Patents, Innovation and Economic Geography

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Francesco LISSONI

GREThA, CNRS, UMR 5113

Université de Bordeaux

CRIOS – Università Bocconi, Milan (IT)

&

Ernest MIGUELEZ

GREThA, CNRS, UMR 5113

Université de Bordeaux

AQR-IREA (Barcelona, ES); CReAM (London, UK)

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GRETHA UMR CNRS 5113

Université de Bordeaux

Avenue Léon Duguit - 33608 PESSAC - FRANCE

Tel : +33 (0)5.56.84.25.75 - Fax : +33 (0)5.56.84.86.47 - www.gretha.fr

Brevets, Innovation et géographie économique

Résumé

Dans cet article, on résume 20 ans de recherche quantitative dans la géographie de l'innovation, au progrès de laquelle les données des brevets ont contribué d'une manière décisive. Nous savons maintenant que l'importance accordée par les premières études des externalités de connaissances en tant que force d'agglomération était excessive. Les flux de connaissances localisées existent, et expliquent l'agglomération, mais ils passent pour une grande part par les marchés du travail et des technologies. De plus, nous savons maintenant que la diffusion des connaissances est affectée par la distance physique, mais aussi par la distance sociale entre les inventeurs ainsi que les frontières internationales et intra-nationales. Nous assistons également à un élargissement continu du focus de la recherche, du niveau local / régional à l'international, avec des questions de migration à venir à l'avant-garde. Nous assistons enfin à un élargissement continu de la mise au point de la recherche, du niveau local / régional à l'international, avec les questions liées à la migration des inventeurs en premier plan.

Mots-clés : géographie économique, brevets, propriété intellectuelle, innovation, inventeurs, spillovers, migration

Patents, Innovation and Economic Geography

Abstract

In this paper we review 20 years of quantitative research in the geography of innovation, to whose advancement patent data have contributed in a decisive way. We know now that the importance attributed by the earliest studies to knowledge externalities as an agglomeration force was excessive. Localized knowledge flows exist, and explain agglomeration, but they are largely mediated by the labor market and markets for technologies. Besides, we know now that physical distance may affect knowledge diffusion, but so do social distance between inventors as well as inter- and intra-national borders. We also witness an ongoing widening of the research focus, from local/regional to international, with migration issues concerning inventors coming to the forefront.

Keywords: economic geography, patents, intellectual property, innovation, inventors, spillovers, migration

JEL: F22, J61, O31, R11, R12

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GRETHA UMR CNRS 5113
Université de Bordeaux
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1. Introduction

The relationship between patents and the geography of innovation is twofold. First, on a substantive level, the national patent laws and enforcement regimes, joint with international treaties, affect international trade and countries' specializations. This, in turn affects the viability of imitation-based catch-up strategies by less developed countries, as well as the flow of foreign direct investments and, possibly, the migration of inventors and entrepreneurs.[1]

Second, on a methodological level, patent data have been for long the main staple of quantitative research on the role played by innovation in shaping economic geography. Besides their longstanding use as innovation indicators, they have been increasingly exploited as a source of information on knowledge diffusion, and on inventors' mobility and networking.[2] In this role, they have contributed to improve the quality of research on a classic topic of economic geography, namely the role of innovation in determining the rise and fall of industrial clusters and, more generally, the spatial distribution of productive activities. A core issue within this research program concerns the public vs private good nature of new technical knowledge (or, to put it otherwise, the existence of knowledge externalities), and the relative role of physical distance, labor mobility, and licensing in making it available to third parties.[3]

The two levels, substantive and methodological, are increasingly overlapping. The social scientists who first made use of patent data for research on economic geography had a limited grasp of the nuances of patent legislation, and even less so of procedures leading from the application to the grant or refusal of patents (let alone of amendment or litigation). This limited their understanding of how such features of patent data may

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[1] A. Agrawal, "Diaspora Networks, Knowledge Flows and Brain Drain", WIPO Economic Research Working Papers with number 15 (2014).

[2] S. Breschi and F. Lissoni, "Knowledge Networks from Patent Data," in H.F. Moed, W. Glänzel and U. Schmoch (edd.), *Handbook of Quantitative Science and Technology Research* (2005) 613–43; Z. Griliches, "Patent Statistics as Economic Indicators: A Survey," *Journal of Economic Literature* 28 (1990) 1661–707; S. Nagaoka, K. Motohashi and A. Goto, "Chapter 25 - Patent Statistics as an Innovation Indicator," in Bronwyn H. Hall and Nathan Rosenberg (ed.), *Handbook of the Economics of Innovation* (Handbook of the Economics of Innovation, Volume 2, 2010) 1083–127

[3] S. Breschi and F. Lissoni, "Knowledge Spillovers and Local Innovation Systems: A Critical Survey," *ICC* 10 (2001) 975–1005

affect the potential and limitations of the latter. It was research on the economic efficiency of national patent systems and firms' patenting strategies that spread awareness in this direction, and contributed to increase data quality.[4]

In this paper we mainly focus on the methodological link, that is on what 20 years of patent-based research has taught us on the role of innovation in shaping economic geography. We know now that the importance initially attributed to knowledge externalities as an agglomeration factor was certainly excessive. Localized knowledge flows exist, and explain agglomeration, but they are largely mediated by the labor market and markets for technologies. Besides, we know now that physical distance may affect knowledge diffusion, but so do social distance between inventors as well as inter- and intra-national borders. We also witness an ongoing widening of the research focus, from local/regional to international, with migration issues coming to the forefront. These trends owe, among other things, to the increasing availability and sophistication of data. This has made been possible by the interplay of institutional support and bottom-up initiatives by applied researchers.

In the remaining of the paper we will first summarize the key theoretical issues concerning the relationship between innovation and geography (section 2). We will then move on to examine how patent data have been exploited to explore such issues (section 3), and on perspective uses for future research (section 4). In section 5, we describe some state-of-the-art datasets whose production and sharing owe to the interaction between scholars and institutions. Section 6 concludes.

