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Climbing the ladder of technological development

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ABSTRACT

Despite being the main thriving force behind economic growth and industrial development, technological innovation remains highly concentrated on a handful of countries. It is therefore of a great interest to know how countries accumulate and develop their innovative capabilities, what kind of obstacles they need to overcome, and whether it is possible to identify opportunities to develop new areas of technological specialization. In this paper we analyze countries' patterns of technological diversification and specialization along the development process. We provide evidence regarding the importance of existing technological capabilities and the relationship among technologies in shaping possible paths of technological development. We show that the likelihood of diversification is higher for those technologies that are related to countries' existing profile of competences. Moreover, we show this effect to be stronger at earlier stages of development. Additionally, we show that countries tend to follow clear patterns of specialization along the development path, by moving towards more complex and valuable technologies.

1. Introduction

Technological innovation is the main thriving force behind economic growth, industrial development, and the rise of living standards. However, only a handful of countries are actively developing new technologies. The United States, Western European countries, Japan and South-Korea host a small fraction of the world's population but are responsible for most technological advances. This unequal distribution of innovative activities sets the role played by different countries in the global value chain. Countries that innovate are able to capture a larger share of the value added, while others are trapped in less profitable activities. Climbing the ladder of economic development also requires climbing the ladder of technological development. But how do countries accumulate and develop their innovative capabilities? What kind of obstacles do they need to overcome? How could they identify opportunities to develop new areas of technological specialization?

These questions have attracted a lot of interest in the innovation literature. An extensive literature has analyzed the process of accumulation of technological capabilities in developing countries (see among others Bell and Pavitt, 1992; Enos, 1991; Lall, 1992; Dahlman et al., 1987; Fransman and King, 1984; Lee and Lim, 2001; Kim, 1999). We have also a good understanding of patterns of sectoral and technological change (Breschi et al., 2000; Malerba and Orsenigo, 1996) and how their dynamics are shaped by cumulative and path dependent processes (Dosi, 1988; Dosi et al., 1988; Malerba, 1992; Patel and Pavitt, 1997).

Despite this extensive literature, we still have a limited understanding of how countries build new technological capabilities along the different stages of their economic development. In fact, cross-country quantitative studies exploring patterns of technological diversification and specialization have been very limited, and often restricted to the analysis of a handful of developed economies (see for instance Boschma et al., 2014, Archibugi and Pianta, 1994 and Cantwell and Vertova, 2004). As a result, we lack a robust and comprehensive bulk of evidence providing a general characterization of the type of technologies countries are more likely to produce, whether they tend to follow coherent patterns of technological specialization as they develop, and to what extent technological change is bounded to pre-existing technological capabilities.

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This paper will address these issues by analyzing countries' patterns of technological diversification and specialization along the development process, as reflected by their patenting activity at the United States Patent and Trademark Office (USPTO). We use disaggregated data on patenting activity by type of technology for 65 countries and covering a period of 15 years (1993–2007). We estimate an econometric model that differentiates between diversification and specialization patterns. In this way we are able to understand both, the general trends in terms of technological production (i.e. specialization patterns) and to single out factors affecting the emergence of new technologies (i.e. diversification patterns).

We contribute to the literature by providing a richer and more comprehensive characterization of countries' patterns of technological development, which includes: a wider and more heterogeneous collection of countries, a novel characterization of technologies aimed at capturing their complexity and economic value, and a measure of cognitive proximity (or relatedness) among technologies as a key determinant of the likelihood of technological diversification.

Our findings provide evidence regarding the importanceof existing technological capabilities (Bell and Pavitt, 1992 and 1997, and Bell, 2009) and relatedness among technologies (Jaffe, 1986; Breschi et al., 2003) in shaping possible paths of technological development. We show that the likelihood of diversification is higher for those technologies that are related to countries' existing profile of competences. Moreover, we show this effect to be stronger at earlier stages of development. On the other hand, we show that countries tend to follow clear patterns of specialization along the development path, by moving towards more complex and valuable technologies. Overall, our findings are in line, and complement related evidence showing that well-performing countries tend to have a productive structure oriented towards the production of more sophisticated and valuable goods (Lall 2000; Hidalgo et al., 2007; Hidalgo and Hausmann 2009; Hausmann and Hidalgo, 2011; Hausmann et al., 2007; Felipe, 2012).

