

The Handbook of Global Science, Technology, and Innovation

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Introduction

Editors' Introduction: Science, Technology, and Innovation Go Global

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“ideas, knowledge, art, hospitality, travel – these are the things which should of their nature be international”
(John Maynard Keynes, 1933)

It is a great pleasure to present in this series dedicated to global policy a collection of fresh papers devoted to science, technology, and innovation. The realm of knowledge is, in fact, an area which is most contributing to the coming of a genuine global society. The community of learned, what in the Enlightenment was labeled the Republic of Letters, has been one of the first components of society to challenge existing geographical and political boundaries, exploring and establishing interactions across different spaces. Medieval cloisters, academic circles, and, more recently, universities and research centers, have welcomed contributions from outsiders and have often been free land for anybody willing to exchange ideas. Scientists as well as craftsmen have been early frequent travelers to learn what other communities were offering and to disseminate the outcome of their ingenuity. Driven by the passion for knowledge and in search of personal rewards, the community of learned has been one of the great vehicles for disseminating ideas, know-how, artefacts, products, and techniques. Long before the word entered into the jargon of our age, knowledgeable people have been mighty pioneers of globalization.

The relationship between science, technology, and innovation and globalization is however not unidirectional. Revolutions in transports, ICT advent, migrations, growth in international trade and in foreign direct investment, are aspects that have substantially shaped human life, including the way in which scientists and engineers work and how they organize their activities. This Handbook is a comprehensive collection of essays that attempts to answer a number of questions related to the way in which the forces of globalization have affected the generation and diffusion of science, technology, and innovation (STI). It is common sense that STI has become more important in everyday life and we know by instinct that the pills we swallow and the mobile phones in our pockets are associated with investigations and discoveries carried out in several parts of the world. But are we sure that the opportunities offered by the new global age have been fully exploited? How can society at large better benefit on a global scale from the knowledge developed?

The rise of the so-called distance-shrinking technologies and their global diffusion, like the World Wide Web, is making communication and the exchange of information virtually instantaneous and with very negligible costs. In a thought-provoking book Thomas Friedman (2006) claims that our planet has become a level playing field as a result of globalization, and that most aspects are today dominated by a global market, which has made historical and geographical divisions increasingly irrelevant. Is this also true for STI? Has the generation of STI become “placeless” or does location continue to play a crucial role in the successful generation of knowledge?

These days, big advancements in science like the mapping of the genome, the discovery of the Higgs boson at the CERN, or the landing of the Rosetta spacecraft on a comet are all the result of big international projects. The CERN

was founded by 12 countries and today has 21 member states, it employs over 2400 people, representing 608 universities and research facilities and 113 nationalities. The Human Genome Project was also established as an international, collaborative research program whose goal was the complete mapping and understanding of all the genes of human beings and it remains the world's largest collaborative biological project. Almost all of the actual sequencing of the genome was conducted at numerous universities and research centers throughout the United States, the United Kingdom, France, Germany, Japan, and China. While we are drafting this introduction, for the first time in history a spacecraft has just landed on a comet as a result of an effort of the European Union in establishing a European Research Area with a budget dedicated to collaborative cross-country research.

Collaborative research is becoming the norm also in ordinary research activity. Collaboration across national boundaries is generally increasing, as reflected in international co-authorship of scientific articles. According to the US National Science Foundation¹ in 1988, only 8% of the world's science and engineering (S&E) articles had international co-authors; by 2009, this share had grown to 23%. For the world's major advanced regions, the 2009 rate ranged from about 27% to 42%.

The production of technology and innovation has also become an activity which is more and more carried out on a global basis. It is typical for corporations in the automobile, electronics, and chemical industries to establish Research and Development (R&D) abroad, in both advanced countries and, more recently, emerging countries. Western companies develop innovations also in emerging countries that eventually are exploited in their domestic markets. Innovations are often the results of cross-country collaboration activity.

This is also extremely visible by looking at figures on the internationalization of patenting activity, one of the typical methods used by profit-seeking agents to secure returns from their inventions and innovations. For many years, inventors were exploiting their innovations in their domestic markets only and were not particularly eager to file their patents abroad. In the last decades, the situation has dramatically changed and foreign-oriented patents – patents that are granted in at least one country other than the applicant's home country – have quintupled since 1970.² Today, the inventions of emerging economies are becoming a fundamental component, and are growing faster than those in established countries. This witnesses a striking shift in the strategies of firms regarding the geographical scope of their innovations.

