The Network Structure of Technological Developments; Technological Distance as a Walk on the Technology Map

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Abstract

This paper presents a global map of technology that characterises the proximity and dependency of technological areas. It addresses the structure of technological output embodied in the network connecting patents to the patent classifications that they are attributed to. The distance between areas of technology is based on the analysis of the co-occurrence of IPC codes assigned to individual patent documents. As our classification of technologies we use an extended version of the WIPO classification of technological fields, unfolding the 35 classes to 389. The global map allows to 'overlay' patents produced by a specific organisation or country against the background of a stable representation of global technological invention and to produce comparisons that are visually attractive, very readable, and potentially useful for policy-making and strategic management. As an illustration, the technological portfolios of two large industrial corporations (IBM and BASF) are projected on this global map of technology, highlighting the technological profile of these groups. As such, the map can provide valuable information about promising areas of further technological development, comparative advantages and missing technological competences.

Introduction

In a context of rising technological knowledge intensity of economic activities, and the increasing globalisation of economic affairs, technological invention is undoubtedly one of the keys to ensuring economic growth and addressing societal challenges. As such it is vitally important that policy makers and managers have a clear understanding of the patterns of technological development.

Much of the analysis of corporate technological invention has however focused on the study of aggregate output of technological invention rather than the underlying patterns of technological development (Archibugi & Pianta, 1994). As technological change is a cumulative and path-dependent process, these patterns do provide valuable information to policy makers and managers. The path-dependence of technological development is captured by the concepts of related variety, cognitive distance, and absorptive capacity (Nooteboom, 2007; Levinthal & March, 1993; Saviotti & Frenken, 2008). The main insight generated by these concepts is that the potential for innovation depends on the distance between the actors, knowledge bases and technological fields involved. In this paper we focus on the technological distance, the distance between technologies or technological fields.

A general measure of technological distance creates understanding of the variety of technologies that are (potentially) available to groups, regions and countries and is thus of vital importance in policy making and strategic management. Although this importance is acknowledged it is difficult to measure and most approaches are technology-specific (Stirling, 2010; Markard & Truffer, 2006).

Here, we deviate from this tradition and construct a general measure of technological distance. In analogy to recently developed global maps of science (Leydesdorff & Rafols, 2009) and economy (Hausman & Hidalgo, 2009) this paper presents a global map of technology that characterises the proximity and dependency of technological areas. As such, the map can provide valuable information about promising areas of further technological development, comparative advantages and missing technological competences. The same tool can be used for mapping any actor's technological profile, be it corporations, universities, public research organisations, regions or countries. Furthermore, the global map allows to 'overlay' patents produced by a specific organisation or country against the background of a stable representation of global technological invention and to produce comparisons that are visually attractive, very readable, and potentially useful for policy-making and strategic management.

In this study, our first objective is to introduce the method for making and/or utilising the global maps to prospective users in the wider innovation policy and management communities. As an illustration, the technological portfolios of two large industrial corporations (IBM and BASF) are projected on this global map of technology, highlighting the technological profile of these groups.

The paper is structured as follows. In Section 2, we discuss the concept of technological distance. Section 3 addresses the methodological issues of using patents to map the network structure of corporate invention. In Section 4, we present some illustration of the global technology map and overlays of patents produced by specific organisations. In Section 5, we discuss the usefulness of technology maps for policy-making and strategic management and we articulate directions of further research.

Technological distance

In the Schumpeterian framework of innovation, technological development is considered as successful new combinations of existing ideas. Furthermore, technological knowledge can be considered as an interconnected set of qualitatively different ideas (Kauffman, 1995; Saviotti, 1998). In cognitive theory, such a depiction has led to stress the trade-off that exists between diversity and similarity: On the one hand, organizations who share a greater overlap in terms of technological competences may find it easier to communicate with one another, facilitating learning. On the other hand only organizations that posses non-overlapping competences and technological knowledge can actually offer something new to be learnt. As a matter of fact, a too strong overlap in competences might even lead to cognitive lock-in (Nooteboom, 2000). This trade-off suggests that from an innovation perspective there is an optimal cognitive distance (Nooteboom, 2007). A measure technological distance can thus contribute to identify the building blocks of technological development.

