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The Impact of Technological Capabilities on Invention: An Investigation Based on Country Responsiveness Scores

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Summary. — This study explores the impact of "technological capabilities" (TCs) on invention (measured by "patenting intensity") in a dataset of 42 emerging and advanced countries observed over 13 years (1995–2007). By computing country responsiveness scores we are able to: (i) rank countries according to their inventive responsiveness; (ii) detect more influential TCs factors; (iii) test the presence of increasing/decreasing patenting returns to TCs. Results show an inverted-U relation between invention responsiveness and TCs intensity. We conclude that self-reinforcing mechanisms characterize the early stage of TCs accumulation (increasing returns), and weakening mechanisms higher levels of TCs intensity (decreasing returns). Findings are widely discussed.

Key words — technological capabilities, responsiveness scores, patenting returns, countries' technological performance

1. INTRODUCTION

This study explores the impact of "technological capabilities" (hereinafter TCs) on "inventive performance" at country level, by assuming *heterogeneous* response of country inventiveness to TCs factors (or inputs). [1]

By and large, two streams of literatures have dealt with this subject: (i) the economics of innovation (especially at firm level), and (ii) the literature on the measurement of TCs (more focused on country level). This study relies on both these perspectives.

From the economics of innovation, especially the "evolutionary theories", we draw the idea that TCs——loosely defined as knowledge and skills that firms continuously acquire, adapt, and improve—are the *primum movens* of firm sustainable innovative capacity and thereby of market success, and that companies' response to TCs is highly *idiosyncratic* since markets are seen—in that perspective—as generating widespread entrepreneurial variety; as for the measurement of country TCs, we follow in the footsteps of previous literature on country TCs conceptualization and assessment, which we assume as reference to measure and interpret TCs structure and dynamic pattern.

Although the paper develops along a classical input–output relation between TCs and invention ("inventive function"), its novelty—also methodological—resides in assuming a different *reaction* (or *responsiveness*) of country invention to TCs factors. This is done by using a Random Coefficient Regression (RCR), an approach in which the usual regression coefficients are assumed to vary across units. The application of such an approach, new within this field of study, leads to some new and interesting analytical findings. Indeed, compared with previous studies on the subject, this paper presents some appreciable novelties and developments.

First, an investigation of TCs-driven patenting performance at country level has not been provided in this literature yet: generally, in fact, papers dealing with country TCs aim primarily at measuring TCs performance by (composite) indicators for comparison and ranking purposes, with no direct reference to assessing the *impact* of TCs on inventive/innovative outcome(s).

Second, our approach allows for measuring a country-specific regression coefficient for each TCs input considered: in this way, each country obtains a specific *responsiveness score* of invention to the various TCs inputs, that can be used for specific analytical purposes, such as: (i) ranking countries according to the level of the responsiveness score obtained, (ii) detecting TCs factors that are more influential in driving country patenting performance, and (iii) studying, more in general, the distribution (variety) of the TCs factors' responsiveness scores across countries.

Third, the knowledge of these idiosyncratic scores can also be exploited to test the presence of increasing/decreasing returns of patents to TCs in a very straightforward and graphically easy-to-read way. This last part also conveys, in our opinion, the most relevant implications of the present paper.

We consider country inventive performance as captured by the number of patents per 100,000 inhabitants. As for TCs measurement, we make use of the GloCap dataset indices, an already existing set of indicators of TCs measured on 42 countries observed over thirteen years, from 1995 to 2007, for a total of 546 observations.

The paper is organized as follows: Section 2 puts forward the conceptual/theoretical background of this study. Section 3 presents the dataset used and discusses the rationale for the choice of the included variables. Section 4 presents a concise exposition of the methodology. Section 5 shows the main results and discusses them, and Section 6, finally, concludes. The model's technical details are set out in Appendix A.

2. BACKGROUND LITERATURE

In an ever larger and more globalized economy sustained growth and welfare can be reached and maintained only

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through the capacity of countries to feed their competitive advantages (Lall, 2001). For a long period of time, mainstream economic theory has stressed the role played by *relative price differentials* in countries' productive resources as the leading factor generating diverse economic performance and prosperity (Ohlin, 1967; Samuelson, 1949). But in recent years a great bulk of new literature and empirical evidence (not only neoclassical) has clearly shown that *quality improvements* in the products and services produced—normally supported by an intensive formal and informal R&D and innovation activity—have assumed increasing importance for developed and developing regions to keep pace with a more competitive global arena (Aghion & Howitt, 1992; Grossman & Helpman, 1991; Krugman, 1986; Romer, 1990). In this regard, fostering "innovation"—generally defined—has nowadays become an imperative of companies' business strategies as well as of the (public) policy agenda.

According to a large body of literature on the determinants of growth and development, country growth and long-term prosperity are assumed to depend on (at least) *four* interlinked factors (not put in order of importance) (Fagerberg & Godinho, 2004; Lall, 1992; Petrakos, Arvanitidis, & Pavleas, 2007): (i) geographical structure, (i) political, socio-demographic and institutional factors, (iii) market and public economic incentives, and (iv) technological capabilities.