2. Innovation and economic geography: the role of knowledge diffusion in space

Research in economic geography investigates the reasons why particular economic activities choose to establish themselves in particular places and the role of agglomeration forces in generating an uneven distribution of economic activity across space. Ultimately, this wide discipline seeks to explain the observed disparities in

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[4] J. Bessen and M.J. Meurer, *Patent failure: How judges, bureaucrats, and lawyers put innovators at risk*, Princeton University Press (2008); D. Guellec and B. van Pottelsberghe de la Potterie, *The Economics of the European Patent System*, Oxford University Press (2007); A.B. Jaffe and J. Lerner, *Innovation and its discontents: How our broken patent system is endangering innovation and progress, and what to do about it*, Princeton University Press (2011)

economic growth rates and development across cities and geographical areas.[5] These issues made it into mainstream economics primarily thanks to the work of the 2008 Nobel Laureate Paul Krugman.[6,7] Although with variations, three agglomeration forces are generally put forward – as first formulated by Alfred Marshall[8], and later revisited by Krugman:

1. ***Labor market pooling***: specialized – i.e., industry-specific – workers prefer locating close to agglomerated firms rather than isolated ones, as this constitutes an insurance against firm-specific labor demand shocks – while ensuring at the same time relatively lower local wages.
2. ***Market for intermediate inputs:*** producers of industry-specific intermediate inputs tend to agglomerate in order to benefit from scale economies and low transport costs.
3. ***Technological externalities***: physical proximity between firms favors intra-industry knowledge "spillovers" – i.e. unintentional flow of information. A firm's invention is more quickly imitated by other local firms than by distant ones, making agglomerated firms more innovative than isolated ones.

In this framework, Edward Glaeser and co-authors[9] point out that, if geographical proximity facilitates the transmission of ideas, it is expected that knowledge spillovers will be particularly important in cities. Glaeser's contributions rescue economic historians' ideas that most innovations are made in cities. In particular, Jane Jacobs[10] stressed that, while a critical feature of Marshallian knowledge externalities is that they are intra-industry, in her view the crucial type of externality comes from the cross-fertilization of ideas across different industries (inter-industry externalities). This makes

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[5] World Bank, "World development report. Reshaping Economic Geography," *The World Bank, Washington DC* (2009)

[6] P. Krugman, "The New Economic Geography, Now Middle-aged," *Regional Studies* 45 (2010) 1–7; P. Krugman, "Increasing Returns and Economic Geography," *Journal of Political Economy* 99 (1991)

[7] On the broad field of economic geography, two recent dissemination books for non-specialists are those of E. Glaeser, *Triumph of the city: How our greatest invention makes US richer, smarter, greener, healthier and happier*, Pan Macmillan (2011) and E. Moretti, *The new geography of jobs* (2012). Other recent scholarly-oriented handbooks include G.L. Clark, M.S. Gertler and M.P. Feldman, *The Oxford handbook of economic geography*, Houghton Mifflin Harcourt (2003), P.-P. Combes, T. Mayer and J.-F. Thisse, *Economic geography: The integration of regions and nations* (2008) and R. Boschma and R. Martin, *The handbook of evolutionary economic geography*, Princeton University Press (2010).

[8] A. Marshall, "Principles of Economics, (New York, 1948)," *Marshall8229Principles of Economics1948* (1890) 229

[9] E.L. Glaeser, H.D. Kallal, J.A. Scheinkman and A. Shleifer, "Growth in Cities," *Journal of Political Economy* 100 (1992) 1126–52

[10] J. Jacobs, "Economy of cities," (1969), Random House, New York

knowledge externalities particularly abundant in diversified cities and metropolitan areas, where the environment favors the rapid inter-personal diffusion of ideas.

After more than 20 years of empirical research, evidence in favor of one or the other type of externalities is, at best, mixed. Some scholars argue that Marshallian and Jacobs externalities are not mutually exclusive phenomena and that, possibly, they co-exist in large cities and metropolitan areas.[11] Others argue that there might be other externalities capable to explain city specialization without relying on knowledge spillovers – e.g., sharing of inputs, including specialized labor.[12] Thus, going back to Marshallian externalities, one can distinguish between pecuniary externalities – i.e., 1 and 2 – and non-pecuniary, or pure, externalities – i.e., number 3. [13] Precisely because of this dichotomy, the rediscovery of economic geography by mainstream economics started by Krugman went initially along with a heated debate on the role of technological externalities. The debate focused on three issues:

1) The measurability of knowledge spillovers, as opposed to pecuniary externalities
2) The relative weight of knowledge externalities with respect to other forms of (market-mediated) knowledge flows
3) The theoretical reasons for presuming knowledge flows, and externalities in particular, to be bound in space

2.1. Pure vs pecuniary externalities

Although originally disregarded by mainstream urban and regional economists, pure knowledge externalities were the cornerstone of innovation and geography studies by non-mainstream industrial economists, regional economists and other social scientists, during the1970s-80s. This line of research, however, did not provide either systematic

[11] S.E. Ibrahim, M.H. Fallah and R.R. Reilly, "Localized sources of knowledge and the effect of knowledge spillovers: an empirical study of inventors in the telecommunications industry," *J Econ Geogr* 9 (2009) 405–31

[12] Glaeser, Kallal, Scheinkman and Shleifer (supra n. 000)

[13] The distinction was first posited by Tibor Scitovsky., who described pecuniary externalities all benefits accruing from other firms' activities, and mediated by markets and the price system; and pure externalities as benefits also accruing from other firms' activities, but not mediated by market mechanisms. See: T. Scitovsky, "Two Concepts of External Economies," *Journal of Political Economy* 62 (1954)

attempts to theoretically formalize the role of knowledge spillovers, nor measurement efforts or intentions to disentangle knowledge externalities from other forms of externalities. Rather, its contributors went for producing several conceptual explanations for the presence of knowledge externalities in both low- high-tech sectors. Such explanations ranged from local cultural traits (e.g., trust attitudes), to dedicated institutions (professional schools, universities, bridging institutions), and to historical and cultural vestiges, or loosely defined social networks.[14]

Meanwhile, mainstream economists contrarily argued that knowledge externalities ought not to be put at the center of analysis, being they unmeasurable, which made all related propositions untestable. Krugman's original standing on this point was clear:[15]

> [...] knowledge flows are invisible; they leave no paper trail by which they may be measured and tracked, and there is nothing to prevent the theorist from assuming anything about them that she likes. So while I am sure that true technological spillovers play an important role in the localization of some industries, one should not assume that this is the typical reason - even in the high technology industries themselves. A sociologist might […] help with survey methods; but I would like [to use] economic analysis before turning to other social sciences (p. 54)

This was too big a challenge not to be seized by applied economists and econometricians. In the 30 years that followed, many ways were found to measure and track spillovers. Some consisted in large survey methods, now turned into part of the economists' toolbox. Others relied on sophisticated econometric methods to infer externalities from specific correlations (e.g., spatial econometrics). Finally, several more were based on patent citations as a proxy for knowledge spillovers.