Technological distance does not only provide insight in the building blocks of technological change but also in its direction. Because technologies evolve as as successful new combinations of existing technologies, innovations rely on a whole series of inventions and insights starting from the current state of technology development. Kauffman (1995) coined the phrase “the adjacent possible” for the set of all those first-order combination. The phrase captures both the limits and the creative potential of change and innovation in technology. The adjacent possible defines all those technologies that are directly achievable from an existing set of competences. The adjacent possible is a kind of shadow future, hovering on the edges of the present state of knowledge, a map of all the ways in which the present can reinvent itself. Each new technology opens up the possibility of other new technologies in a process of path dependent branching. In other words, new technological knowledge is developed from existing competences embodied in tacit knowledge, skills and infrastructures. As a consequence, the extent to which a group, region or country can take advantage of the knowledge created by others depends on the technological distance between the creator and the user of such knowledge.

A measure of technological distance can thus not only serve to identify past patterns of technological development but also to identify fruitful building blocks and directions for future technological development.

Data and Methodology

The quality of any measure of distance depends on the quality of the underlying classification. We use patents as our measure of technological development. While patents are considered an intermediate indicator data availability and the possibility to capture also emerging technological fields explain their widespread use in the study of technological change (Archibugi & Pianta, 1994; OECD, 2009). In order to overcome some of the difficulties associated with the use of patents as an indicator for technological change, we use a subset of all patents for the construction of the global technology map.

More specifically, this research uses the Corporate Invention Board (CIB) dataset. This sample of patents analysed for constructing the global map of technology encompasses all priority patents (over 6 million documents) applied for worldwide between 1986 and 2005 by the 2,400 largest private R&D performers—i.e., the corporations monitored in the EU Industrial R&D Investment Scoreboard. The CIB complements the “Industrial R&D Investment Scoreboard” produced annually by European Commission’s Institute for Prospective Technological Studies. The industrial R&D Investment Scoreboard analyses the performances of the 2,000 industrial companies (1,000 based within the European Union, 1,000 outside) with the highest annual R&D investments. CIB represents a significant share of private R&D investments as the industrial corporations included in the project account for 80% of world total private R&D.

While patent classification systems provide a starting point for identifying patents that belong to a specific technological domain, they do not constitute a classification of technological fields (OECD, 2009). In order to overcome this problem, we developed an original classification of technology that distributes all inventions in 389 non-overlapping classes. This classification is based on WIPO hierarchical classification that distinguishes, at its finest aggregation level, 35 technological fields, these 35 fields, being grouped in 5 technological domains.[1] The global technology map depicts how these technological fields are connected.

[1] WIPO 2008, World Patent Report–A Statistical Review, 2008, Annex B. IPC and Technology Concordance Table, p.54.

The distance between areas of technology is based on the analysis of the co-occurrence of IPC codes assigned to individual patent documents. The more often a code is assigned to patent documents within one area together with codes from another area, the stronger the relationship between those codes and the shorter the (technological) distance between the technological areas to which these codes belong.

Recently, a number of scholars have turned to co-occurrence analysis to assess dynamics of branching and relatedness. Co-occurrence analysis measures the relatedness between two industries by assessing whether two industries are often found together in one and the same economic entity. Hidalgo et al. (2007) counted the number of times that two industries showed a revealed comparative advantage (the co-occurrence) in the same country (the economic entity). Similarly, Teece, Rumelt, Dosi and Winter (1994) and Bryce and Winter (2009) counted the number of times one firm (the economic entity) owned plants in two different industries (the co-occurrence). Heimeriks and Boschma (2012) used co-occurrence analysis to measures the relatedness between topics of research by assessing whether title words are often found together in one and the same paper. The global technology map thus provides a "bottom up" measure of the technological distance between different technological fields. The graphs have been generated with Gephi, using the "force atlas" option for nodes' spatialisation.

Results

Figure 1 provides the basemap for the more than 6 million patents covering the period between 1986 and 2005. 389 nodes are distinguished and coloured according to the technological domains they belong to.

