	78 %
2005	10615	119059	81 %
2006	11480	126573	80 %
2007	11999	133211	79 %
2008	12341	151342	82 %
2009	12484	154965	83 %
2010	12018	162867	85 %
TOTAL	153572	1671950	

Source: ISI-WOS. Note: Source records include articles, conference proceedings and abstracts, and reviews.

Table 2. Share from all references in Finnish research by major geographical regions, 1995-2010

Year	EU-27	North America	Asia	Europe (non-EU)	Oceania	TOTAL reference counts	Records with references
1995	43,79 %	47,06 %	4,08 %	2,37 %	1,32 %	65191	3168
1996	44,59 %	45,91 %	4,17 %	2,50 %	1,43 %	79517	3846
1997	45,33 %	45,08 %	4,27 %	2,43 %	1,40 %	92175	4387
1998	46,08 %	43,72 %	4,34 %	2,75 %	1,55 %	127161	6244
1999	48,25 %	41,33 %	4,51 %	2,89 %	1,50 %	150980	6925
2000	47,70 %	41,04 %	5,01 %	2,91 %	1,65 %	174241	7394
2001	49,12 %	39,17 %	5,13 %	3,12 %	1,82 %	186672	7540
2002	49,51 %	38,50 %	5,38 %	3,05 %	1,86 %	204055	7687
2003	49,81 %	37,78 %	5,42 %	3,20 %	1,97 %	229912	8132
2004	50,10 %	37,28 %	5,56 %	3,31 %	1,96 %	239589	8425
2005	50,20 %	36,40 %	6,13 %	3,18 %	2,12 %	268553	8665
2006	50,10 %	36,03 %	6,50 %	3,23 %	2,04 %	286880	9200
2007	50,54 %	35,22 %	6,46 %	3,37 %	2,27 %	307738	9552
2008	50,51 %	34,71 %	6,77 %	3,35 %	2,36 %	351722	10196
2009	50,78 %	34,13 %	7,02 %	3,43 %	2,34 %	361318	10461
2010	50,16 %	34,13 %	7,12 %	3,57 %	2,43 %	381567	10325

Source: ISI-WOS.

Table 3. Share from all references in Finnish research – Top-10 countries, 1995-2010

YEAR	USA	Finland	UK	Germany	France	Canada	Japan	Sweden	Italy	Netherlands	TOTAL reference counts	Source records
1995	43,47 %	17,88 %	6,97 %	3,39 %	3,64 %	3,59 %	3,43 %	3,89 %	2,19 %	2,10 %	65191	3168
1996	42,06 %	17,66 %	7,18 %	3,49 %	3,50 %	3,85 %	3,46 %	3,73 %	2,49 %	2,26 %	79517	3846
1997	41,08 %	18,31 %	6,35 %	3,90 %	3,50 %	4,00 %	3,52 %	3,92 %	2,43 %	2,41 %	92175	4387
1998	39,95 %	17,72 %	7,35 %	3,87 %	3,46 %	3,77 %	3,48 %	4,02 %	2,40 %	2,51 %	127161	6244
1999	37,64 %	19,00 %	7,25 %	4,09 %	3,56 %	3,70 %	3,59 %	3,82 %	2,77 %	2,68 %	150980	6925
2000	37,36 %	18,99 %	7,03 %	4,50 %	3,47 %	3,68 %	3,98 %	3,71 %	2,59 %	2,56 %	174241	7394
2001	35,42 %	19,41 %	7,15 %	4,62 %	3,41 %	3,75 %	3,91 %	3,74 %	2,76 %	2,60 %	186672	7540
2002	34,63 %	19,63 %	7,04 %	4,60 %	3,54 %	3,87 %	4,05 %	3,69 %	2,81 %	2,41 %	204055	7687
2003	34,08 %	19,34 %	7,27 %	4,87 %	3,46 %	3,70 %	3,84 %	3,58 %	2,87 %	2,59 %	229912	8132
2004	33,79 %	19,24 %	7,24 %	5,00 %	3,32 %	3,49 %	3,81 %	3,73 %	2,98 %	2,68 %	239589	8425
2005	33,02 %	18,71 %	7,59 %	5,23 %	3,43 %	3,38 %	4,06 %	3,41 %	3,05 %	2,76 %	268553	8665
2006	32,45 %	18,54 %	7,28 %	5,23 %	3,46 %	3,58 %	4,06 %	3,50 %	2,83 %	2,82 %	286880	9200
2007	31,68 %	17,98 %	7,36 %	5,46 %	3,61 %	3,54 %	3,85 %	3,49 %	2,90 %	2,93 %	307738	9552
2008	31,11 %	17,69 %	7,60 %	5,39 %	3,54 %	3,60 %	3,73 %	3,58 %	3,05 %	2,76 %	351722	10196
2009	30,57 %	17,23 %	7,84 %	5,39 %	3,57 %	3,55 %	3,66 %	3,51 %	3,07 %	3,00 %	361318	10461
2010	30,55 %	16,70 %	7,66 %	5,31 %	3,65 %	3,57 %	3,47 %	3,42 %	3,17 %	2,83 %	381567	10325