[14] Two classic examples from this literature are: S. Brusco "The Emilian model: productive decentralisation and social integration" *Cambridge journal of economics*, 167-184 (1982) ; .A. Saxenian, "Regional advantage: Culture and competition in Silicon Valley and Route 128," *Harvard University, Cambridge, MA* (1994). Survey by: A.J. Scott, "Economic geography: the great half-century" *Cambridge Journal of Economics*, *24*(4), 483-504 (2000)

[15] P. Krugman, *Geography and trade* , MIT Press, Cambridge MA (1991)

2.2. Knowledge flows or knowledge spillovers?

Another highly debated topic concerned the specific role of knowledge externalities with respect to other forms of (market-mediated) knowledge flows as agglomeration forces. Economists have long understood the precise meaning of knowledge spillovers. As Grossman and Helpman[16] put it, by knowledge spillovers

> we mean that (1) firms can acquire information created by others without paying for that information in a market transaction, and (2) the creators (or current owners) of the information have no effective recourse, under prevailing laws, if other firms utilize information so acquired. (p. 16)

Yet, in spite of this unequivocal definition, the related literature has often associated knowledge spillovers with any means of diffusion of knowledge and ideas. However, under a more careful inspection, what have been considered to be pure externalities may turn to be knowledge flows arising from market transactions.[17] Knowledge diffusion may exist and may be critical to combine and recombine previously unconnected ideas, leading to new knowledge production and subsequent innovations. However, there is no a priori reason to assume that it does in the form of a pure externality: technology licensing, labor mobility, collaborations, and spin-offs may all have a role, possibly in association with some form of pecuniary externality, but also independently.

2.3. The geographical breath of knowledge flows

A key element of the knowledge spillovers explanation of agglomeration concerns the geographical reach of spillovers. A necessary assumption is that spillovers are subject to a strong spatial decay, thus being accessible only at short distances. This in turn requires assuming that, both in hi-tech and low-tech industries, *tacit* knowledge – as opposed to *information* – plays an important role. Knowledge is tacit to the extent that it escapes full codification in patents, articles or books. As such, effective knowledge exchanges

[16] G. Grossman and E. Helpman, *Innovation and growth in the global economy*, MIT Press (1993).
[17] P.A. Geroski, "What do we know about entry?," *International Journal of Industrial Organization* 13 (1995) 421–40

require face-to-face interactions, frequent meetings, and the formation of social capital.[18]

Accordingly, the concept of localized knowledge spillovers (LKS) has become a cornerstone of the geography of innovation literature.

However, several scholars have found that the market-based mechanisms listed above are also likely to produce some highly localized patterns of knowledge diffusion. This is not to deny the importance of geography. Spatial proximity reduces the cost of trading knowledge in the marketplace and makes possible the flow of ideas, while at the same time fosters trust and mutual understanding between agents, facilitating again the exchange of knowledge via market mechanisms.

3. Patents as indicators and economic geography

3.1. Localized Knowledge Spillovers: measurement and estimation issues

Among other things, patent documents contain information on the applicants and inventors, including their geographical origin – down to the level of street addresses. This information has allowed researchers to geo-localize, in an increasingly sophisticated way, inventive activity, and to investigate spatial differences in knowledge production, as a function of several inputs such as regional R&D expenditures as well as other regional features (we will come back to it below).

In parallel, Jaffe and co-authors challenged Krugman's statement on the invisibility of knowledge spillovers by arguing that

> knowledge flows do sometimes leave a paper trail, in the form of citations in patents (p. 578) [19].

[18] D.B. Audretsch and M.P. Feldman, "R&D Spillovers and the Geography of Innovation and Production," *American Economic Review* 86 (1996) 630–40; M.P. Feldman and D.B. Audretsch, "Innovation in cities:: Science-based diversity, specialization and localized competition," *European Economic Review* 43 (1999) 409–29; P. Martin and G. I.P. Ottaviano, "Growing locations: Industry location in a model of endogenous growth," *European Economic Review* 43 (1999) 281–302

[19] A.B. Jaffe, M. Trajtenberg and R. Henderson, "Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations," *The Quarterly Journal of Economics* 108 (1993) 577–98

Patent (or prior art) citations can be found on the search reports filed by inventors and/or produced by patent examiners. They have been assumed to hide, along with lots of statistical noise, some knowledge debt running from the citing to the cited inventors (similarly, one can look for a debt from citing inventors to scientists by checking the citations to the non-patent literature, also found in search reports). By comparing the geographical location of the inventors (or the applicants) of the cited and the citing patents, Jaffe and co-authors then proposed the first test of the geographic localization of spillovers. Their classic methodology consists in taking a sample of cited patent-citing patent pairs (excluding self-citations at the firm level), and compare them with a control sample, in which the citing patents are replaced with patents with the same application year and technological field, but no citation links to the cited pair members. By comparing the rate of co-location (at the city or state level) of the cited-citing pairs to that of the cited-control pairs, and finding the former to be higher than the latter, Jaffe and co-authors showed that citations tend to concentrate in space high and above what one would expect by simply looking at the geographical distribution of patents, by technology.

Despite some methodological reservations raised by Thompson and M. Fox-Kean[20], Jaffe's et al. methodology has become the basis of the patent-based geography of innovation literature. Follow-up research has concentrated on disentangling how different dimensions of geographical distance affect knowledge diffusion, as well as on questioning Jaffe et al.'s original interpretation of their evidence. In all cases, patent data have proven to be extremely valuable sources of information.