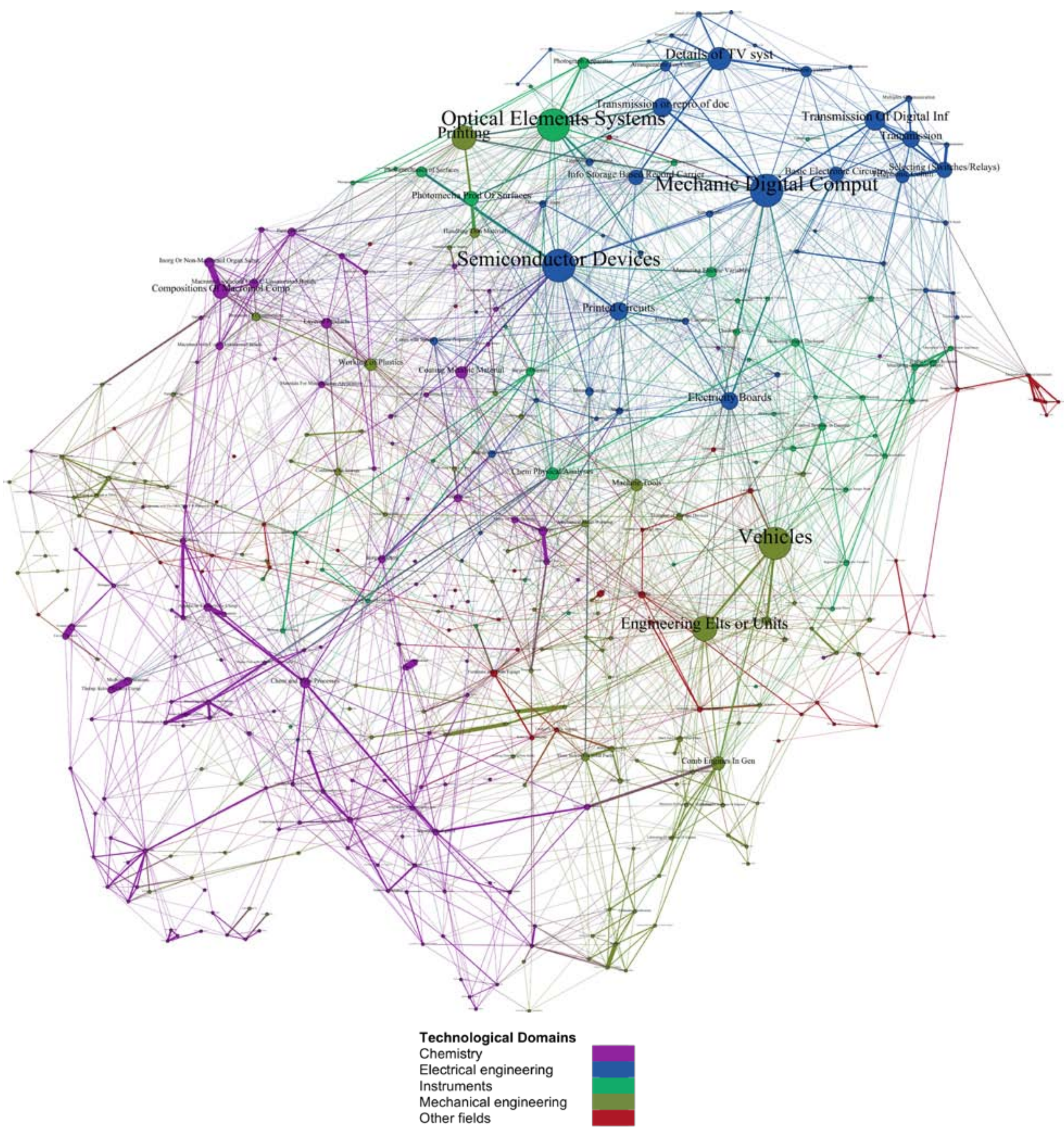

Figure 1. Global Map of Technological Complexity.

The global technological map allows to ‘overlay’ patents produced by a specific organisation or country against the background of a stable representation of global technological invention and to produce comparisons that are visually attractive, very readable, and potentially useful for policy-making and strategic management. The colours in the overlay map correspond to the colours in the global map provided above.

The overlay map of IBM patents against a stable global map is shown below (figure 2). The map immediately highlights the technological areas in which IBM is most active (e.g. semiconductor devices, printed circuits). Furthermore the map provides information about the relations that exist between technological areas within the group.