A country's geography is no doubt an important driver of economic growth. Various geographical elements have been put forward, such as: the availability of natural resources (including energy), land fertility, proximity to (or distance from) wealthy areas, climate, and topography characteristics, just to list a few (Armstrong & Read, 2006; Easterly & Levine, 2003; Porter, 1998).

Political stability, social, and demographic aspects (degree of cooperation and social capital, population dynamics as migration and aging, *etc.*) have been likewise deemed relevant for growth. Formal and informal institutions, in particular, are assumed as a fundamental framework within which economic incentives may (positively or poorly) operate. They are important as a shared belief in the economics of development is that a significant quota of underdevelopment is to be ascribed to the "deficiency of institutions", weakening the formation, and accumulation of trust and social capital (Knack & Keefer, 1995, 1997; North, 1990; Rodrik, 2000). [2]

Economic incentives regard elements such as changes in commodities' and factors' relative prices, interest rate, access to credit, balance of payment dynamics, fiscal and monetary policies. But also the state of (home and foreign) competition, basically depending on market structure (monopolistic and oligopolistic power, legal and technical barriers to entry and exit, hindrances to free trade, *etc.*), may influence the rate and direction of economic development.

Besides geography, institutions, and economic incentives, TCs are playing a rising role as factors triggering growth, especially since the shift from the "traditional" (based on extensive use of capital assets and labor force) toward the "knowledge-based" economy paradigm has taken place (OECD, 1996).

At country level, TCs are generally defined as the capacity of a given country to generate, use, adapt, absorb, and transmit knowledge to develop and master, in an effective way, technological innovations directed to promoting growth (Kim, 1980). [3] Lall (1992) suggests distinguishing three TCs components: physical capital, human capital, and technological effort. Physical capital is meant as a "basic" capability, as no industry might exist without a certain amount of productive infrastructures (equipment, railroads, motorway networks, *etc.*). Human capital, promoted by higher education and training as well as learning-by-doing, increases the capacity to more effectively exploit the potential residing in physical assets (Lucas, 1988). Nevertheless, without a steady national technological effort, i.e., "efforts by productive enterprises to assimilate and improve upon the relevant technology" (Lall, 1992, p. 170), skilled labor and material infrastructures would be badly combined and exploited. In this perspective, technological effort assumes the role of a *meta-competence*, that is, a competence in further developing and exploiting other competencies.

The theoretical underpinning of the macro (country) approach to TCs has its roots in the Resource Based View (RBV) (Penrose, 1959) and in the evolutionary (neo-Schumpeterian) theories of the firm (Nelson & Winter, 1982), i.e., in a microeconomic context.

In the RBV approach, the enterprise is viewed as an integrated set of tangible and intangible resources—thought of as inputs of the production process—determining its ultimate performance. Although all resources are valuable and needed, the most essential one is represented by the so-called *core-compentences*, i.e., those tacit, scarce, firm-specific, and difficult-to-imitate skills entailing a differential and idiosyncratic firm comparative advantage over competitors: they are *meta-resources* because they allow for combining all the other resources in a more efficient and effective way (Wernerfelt, 1984, 1995). Moreover, a fundamental competence for companies to gain comparative innovative advantages is found in their so-called "absorptive capacity" defined as "the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends" (Cohen & Levinthal, 1990, p. 128). [4]

In the evolutionary theory of the firm, the key competences leading to comparative advantages are *learning capacity* (learning by doing, by using, by searching, by interacting, and by monitoring) and *skills* (models, codes, and practices for decoding and integrating internal and external specific knowledge). Both learning and skills are embedded in firm *routines*, defined as decision rules and procedures of mechanical and repetitive behaviors through which companies conduct their organizational activities (Nelson & Winter, 1982). Routines represent the *organizational memory* of the firm within which it accumulates knowledge, learning, and skills over time and space. They are changed adaptively in response to a changing external environment. [5]

Having said that, the assumption of this study is that TCs are the fundamental component of country inventive capacity and, consequently, of steady growth (Fagerberg *et al.*, 2010). Nevertheless, as clearly proved by the previous literature, TCs are far from being equally distributed across countries and, within countries, across sectors and companies (Archibugi & Coco, 2005; Archibugi & Pietrobelli, 2003). On the contrary, just a small "club" of (advanced) countries shows high TCs performance (measured, as we will see, through a battery of indicators), while the majority of countries worldwide are still lagging behind (Castellacci & Archibugi, 2008). This uneven distribution depends on the achieved level of TCs, as well as on the different weight that single TCs factors may assume across countries. In fact, being TCs a multifaceted and multidimensional reality, no single indicator (let's say, for instance, "R&D intensity") might be able to capture their complex and articulated nature (Cerulli & Filippetti, 2012). Thus, TCs are usually measured by relying on a pre-specified set of "factors" that—altogether—are considered representative of the entire phenomenon (Archibugi, Denni, & Filippetti, 2009; Fagerberg & Srholec, 2008; Grupp & Schubert, 2010; James, 2006). [6]

Once assumed that countries are strongly *heterogeneous* in terms of TCs, it can be deduced that also their TCs-driven