Concerning distance, Jaffe et al. treated it as a binary variable, simply focusing on whether patent citations occur mostly within states or within metropolitan areas, irrespective of the relative geo-localized position of the patents. Quite recently, Murata et al.[21] go beyond this limitation by developing a physical distance-based test able to capture cross-boundary, spatially close knowledge spillovers. They find that simple, continuous geographical distance also matters, even when building the control sample at

[20] P. Thompson and M. Fox-Kean, "Patent Citations and the Geography of Knowledge Spillovers: A Reassessment," *The American Economic Review* 95 (2005) 450–60

[21] Y. Murata, R. Nakajima, R. Okamoto and R. Tamura, "Localized knowledge spillovers and patent citations: A distance-based approach" ***(****Review of Economics and Statistics* (forthcoming)

a finer technological aggregation. At the same time, Singh and Marx[22] show that physical distance and administrative borders play independent roles as obstacles to knowledge diffusion, both of them being significant when inserted in an exercise *à la* Jaffe et al. Belenzon and Schankerman[23], who concentrate their attention on university-industry knowledge spillovers, arrive to similar conclusions. They show that citations to patents filed by US universities at USPTO decline sharply with distance from the universities and are strongly constrained by state borders.

The main reason for looking at patent citations as useful ‘flow’ indicators resides in the belief that invention is a cumulative and social process, and that patent document do not fully disclose the knowledge contents of inventions. Thus, many bits of knowledge that are necessary to exploit or improve upon the patented inventions, need to be passed on by practical demonstrations, clarification of terminology through examples and metaphors, debugging of codified messages, and so forth. All of these activities require personal interaction between inventors (of citing and cited patents), which are favored by geographical proximity.

In this respect, critics of the use of patent citations point out that patent examiners, rather than inventors, are ultimately responsible for many if not all the citations attached to patent documents, depending on patent offices’ practices.. Even when citations track down effectively some sort of knowledge flow, it remains to be discussed whether the latter runs between the inventors of the cited and the citing patent (inter-personal knowledge flow), or, more simply, between the cited patent and the inventor who cites it, such as when the inventor retrieves patent information directly from a database (direct retrieval).[24]

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[22] J. Singh and M. Marx, “Geographic Constraints on Knowledge Spillovers: Political Borders vs. Spatial Proximity,” *Management Science* 59 (2013) 2056–78

[23] S. Belenzon and M. Schankerman, “Spreading the Word: Geography, Policy, and Knowledge Spillovers,” *Review of Economics and Statistics* 95 (2013) 884–903

[24] Several papers have shown that a large proportion of patent citations are added by the examiners, and not by the inventors or applicants – see J. Alcácer and M. Gittelman, “Patent Citations as a Measure of Knowledge Flows: The Influence of Examiner Citations,” *Review of Economics and Statistics* 88 (2006) 774–79 – around 40% in the US, 93% for the EPO. Other studies also find that the usefulness of patent citations as a measure of knowledge flows varies greatly across technologies and geographical areas – see E. Duguet and M. MacGarvie, “How well do patent citations measure flows of technology? Evidence from French innovation surveys,” *Economics of Innovation and New Technology* 14 (2005) 375–93.

While the jury is still out on deciding on whether patent citations are good proxies for knowledge flows, patents have also been increasingly exploited for the information they provide on inventors. Inventors are an important class of knowledge workers, especially in sectors where R&D is a key innovation input. Thanks to patent-based information on their home or work address, as well as on the identity of the assignees of their patents, they can be tracked down, contacted and asked directly relevant questions. Two examples of this survey-based research on inventors are:

(1) the PatVal-EU survey, which surveyed the inventors of 9,017 EPO applications with priority date 1993-1997 from Denmark, France, Germany, Hungary, Italy, Netherlands, Spain, and the UK;[25]

(2) the RIETI-Georgia Tech inventor survey, which collects questionnaires from a sample of US and Japanese inventors of triadic patents, including 1,900 inventors from the US and 3,600 from Japan.[26]

Giuri and Mariani[27] have relied on the PatVal-EU questionnaire to investigate the role of education as a meeting factor in the relationship between geography and spillovers. They find that inventors with higher education degrees tend to access more distant knowledge sources than less educated ones, even after taking into consideration their higher capability to absorb knowledge in general.

Another strand of literature has studied LKS by looking at the spatial distribution of patents, at the level of geographical units such as states, regions or metropolitan areas, based upon a regional knowledge production function (KPF) approach. Jaffe's (1989)[28] pioneering paper models the spatial distribution of corporate patents across US states and broad technological areas as a function of the states' public and private R&D expenditure. It is shown that that the number of corporate patents is positively affected by the R&D performed by local universities, after controlling for private R&D inputs. Albeit in the absence of explicit modelling or testing, Jaffe interprets these results as further support to the existence of LKS, which in this case would run from academic

[25] P. Giuri, M. Mariani, S. Brusoni, G. Crespi, D. Francoz, A. Gambardella, W. Garcia-Fontes, A. Geuna, R. Gonzales, D. Harhoff, K. Hoisl, C. Le Bas, A. Luzzi, L. Magazzini, L. Nesta, Ö. Nomaler, N. Palomeras, P. Patel, M. Romanelli and B. Verspagen, "Inventors and invention processes in Europe: Results from the PatVal-EU survey," *Research Policy* 36 (2007) 1107–27

[26] J.P. Walsh and S. Nagaoka, "Who Invents?: Evidence from the Japan-U.S. inventor survey," (2009)

[27] P. Giuri and M. Mariani, "When Distance Disappears: Inventors, Education, and the Locus of Knowledge Spillovers," *Review of Economics and Statistics* 95 (2013) 449–63

[28] A.B. Jaffe, "Real Effects of Academic Research," *The American Economic Review* 79 (1989) 957–70

research to corporate innovative activities. This evidence has been confirmed by subsequent studies.[29]

An important extension of the regional KPF approach makes use of spatial econometrics, in order to take into account cross-border effects in a KPF. Anselin et al.[30] show that university research of one particular region has a positive impact on regional rates of innovation of nearby or contiguous regions; in the case of the US, this effect extends over a range of 75 miles from the knowledge source. Similarly, for Europe, Bottazzi and Peri[31] show that regional patent intensities are affected not only by local R&D expenditures, but also from R&D conducted in other regions, up to a range of 300 km.[32]

In the same vein, the 2000s have seen an increasing number of contributions modelling the patent intensity of regions as a function of the patent production per capita of other regions. Based on ad-hoc matrixes describing the relationships between geographical units (distance, common borders etc.), this literature has consistently found a strong co-occurrence of high values of patent intensity in one region with high values of patent intensity in nearby ones. This has been interpreted, again, as evidence of LKS.[33]

Within this macro tradition, a number of scholars have focused on the role of dense, large and diverse cities in fostering innovation outcomes. These contributions take on board Jane Jacobs' emphasis on the prevailing role of urban diversity for knowledge spillovers. They also give answer to the evidence found on the disproportionate production of patents in metropolitan areas: e.g., Chatterji et al.[34] reports that during the 1990s, 92% of patents were granted to residents of metropolitan areas in the US – while only three-quarters of the US population resided in these areas.