The paper is structured as follows: the next section presents the literature review and outlines the conceptual framework. In Section 3 we illustrate the data and describe the methodology, while Section 4 presents the results. The last section discusses the findings and sketches some policy implications.

2. Theoretical background

2.1. On technological diversification and development

Within the innovation literature, country-level studies have focused on exploring patterns of technological specialization and/or diversification of advanced economies. For instance, Archibugi and Pianta (1991) found an inverse relationship between countries' technological size (measured as cumulative R&D expenditure) and the degree of sectoral concentration of technological activities. They covered the period 1975–1988 and used patent information for around a dozen of countries, mostly OECD members. Cantwell and Vertova (2004), and Vertova (1999 and 2001) investigated patterns of technological specialization by looking at the patenting activity of a handful of developed economies between 1890 and 1990. They found a similar pattern regarding the relationship between countries' technological size and the degree of concentration in patenting activity, and additionally, that only few countries were able to specialize in fast-growing technological fields.

Besides the patent-based evidence, a more detailed overview of the topic has been provided by empirical studies using international trade data. For example, Lall (2000) explored export patterns of developing economies using bilateral trade data. He found that countries with an export portfolio oriented towards technology-intensive products tend to grow faster in the world trade. Similarly, Rodrik (2008) argued that a structural transformation in the export basket from traditional to non-traditional products constitutes the main engine of growth. Hausmann et al. (2007) developed an index to measure the quality of countries' export baskets and showed that countries specializing in products which lay higher on this quality spectrum tend to perform better. Moreover, Hidalgo et al. (2007) and Hidalgo and Hausmann (2009), Hausmann and Hidalgo (2011) found evidence that countries' export patterns become more sophisticated and complex as they develop. All in all, the above studies seem to agree on the fact that the distribution of the productive structure of well-performing countries tends to be biased towards the production of more sophisticated or/and valuable goods.

More recently, the role of relatedness among products and technologies and its effect on the diversification process of regions and firms has gained considerable attention, as reflected by the number and diversity of studies incorporating this concept (Hidalgo and Hausmann, 2009; Frenken et al., 2007; Frenken and Saviotti, 2008). The main idea behind the concept of relatedness is that firms' diversification possibilities (or regions/countries) are affected by the degree to which products or technologies are connected to one another, where the link between two technologies/products is usually measured as how much they share in terms of common scientific knowledge, technical principles, heuristics, and common needs in general. The concept of relatedness suggests that technological change may follow a path dependent process, in which production of new knowledge is bound to the existing knowledge (Dosi, 1988; Patel and Pavitt, 1997).

At country level, the pioneering study of Hidalgo et al. (2007) shows that countries are able to develop products which are close (in terms capabilities needed to produce them) to their current basket of products, providing evidence on the importance of product relatedness. Additionally, Saviotti and Frenken (2008) show that developing related products is beneficial in the short term, while long-term growth comes from the emergence of unrelated sectors.

At regional level, strong support has been found to the role of relatedness in driving either technological or sectoral development. For example, Boschma et al. (2015) and Rigby (2015) showed that technological relatedness was a crucial driving force behind technological change in U.S. cities. Colombelli et al. (2014) found that the development of new nanotechnologies is linked to the structure of the existing local knowledge base. Similarly, but focusing on industrial diversification of regions, Neffke et al. (2011), Boschma et al. (2015), and Essletzbichler (2015) showed that regions are more likely to enter into industries which are related to those already in place.

At firm level, results show that firms tend to follow coherent patterns of diversification. Jaffe (1986) and Breschi et al. (2003) found that firms' tend to diversify into groups of technological activities that share a common or complementary knowledge base. Yip (1982) studied firms' choices between internal development and acquisition and found that the likelihood of entry into new markets increases as those markets are more related to firms' own characteristics. MacDonald (1985) analyzed patterns of diversification within U.S. manufacturing firms, finding they were more likely to enter rapidly growing industries, and industries that were related to their primary activities through supply relationships or marketing similarities. Additionally, Teece et al. (1994) showed U.S. manufacturing firms maintain certain level of coherence while diversifying.

As shown above, robust evidence at both firm and regional level has convincingly shown the presence of a link between diversification and relatedness. However, comprehensive quantitative evidence at country level is lacking. The few existing studies