Source: ISI-WOS

Table 4. Share from all references in Finnish Natural sciences research by major geographical regions, 1995-2010

YEAR	EU-27	North America	Asia	Europe (non-EU)	Oceania	TOTAL reference counts	Source records
1995	43,26 %	46,43 %	4,84 %	3,06 %	1,05 %	24858,69	1417
1996	45,20 %	43,26 %	5,49 %	3,31 %	1,36 %	28212,13	1628
1997	45,21 %	43,33 %	5,62 %	3,07 %	1,28 %	33648,77	1907
1998	46,50 %	41,31 %	5,34 %	3,55 %	1,46 %	50144,25	2973
1999	48,15 %	39,62 %	5,44 %	3,80 %	1,26 %	58694,04	3307
2000	47,35 %	39,60 %	6,00 %	3,65 %	1,56 %	70670,88	3505
2001	49,35 %	37,24 %	5,76 %	4,23 %	1,58 %	78702,5	3653
2002	49,12 %	36,98 %	6,52 %	3,95 %	1,61 %	89443,34	3803
2003	50,29 %	35,61 %	6,38 %	4,08 %	1,62 %	102600,22	4064
2004	50,05 %	35,31 %	6,84 %	4,12 %	1,62 %	106979,56	4181
2005	50,24 %	34,61 %	7,22 %	4,05 %	1,72 %	119666,66	4296
2006	49,45 %	34,79 %	7,70 %	3,91 %	1,85 %	129943,54	4684
2007	50,53 %	33,48 %	7,73 %	4,10 %	1,97 %	145891,97	4839
2008	49,48 %	33,73 %	8,22 %	4,13 %	2,03 %	161596,39	5021
2009	50,26 %	32,47 %	8,79 %	4,11 %	1,99 %	168322,03	5132
2010	48,94 %	33,40 %	8,81 %	4,16 %	2,06 %	182426,18	5175

Source: ISI-WOS

Table 5. Share from all references in Finnish Medicine and Health sciences research by major geographical regions, 1995-2010

YEAR	EU-27	North America	Asia	Europe (non-EU)	Oceania	TOTAL reference counts	Source records
1995	43,77 %	47,75 %	3,67 %	2,05 %	1,42 %	43553,66	1720
1996	44,11 %	47,56 %	3,42 %	2,08 %	1,40 %	53679,87	2091
1997	44,56 %	46,82 %	3,67 %	2,04 %	1,46 %	61804,75	2368
1998	45,33 %	45,73 %	3,75 %	2,22 %	1,58 %	82808,76	2886
1999	47,92 %	42,78 %	3,95 %	2,27 %	1,64 %	96477,65	3064
2000	46,83 %	43,14 %	4,57 %	2,24 %	1,65 %	107357,21	3180
2001	48,79 %	40,71 %	4,75 %	2,26 %	1,92 %	109847,92	3149
2002	48,89 %	40,48 %	4,77 %	2,26 %	1,97 %	115325,6	2922
2003	48,51 %	40,53 %	4,74 %	2,49 %	2,13 %	129945,07	3115
2004	49,69 %	39,52 %	4,59 %	2,52 %	2,13 %	132242,64	3148
2005	49,19 %	38,93 %	5,32 %	2,35 %	2,39 %	145203,58	3099
2006	49,86 %	37,92 %	5,65 %	2,50 %	2,14 %	151754,52	3202
2007	49,60 %	37,82 %	5,64 %	2,52 %	2,48 %	154878,3	3225
2008	51,07 %	36,08 %	5,66 %	2,51 %	2,53 %	177851,23	3514
2009	50,64 %	36,26 %	5,65 %	2,67 %	2,61 %	181076,36	3444
2010	50,31 %	36,04 %	5,60 %	2,88 %	2,71 %	186623,48	3541

Source: ISI-WOS

Table 6. Share from all references in Finnish Engineering and technology research by major geographical regions, 1995-2010