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[29] Z.J. Acs, D.B. Audretsch and M.P. Feldman, "R&D Spillovers and Recipient Firm Size," *The Review of Economics and Statistics* 76 (1994) 336; Audretsch and Feldman (supra n. 000); Feldman and Audretsch (supra n. 000)

[30] L. Anselin, A. Varga and Z. Acs, "Local Geographic Spillovers between University Research and High Technology Innovations," *Journal of Urban Economics* 42 (1997) 422–48

[31] L. Bottazzi and G. Peri, "Innovation and spillovers in regions: Evidence from European patent data," *European Economic Review* 47 (2003) 687–710

[32] NUTS is the French acronym for *Nomenclature d'Unités Territoriales Statistiques* and it is the European standard for referencing the subdivision of countries for statistical purposes.

[33] See, e.g., C. Autant-Bernard and J.P. LeSage, "Quantifying Knowledge Spillovers Using Spatial Econometric Models," *Journal of Regional Science* 51 (2011) 471–96

[34] A. Chatterji, E.L. Glaeser and W.R. Kerr, "Clusters of Entrepreneurship and Innovation", NBER Working Paper No. 19013 (2013)

Econometric evidence in this direction is provided by Gerald Carlino[35,36], who model the rate of patenting per capita as a function of the urban features of metropolitan areas, such as urban size or population density. Again, this approach does not directly look at knowledge spillovers, but it builds on the assumption that the concentration of employment in cities is explained by the inventors' need to access tacit knowledge.

3.2. Labor mobility, networks and economic geography

Economists have long shared the view that inter-firm mobility of skilled employees transmits knowledge across organizations[37]. Patent data provide a mean to test this classic hypothesis and to test to what extent it can explain the observed concentration of knowledge flow in space.

A pioneering study in this sense is due to Almeida and Kogut[38], who show that inter-firm mobility of inventors in the US semiconductor industry influences the local transfer of knowledge across firms. This suggests that knowledge externalities go along with mobility within spatially defined labor markets. Breschi and Lissoni[39] extend Jaffe et al.'s classic approach by considering not only the role of spatial distance between inventors, but also that of social distance. They show that mobility of inventors across firms occurs largely within the same locations, so that many citations occurring between companies are in fact personal self-citations by mobile inventors. The same inventors, by joining different teams, end up building a localized collaboration network that largely explains the observed spatial patterns of citations flows (social distance between any two inventors can be measured by the number of collaboration ties that separate

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[35] G.A. Carlino, S. Chatterjee and R.M. Hunt, "Urban density and the rate of invention," *Journal of Urban Economics* 61 (2007) 389–419

[36] G.A. Carlino and R.M. Hunt, "What Explains the Quantity and Quality of Local Inventive Activity?", Federal Reserve Bank of Philadelphia Working Paper No. 09-12 2009)

[37] K.J. Arrow, "The Economic Implications of Learning by Doing," *Review of Economic Studies* 29 (1962) 155–73. For some contrary evidence, see: M. Maliranta, P. Mohnen and P. Rouvinen, "Is inter-firm labor mobility a channel of knowledge spillovers? Evidence from a linked employer–employee panel," *Industrial and Corporate Change* 18 (2009) 1161–91; J. Møen, "Is Mobility of Technical Personnel a Source of R&D Spillovers?," *Journal of Labor Economics* 23 (2005) 81–114

[38] P. Almeida and B. Kogut, "Localization of Knowledge and the Mobility of Engineers in Regional Networks," *Management Science* 45 (1999) 905–17

[39] S. Breschi and F. Lissoni, "Mobility of skilled workers and co-invention networks: an anatomy of localized knowledge flows," *Journal of Economic Geography* 9 (2009) 439–68

them).[40] These findings are confirmed by Miguelez and Moreno[41], who study the determinants of cross-regional mobility of inventors of EPO applications for a sample of European countries. By tracking cross-regional movements of inventors, the authors find both descriptive and analytical evidence on the critical role of spatial distance as well as country borders in hampering the mobility of this specific class of knowledge workers.

Mobile inventors do not only transfer knowledge from their original location to their destinations, but also allow for the opposite flows, thanks again to social networks. Agrawal et al[42] find that citations to mobile inventors' patents filed after their transfer from one city to another come disproportionately from their prior locations.

However, not all inventors who appear to have signed patents for different assignees can be treated as mobile, in the sense of having worked for different employers. Many of them may be freelance inventors or inventors working for non-practicing entities (such as universities), who either sell their inventions as part of research contracts, or sell the patents they have filed to other companies.[43] While inventors moving across companies may generate spillovers (to the extent that they spread knowledge from one company to another, without any compensation for the former), those who sell their inventions operate on a market for technologies, which may generate some pecuniary externalities, and yet treat knowledge as an entirely private good.

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[40] Important contributions on the role of social networks (patent co-inventorships) to explain localized citations flows is due to, e.g., J. Singh, "Collaborative Networks as Determinants of Knowledge Diffusion Patterns," *Management Science* 51 (2005) 756–70, who uses data from the USPTO and finds strong evidence that the existence of interpersonal ties in the form of co-patents increases the probability of knowledge flows, as measured by patent citations. In particular, he finds that these ties are critical to explain knowledge flows within regions and within firms' boundaries, as opposed to inter-regional and inter-organizational flows – geography matters only because interpersonal networks tend to be regional in nature. Along these same lines, S. Breschi and F. Lissoni, "' Cross-Firm' Inventors and Social Networks: Localized Knowledge Spillovers Revisited," *Annales d'Economie et de Statistique* (2005) 189–209 mine a data set of over 30,000 EPO patent applications by Italian inventors as a source of relational data. They find that the original Jaffe et al. results hold only for patents whose inventors are socially connected, and that short social distances greatly enhances the probability to observe co-location between cited and citing patents. This is taken as evidence that geographical proximity is not a sufficient condition for accessing spillovers, as long as these circulate only within tightly knitted social networks.