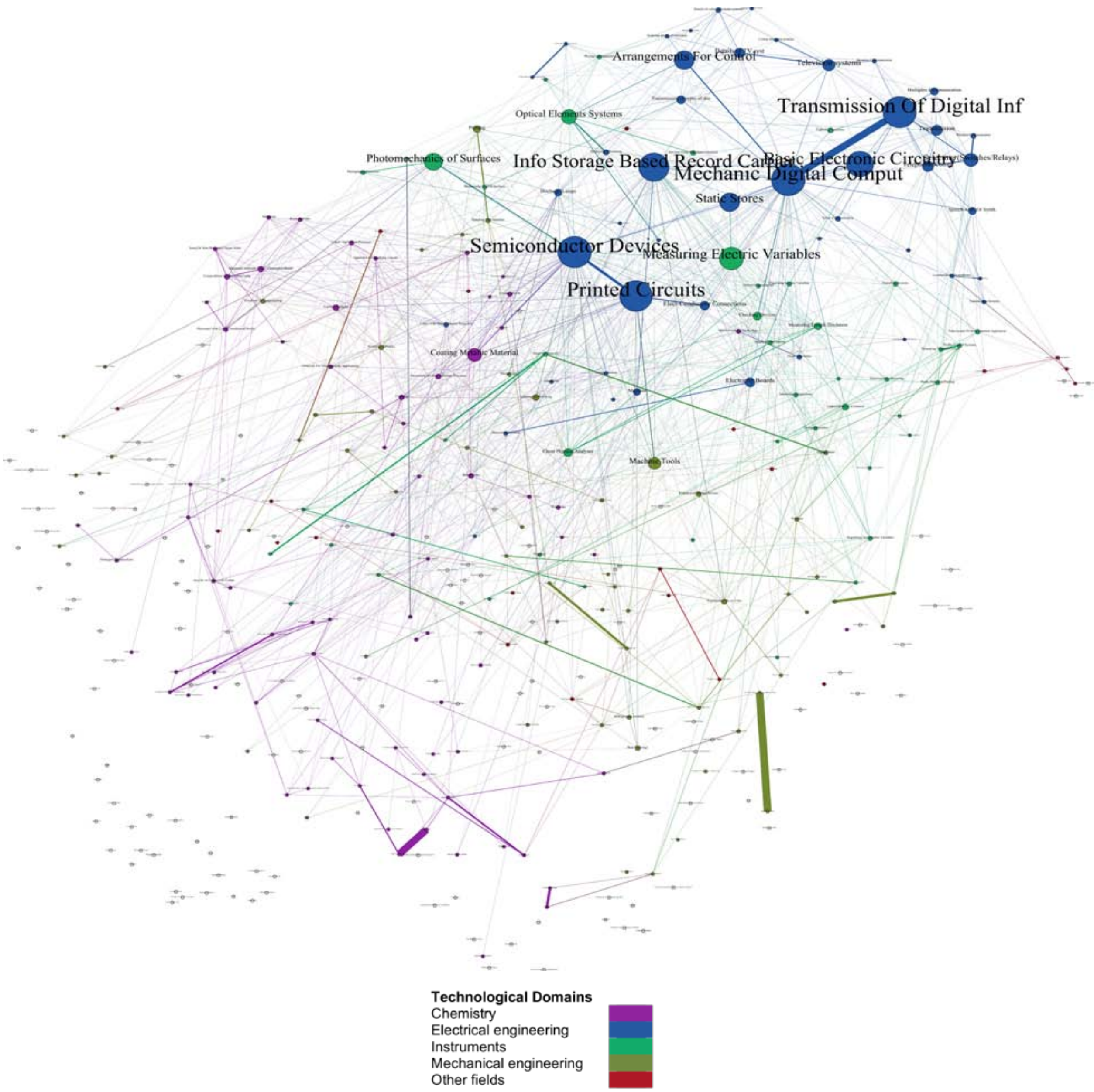

Figure 2. IBM 47 998 priority patents applied for worldwide between 1986 and 2005.

Another example is provided by the overlay map of BASF patents (figure 3). It is immediately visible that the technological profile of BASF is very different than that of IBM. Two clusters of strongly related technologies are visible on the left side of the map.