YEAR	EU-27	North America	Asia	Europe (non-EU)	Oceania	TOTAL reference counts	Source records
1995	50,64 %	37,81 %	6,45 %	2,23 %	1,08 %	2641,8	287
1996	49,48 %	39,79 %	5,70 %	2,05 %	1,63 %	4518	428
1997	52,62 %	36,15 %	5,78 %	2,83 %	1,09 %	5964,9	478
1998	49,23 %	38,15 %	6,28 %	2,76 %	1,64 %	7862,87	796
1999	50,04 %	38,18 %	6,27 %	2,95 %	0,99 %	10248,68	980
2000	51,42 %	34,98 %	6,71 %	3,35 %	1,61 %	11810,42	991
2001	50,69 %	35,43 %	6,77 %	3,73 %	1,69 %	14439,34	1184
2002	51,60 %	34,33 %	7,60 %	3,18 %	1,57 %	18179,76	1299
2003	52,10 %	32,72 %	8,16 %	3,61 %	1,57 %	21497,97	1374
2004	51,83 %	32,83 %	8,05 %	3,54 %	1,54 %	22557,03	1354
2005	51,51 %	32,01 %	9,10 %	3,50 %	1,65 %	25095,1	1557
2006	49,47 %	33,36 %	9,80 %	3,50 %	1,55 %	29961,9	1690
2007	50,93 %	31,98 %	9,37 %	3,39 %	1,78 %	36798,54	1836
2008	49,95 %	30,70 %	11,39 %	3,71 %	1,61 %	38360,19	1928
2009	49,21 %	30,51 %	12,32 %	3,49 %	1,72 %	40323,56	1927
2010	48,61 %	30,22 %	12,88 %	3,49 %	1,75 %	41238,79	1905

Source: ISI-WOS

Table 7. Share from all references in Finnish Social sciences research by major geographical regions, 1995-2010

YEAR	EU-27	North America	Asia	Europe (non-EU)	Oceania	TOTAL reference counts	Source records
1995	37,81 %	53,97 %	1,66 %	1,02 %	2,37 %	651,94	90
1996	37,40 %	57,65 %	0,79 %	1,33 %	1,88 %	1007,99	107
1997	42,53 %	50,72 %	1,06 %	1,43 %	3,22 %	1330,58	133
1998	38,91 %	54,78 %	2,02 %	1,42 %	1,77 %	2960,48	314
1999	41,97 %	50,58 %	1,85 %	1,74 %	2,17 %	2835,14	271
2000	42,98 %	50,28 %	1,59 %	1,54 %	2,17 %	3874,05	323
2001	43,37 %	48,70 %	2,34 %	1,73 %	2,46 %	4943,92	370
2002	46,22 %	45,32 %	2,26 %	2,47 %	1,93 %	4902,01	360
2003	44,28 %	47,02 %	1,94 %	2,15 %	2,91 %	6840,13	455
2004	45,76 %	45,14 %	2,14 %	2,36 %	3,11 %	8518,77	460
2005	47,79 %	42,41 %	2,50 %	2,45 %	2,54 %	9249,49	475
2006	44,64 %	45,70 %	2,21 %	2,24 %	2,79 %	10537,93	534
2007	45,93 %	44,24 %	2,56 %	2,56 %	2,76 %	14726,04	632
2008	45,21 %	44,13 %	3,07 %	2,52 %	3,18 %	17135,27	796
2009	47,17 %	41,70 %	2,60 %	3,03 %	3,55 %	21154,38	938
2010	47,31 %	40,69 %	2,99 %	2,67 %	3,92 %	21314,89	954

Source: ISI-WOS.

Table 8. Share from all references in Finnish Agricultural sciences research by major geographical regions, 1995-2010

YEAR	EU-27	North America	Asia	Europe (non-EU)	Oceania	TOTAL reference counts	Source records
1995	43,83 %	43,60 %	4,56 %	3,30 %	2,27 %	898,27	95
1996	45,85 %	40,42 %	4,46 %	2,67 %	4,23 %	1178,85	123
1997	50,56 %	39,40 %	3,10 %	3,12 %	1,97 %	2001,64	188
1998	49,94 %	38,47 %	3,22 %	3,72 %	2,77 %	3815,72	372
1999	51,81 %	36,53 %	3,17 %	4,59 %	2,46 %	3961,23	374
2000	55,95 %	32,04 %	3,50 %	3,38 %	2,98 %	4922,27	404
2001	55,44 %	33,79 %	3,23 %	3,76 %	1,79 %	5832,59	400
2002	61,97 %	26,50 %	3,40 %	4,01 %	2,37 %	7507,42	493
2003	59,66 %	27,49 %	4,20 %	4,41 %	2,35 %	7354,7	429
2004	58,42 %	28,59 %	3,92 %	4,44 %	2,54 %	9222,57	469
2005	59,36 %	26,97 %	3,30 %	4,33 %	3,43 %	10193,12	475
2006	59,91 %	26,51 %	4,26 %	4,36 %	2,68 %	13326,87	537
2007	61,89 %	24,10 %	3,85 %	4,52 %	2,87 %	12713,46	520
2008	60,04 %	25,76 %	3,94 %	4,18 %	3,50 %	14635,98	559
2009	61,31 %	24,36 %	4,66 %	4,42 %	2,46 %	17020,96	568
2010	60,88 %	23,43 %	5,08 %	4,86 %	2,87 %	16710,6	546

Source: ISI-WOS.