[41] E. Miguélez and R. Moreno, "What Attracts Knowledge Workers? The Role of Space and Social Networks," *Journal of Regional Science* 54 (2014) 33–60

[42] A. Agrawal, I. Cockburn and J. McHale, "Gone but not forgotten: knowledge flows, labor mobility, and enduring social relationships," *Journal of Economic Geography* 6 (2006) 571–91

[43] On the importance of company-assigned academic patents see: F. Lissoni (2012). Academic patenting in Europe: An overview of recent research and new perspectives. *World Patent Information*, *34*(3), 197-205. On the quantitative relevance of change of property in patents C.J. Serrano, "The dynamics of the transfer and renewal of patents," *The RAND Journal of Economics* 41 (2010) 686–708

Following this lead, some scholars have studied the geographical reach of patent licensing activities, especially by universities. University licensing terms may be extremely complex, and very often involve the inventors themselves as licensees, or as shareholders of the licensee firm. This is because most of the university patents protect early prototypes and "proofs of concept" that need much further development, which in turn call for the direct involvement of the inventors.[44] In all of these cases, we may expect to observe a good deal of knowledge being transferred from university inventors to industrial researchers within companies, which we can hardly classify as a spillover. At the same time, as long as the university inventors retain their academic positions, but are consulted frequently by the licensee company, those knowledge flows will remain highly bounded in space. This is especially the case with contracts that bundle the provision of complementary tacit and codified knowledge, as when technical assistance and training is provided along with the patent license.[45]

Evidence in this latter direction is provided by Mowery and Ziedonis[46], who observe that the Jaffe et al.'s test did not control for the possibility that many cited-citing patent couples hide a licensing link, as when a licensee builds upon (and cites) the licensed patent to produce an invention of his own. They examine over 14,000 patents granted over many years to Columbia University, University of California, and Stanford University, for which they calculate both the number of licenses granted to companies from 50 large metropolitan areas and the number of citations coming from the same areas (excluding citations from the licensees). Separate regressions of the two dependent variables over the distance between universities and metropolitan areas, plus a wide range of controls, show that distance takes a higher toll on licenses than citations, and conclude that spillovers are less localized than knowledge flows mediated by licenses.

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[44] R. Jensen and M. Thursby, "Proofs and Prototypes for Sale: The Licensing of University Inventions," *American Economic Review* 91 (2001) 240–59; J. Colyvas, M. Crow, A. Gelijns, R. Mazzoleni, R.R. Nelson, N. Rosenberg and B.N. Sampat, "How do university inventions get into practice?," *Management Science* 48 (2002) 61–72

[45] A. Arora, "Contracting for tacit knowledge: the provision of technical services in technology licensing contracts," *Journal of Development Economics* 50 (1996) 233–56. See also, G.A. Crespi, A. Geuna and L. Nesta, "The mobility of university inventors in Europe," *The Journal of Technology Transfer* 32 (2007) 195–215, who find that hiring a university inventor the employer access to her tacit knowledge.

[46] D.C. Mowery and A.A. Ziedonis, The Geographic Reach of Market and Non-Market Channels of Technology Transfer: Comparing Citations and Licenses of University Patents, NBER Working Paper No. 8568 (2001)

4. Future research

Despite the large amount of patent-based research in economic geography produced over the last 20 years, many questions remain open.

One emerging topic, at the crossroads of economic geography and the economics of intellectual property, is that of inventors' migration, where inventors are considered both as a representative sample of highly skilled workers, and a special category among the latter, one whose migration choices is affected by the relative strength of IP rights in different countries.

The economic analysis of inventor migration relates to geography on a substantive level. First, recent research has shown that skilled migration, and in particular of scientists and engineers, is the most dynamic component of total migration worldwide. At the same time, the geographical distribution of skilled migrants within host countries is very uneven, with large cities attracting most of them.[47] Last, but not least, a consensus exist on the importance of skilled immigrants to science and technology progress in their host countries.[48] These three factor combined suggest that migrant scientists and engineers (including inventors) may significantly affect the spatial distribution of innovation production and, ultimately, the economic growth differentials across regions.

Second, some studies seem to suggest that geographical innovation clusters have become more and more interconnected, and that while geographical proximity is critical for innovation, opportunities for learning by interacting also exist beyond clusters' boundaries.[49] One such extra-cluster interactions across countries are high-skilled migration and business travels back and forth from Bangalore to Silicon Valley.[50]

[47] W.R. Kerr, "The agglomeration of US ethnic inventors," *Agglomeration economics* (2010) 237–76; M. Nathan, "Ethnic Inventors, Diversity and Innovation in the UK: Evidence from Patents Microdata", SERC Discussion Paper 0092 (2011)

[48] P.E. Stephan and S.G. Levin, "Exceptional contributions to US science by the foreign-born and foreign-educated," *Population Research and Policy Review* 20 (2001) 59–79

[49] M. Gittelman, "Does Geography Matter for Science-Based Firms? Epistemic Communities and the Geography of Research and Patenting in Biotechnology," *Organization Science* 18 (2007) 724–41; J. Owen-Smith and W.W. Powell, "Knowledge Networks as Channels and Conduits: The Effects of Spillovers in the Boston Biotechnology Community," *Organization Science* 15 (2004) 5–21

[50] A. Saxenian, *The New Argonauts: Regional Advantage in a Global Economy*, Harvard University Press (2006)

Economists and other social scientists are at present investigating to what extent these interactions may allow for knowledge transfer from immigrants' host countries to their countries of origin, thus compensating for the latter's loss of skilled workers (brain drain).