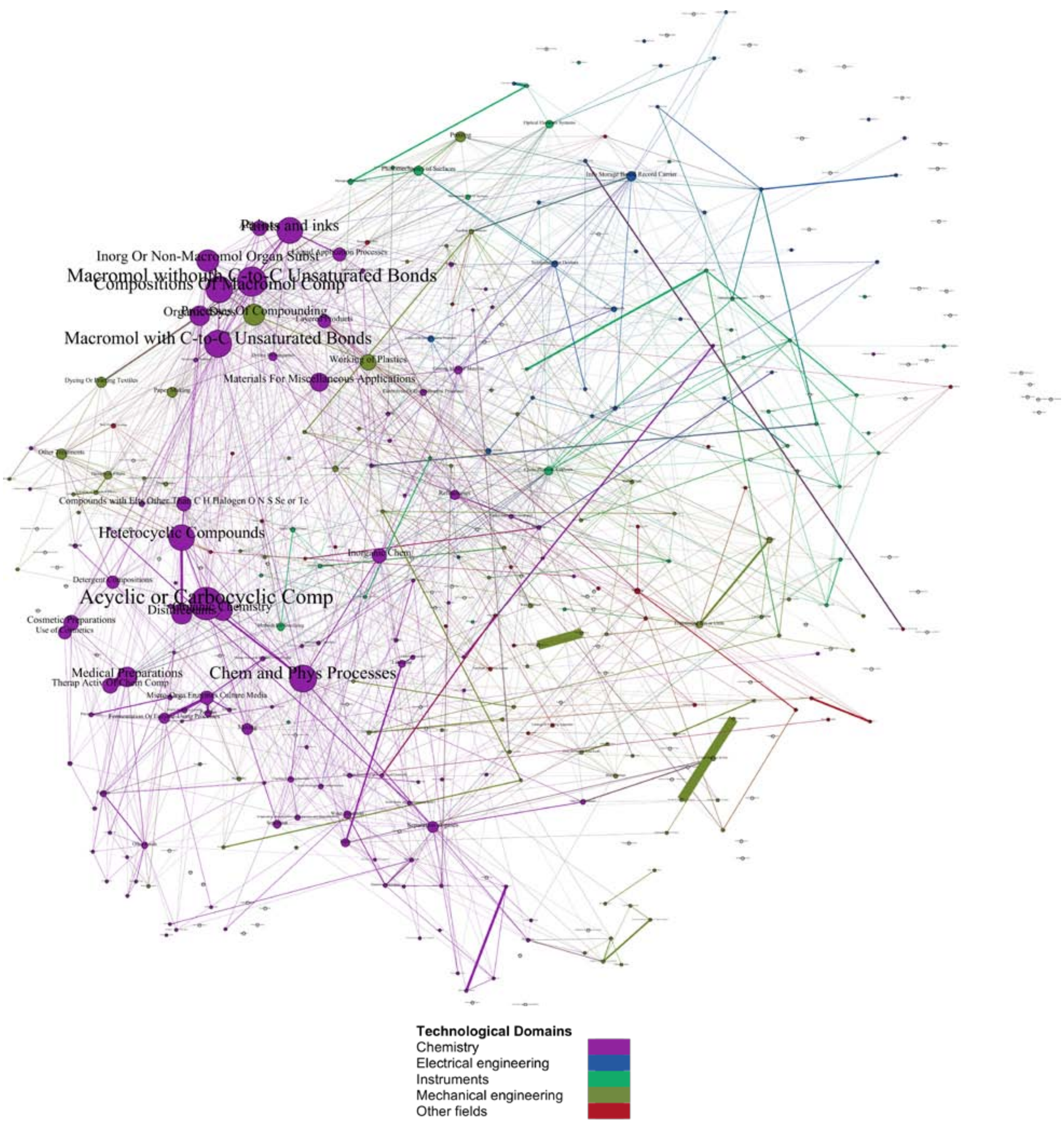

Figure 3. 19 170 BASF priority patents applied for worldwide between 1986 and 2005.

Discussion and concluding remarks

Countries, regions and firms differ markedly in the diversification of their technological capabilities. Technologies differ in the number of countries and firms that produce them (Hidalgo & Hausman, 2009). The technology maps presented here provide new insights in the global pattern of technological developments in general, and the pattern of technological distances in specific.

It is generally assumed that technological distance and, related, the absorptive capacity of host country firms explains the extent of technological spillovers from others and through foreign direct investment (FDI). Technological spillovers are informal, involuntary, non-market transfers that occur when the activities of one firm affect the productivity or technology of another firm in ways that are not fully captured by the source firm (Eden, 2009). The relationship between spillovers and technological distance holds important policy implications for the attraction of FDI, with the laissez-faire view that all inward FDI into all sectors and regions is equally valuable in terms of technological spillovers being increasingly challenged (Altomonte & Pennings, 2009; Buckley, Clegg & Wang 2007).

Addressing the issue of specialization in research and innovation is a crucial policy issue, especially for regions and organizations that are not leaders in any of the major science or technology domains (Foray & *al*., 2009). The question is whether there is a 'smart specialization' alternative to policies that spreads investments thinly across several technological fields and, as a consequence, not making much of an impact in any one area (Todtling & Trippl, 2005). A more promising strategy appears to be to invest in programs that will complement existing skills and infrastructures to create future capability and comparative advantage (Hausmann & Hidalgo, 2009).

Further research can specify whether there is a systematic relationship between the diversification of a country's and firms portfolio and the ubiquity of their technology as Hidalgo and Haussmann (2009) suggest. It can be expected that the amount of productive knowledge that each country and firm holds provides a superior measure of productive knowledge can account for the enormous income differences between the nations and firms of the world and has the capacity to predict the rate of growth.

In this paper, we mapped the structure of technological output embodied in the network connecting over 6 million patents to the patent classifications that they are attributed to. The resulting global map of technology characterises the proximity and dependency of technological areas and provides a "bottom up" measure of the technological distance between different technological fields. The global map allows to 'overlay' patents produced by a specific organisation or country against the background of a stable representation of global technological invention and to produce comparisons that are visually attractive, very readable, and potentially useful for policy-making and strategic management.

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