Patent and inventor data are increasingly exploited in this sense. In particular, Agrawal et al.[51] and Kerr[52] look at the relation between ethnic inventors in the US and knowledge flows back to the ethnic inventors' country of origin, finding relatively weak evidence of a positive relation between the two – stronger for the most valuable innovations and for certain technological fields and particular ethnic groups. At the same time, Foley and Kerr[53] and Miguelez[54] find stronger effects on the relationship between inventor diasporas and the formation of international co-inventorship teams. However, empirical evidence is still scarce and generally focused on a limited number of sending and receiving countries.

Information on migration can be extracted from patent data in three ways. A basic approach consists in tracking inventors' international mobility by following their patenting histories across different countries.[55] This approach suffices to study in- and out-flows of one single country (e.g., the US), although it is not the most appropriate methodology to depict the whole picture of inventor migration flows across several countries. For example, one could apparently observe many inventors migrating from the US to China or India, when they are actually returnee inventors that applied for their first patent while studying or working in the US, and the following ones after having come back to their home countries.

A second approach consists in combining inventor-based data with extensive information on the ethnic origin of names and surnames from official registers. A

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[51] A. Agrawal, D. Kapur, J. McHale and A. Oettl, "Brain drain or brain bank? The impact of skilled emigration on poor-country innovation," *Journal of Urban Economics* 69 (2011) 43–55

[52] W.R. Kerr, "Ethnic Scientific Communities and International Technology Diffusion," *Review of Economics and Statistics* 90 (2008) 518–37

[53] C.F. Foley and W.R. Kerr, "Ethnic Innovation and U.S. Multinational Firm Activity," *Management Science* 59 (2013) 1529–44

[54] E. Miguélez, "Inventor Diasporas and the Internalionalization of Technology", Cahiers du GREThA 2014-12 (2014)

[55] A. Oettl and A. Agrawal, "International labor mobility and knowledge flow externalities," *Journal of International Business Studies* 39 (2008) 1242–60

pioneering strategy in this direction is provided by Kerr[56], who combines inventor data (name and surname) from the USPTO with the Melissa ethnic-name database, a commercial repository of names and surnames of US residents, classified by likely country of origin. More recently, Breschi et al.[57] have built on the same approach by experimenting with the IBM-GNR system, a commercial product which associates a list of names and surnames to a likely country of origin.

A third approach consists in collecting information on the nationality of their inventors. This has been made possible by WIPO, which has released a dataset of inventors listed in Patent Cooperation Treaty (PCT) applications containing, not only the inventors' country of residence, but also their nationality.[58] Contrary to the methods documented above, this dataset has the advantage that makes unnecessary to perform complicated, and necessarily imperfect, algorithms in order to ascertain the likely origin of inventors. Moreover, it includes a very large number of sending and receiving countries. Unfortunately, it also comes with some limitations, such as the fact that the numbers do not include immigrant inventors who became citizens of the host countries, thereby underestimating migration figures.

5. Research infrastructure and data sharing

As illustrated by the previous sections, patent data for research in economic geography have now been in use for more than 20 years. Over this period, data collection and sharing have moved from being confined to bottom-up initiatives of individual researchers to involving some institutional actors. Still, the journey has not yet arrived to its end, as none of the institutional actors presently involved provide all the indicators required by the researchers, nor a consensus has been reached on several methodological issues. The present situation is best described as one in which institutional actors interact with influential groups of researchers on a continuative

[56] W.R. Kerr, "The Ethnic Composition of US Inventors" Harvard Business School Working Papers 08-006 (2007)

[57] S. Breschi, F. Lissoni and G. Tarasconi, "Inventor Data for Research on Migration and Innovation: A Survey and a Pilot", WIPO Economic Research Working Papers 17 (2014)

[58] See E. Miguelez and C. Fink, "Measuring the International Mobility of Inventors: A New Database", WIPO Economic Research Working Papers 08 (2013), and for an early and partial use of this information, see V. Wadhwa, A. Saxenian, B.A. Rissing and G. Gereffi, "America's New Immigrant Entrepreneurs: Part I" (Rochester, NY 2007).

basis, by providing access to regularly updated raw or semi-structured data,on the basis of users' feedbacks.

5.1. From the NBER dataset to PatStat

Early research on LKS (see section 2) built upon a dataset of USPTO patents that was later made generally available by Hall et al.[59] under the name of "NBER patent citation data file" (in short, NBER dataset). The NBER dataset was widely exploited by all subsequent research, but its diffusion was not supported institutionally, nor any mechanism was put in place to collect users' feedbacks. As the dataset contained only unstructured raw data, most users ended up in huge and wasteful duplications of data cleaning efforts. As for information on inventors, the NBER dataset did not provide any unique identifier for inventors appearing on different patents either with the same name but different addresses, or with misspelled or slightly changed names. This implied the impossibility to check for self-citations at the individual level, to track mobile inventors who move across cities or countries, or to build inventor networks, unless the data user performed a name disambiguation effort of her own initiative.[60] The same applied to companies' names, with the additional problem that distinct companies could belong to the same group or merge at different points in time.

Recent efforts to update and upgrade the NBER dataset have addressed specifically this issue. Lee Fleming and co-authors[61] have produced and made publicly available several generations of disambiguated inventor data. One limitation of this data development trajectory is its USPTO-centrism, which makes it not immediately useful for research based also on data from several patent offices (such as when patent citations need to be collected at the patent family level [62]).

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[59] B.H. Hall, A.B. Jaffe and M. Trajtenberg, "The NBER patent citation data file: Lessons, insights and methodological tools", NBER Working Paper No. 8498 (2001)

[60] On name disambiguation, see: J. Raffo, and S. Lhuillery (2009). How to play the "Names Game": Patent retrieval comparing different heuristics. *Research Policy*, *38*(10), 1617-1627.

[61] See G.-C. Li, R. Lai, A. D'Amour, D.M. Doolin, Y. Sun, V.I. Torvik, A.Z. Yu and L. Fleming, "Disambiguation and co-authorship networks of the U.S. patent inventor database (1975–2010)," *Research Policy* 43 (2014) 941–55

[62] On patent families, see: C. Martínez, (2011). Patent families: When do different definitions really matter?. *Scientometrics*, *86*(1), 39-63.

A different, more inclusive trajectory is the one initiated by the EPO with the creation of PatStat, the Worldwide Patent Statistical Database.

PatStat is a very large database covering around 80 patent offices (including all the largest ones), which EPO distributes for a low fee to non-commercial users interested to large scale statistical analysis.[63] Launched in the second half of the 2000s, PatStat is now supported by several other organizations, such as the OECD, Eurostat, USPTO, and WIPO, which either contribute by producing complementary data, or by simply supporting its use, making it a de facto standard.

A unique identifier (stable through editions since April 2011) allows to re-unite all information concerning the individual patent applications (from the title to the inventors and applicants, as well as to all legal information) as well as, with some elaboration, the information concerning patent families. Starting with the April 2013 edition, inventors and applicants are also assigned a stable unique identifier (PERSON_ID), albeit one which is not based on any name disambiguation algorithm (but simply on the exact matching of names and addresses through applications).

PatStat users' inputs are collected and diffused by means of dedicated forums[64] and websites, and have produced significant improvements in the data that are distributed. This emerging infrastructure has given birth to a users' community, in which economic geographers and regional economists are largely implicated, especially for what concerns information on inventors and localities (addresses of both inventors and applicants). Further relevant information concerns applicants (name disambiguation and identification of industrial groups) and non-patent literature citations.

5.2. PatStat-based complementary data for geographical analysis

The most important PatStat-based complementary dataset for research on economic geography is RegPat, which is produced, regularly updated, and publicly diffused by the OECD. Regpat provides standardized information on the addresses of inventors and

[63] For access and documentation : http://www.epo.org/searching/subscription/patstat-online.html
[64] Such as the yearly conference on "Patent Statistics for Decision Makers", and the accompanying PatStat workshops. For FAQ and forums, see: http://forums.epo.org/patstat/. An unofficial, but popular blog, is: http://rawpatentdata.blogspot.it/

applicants of EPO and PCT patents for all OECD and EU28 countries, plus BRICS. [65] This is done first by parsing and disambiguating the addresses, so to obtain a postal code and city name, and then assigning a NUTS3 or equivalent regional code. Low quality of the address information has prevented so far the full extension of Regpat to USPTO patents. Still, patent family information from PatStat allows in principle to geo-localize most USPTO applications with an EPO or PCT equivalent.

Regpat has still some way to go in terms of coverage (of patent offices), but we are not aware of any major data quality issue. The same cannot be said for information concerning the identity of applicants and inventors. In this respect, two databases exist, both reachable through the OECD and the EPO, which contain partially disambiguated information on patent applicants, namely: the HAN/OECD[66] and the EEE-PPAT datasets[67].

While both the HAN/OECD and the EEE-PPAT databases mark a great improvement in data quality information, they are still affected by data quality issues. Most notably, they could be improved upon in terms of type II errors (false negatives). These limitations affect some information at the core of research programs on the geography of innovation, most notably those on knowledge diffusion (which requires identifying self-citations at the company level) and inventor mobility (which investigates not only mobility in space, but also across companies).

The state of the art is still more fluid when it comes to information on inventors. The only PatStat-based inventor database is EPO-INV, which makes use of an idiosyncratic patent-inventor code (soon to be replaced by PatStat original PERSON-ID).[68]

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[65] See S. Maraut, H. Dernis, C. Webb, V. Spiezia and D. Guellec, "The OECD REGPAT Database", OECD Science, technology and Industry Working Papers, 2008/02 (Paris 2008)

[66] G. Thoma, S. Torrisi, A. Gambardella, D. Guellec, B.H. Hall, & D. Harhoff, "Harmonizing and combining large datasets–an application to firm-level patent and accounting data", National Bureau of Economic Research, No. w15851 (2010). See also: http://www.oecd.org/science/inno/oecdpatentdatabases.htm (last visited: September 2014)

[67] T. Magerman,Grouwels J., Song X. & Van Looy B. "Data Production Methods for Harmonized Patent Indicators: Patentee Name Harmonization".EUROSTAT Working Paper and Studies, Luxembourg (2009). See also: https://www.ecoom.be/nl/EEE-PPAT (last visited: September 2014)

[68] On APE-INV see: Pezzoni, M., Lissoni, F., & Tarasconi, G. "How to kill inventors: testing the Massacrator© algorithm for inventor disambiguation", Cahier du GREThA No. 2012-29, Groupe de Recherche en Economie Théorique et Appliquée, Université de Bordeaux (2012). See also: http://www.esf-ape-inv.eu/ (last visited: September, 2014)

A common issue for both the datasets on inventors and on applicants is that no *ex ante* name disambiguation effort can produce an entirely satisfactory result (the same may apply to geo-localization, but to a smaller extent). Users' feedbacks are necessary, but the organizational and technical challenges for incentivizing their provision and making the collection possible are huge. Some attempts have been made (most notably by the APE-INV research program[69]), but to little avail. Institutional support would be decisive.

6. Conclusions

Patent data have greatly contributed to the advancement of the geography of innovation literature. Most notably, they have contributed to create a consensus on the extent of the localization in space of knowledge flows. However, several scholars in the field have questioned the interpretation of this evidence in terms of pure knowledge externalities. Market-based channels, such as licensing (with consulting) and labor mobility of human capital are most likely to play a very important role.

Patent data have also allowed studying in greater depth the various dimensions of distance affecting knowledge diffusion. It has been found that physical and transport distance plays a complementary, but independent role with respect to administrative boundaries (both within and between countries). In addition, social distance, as measured by the positions of inventors on professional networks, as well as by cultural differences (such as those concerning migrant inventors from different countries), has also been found to play a role. These progresses have been made possible by the birth and expansion of a community of patent data users that increasingly shares its resources and solicit institutions to provide support, in the form of data inputs and coordination.

Future research will continue to expand our understanding of the ways in which distance affect knowledge diffusion and, in turn, explain the agglomeration of both innovation and economic activities in general. A new research front is opening up, which concern countries once considered peripheral to the innovation process, but

[69] Den Besten, M., Lissoni, F., Maurino, A., Pezzoni, M., & Tarasconi, G. (2012).*APE-INV Data Dissemination and Users' Feedback Project*. Mimeo dated 06/06/2012, available at: http://www. esf-ape-inv. eu.

which now contribute to it either directly (also in the form of patented inventions) or indirectly, through the migration of students, scientists, and engineers. Success in this and other directions of research will depend also on the capability of institutional actors to support data users' cumulative effort and limit the amount of wasteful duplicative data mining efforts.

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