The influence of globalization is not only visible in the *production* of STI, but is also macroscopic in the *diffusion* of STI. The diffusion of knowledge has increased rapidly as a result of a number of factors. Global integration has accelerated exchanges across countries and the development of global value chains (Meliciani and Savona 2014). Further, distance-shrinking technologies have dramatically reduced the time and cost of transmitting information across the world. As a result, any new technology could reach any corner of the world, provided there is enough absorptive capacity to make sense of it. The lags with which new technologies arrive to countries have dropped dramatically over the last 200 years: “technologies invented in the nineteenth century such as telegrams or railways often took many decades to first arrive to countries. In contrast, new technologies such as computers, cell phones or the internet have arrived on average within a few decades (in some cases less than one) after their invention” (Comin and Ferrer 2013: 1).

Mobility of people has also increased dramatically, encouraging face-to-face interaction, adding another important dimension to the globalization of STI. Professor Venkatraman Ramakrishnan, who received the 2009 Nobel Prize in Chemistry for studies of the structure and function of the ribosome, was born in India and studied at Ohio University but when he received his Nobel Prize, he worked in Cambridge in the United Kingdom. This is a rather recurrent story of top scientists and engineers. While migration has historically characterized individuals with low skills and education, over the years a new phenomenon has emerged in the form of migration of highly skilled workers and talents, the so-called *global creative class* (Florida 2005). Today, when countries debate their immigration policy, one question at stake is how to attract skilled workers who foster innovation and entrepreneurship. Inventors tend to be quite mobile, with 10% of inventors worldwide showing a migratory background in 2005. The United States is by far the most popular destination for migrant inventors, hosting 57% of the world's inventors who reside outside their home country. By contrast, China and India are the largest providers of inventors (Fink, Miguelez, and Raffo 2013).

The globalization of STI has not made the world flatter but rather more fragmented. Spatial agglomeration continues to be crucial for the generation and diffusion of knowledge and it continues to exert an effect on a larger scale. The economic agents producing knowledge and technologies in specific domains continue to agglomerate in specific areas and districts, which are extending also in emerging countries. Bangalore in India is developing along lines that resemble the Silicon Valley in California, while the large concentration of hi-tech industries in a few coastal regions in China is mirroring the concentration of technology-based activities in some regions of the Western countries. The

geography of technology and innovation has not disappeared with globalization; rather it has expanded its scale.

An Attempt to Categorize the Globalization of STI

The facts and trends mentioned above are explored in a growing literature and the chapters collected in this volume provide an overview of how globalization is shaping STI. The increasing evidence collected by scholars, business strategists, and policy analysts is often fragmentary and can sometimes point out different or even opposite trends. It might therefore be useful to approach such a huge literature through a categorization of the various forms of globalization of STI, looking at how knowledge is developed, disseminated, and exploited. An attempt to categorize global STI is provided in [Table 0.1](#). It is possible to identify four principal ways according to which STI is generated and disseminated in the global sphere. This categorization has as unit of analysis the individual scientific and technological activity (i.e., a successful research project, the introduction of a product, a process, or component). It is therefore possible that the same players (e.g., a university, a company, a research lab) make use of different categories for each individual STI activity they carry out.

Table 0.1 Categories of globalization of scientific, technological, and innovative activities.

Source: Archibugi and Iammarino (2002), Archibugi and Michie (1995).

<i>Categories</i>	<i>Public</i>	<i>Business</i>
Nationally confined knowledge development	Activities promoted by public institutions in the national context	Business players developing knowledge and innovations for local markets only
International dissemination and exploitation of nationally generated knowledge and innovation	Although developed predominantly in the national context, the outcome of knowledge is disseminated internationally through a variety of channels of the academic community, including scientific papers and conferences	National and multinational corporations (MNEs) develop knowledge within their home country and attempt to profit from them internationally through trade, licenses, or international production
Global techno-scientific collaborations	Preserving their national identity, this includes collaboration across scientists and institutions of different countries, generally for specific research projects	Independent companies undertake arm-length strategic technological agreements to reduce the costs and risks of specific innovative projects

<i>Categories</i>	<i>Public</i>	<i>Business</i>
Global generation of knowledge	Knowledge generated in permanent institutions financed by several national governments or by international organizations	Knowledge generated by MNEs in their headquarters and their subsidiaries, through intra-firm but international innovative networks

The first category, **nationally confined knowledge developments**, occurs when there is no knowledge transmission across borders. This category should not be included in the globalization discourse since both the knowledge development and its dissemination occurs at the local or at the national levels. We may wonder how important this category is in contemporary society, and many readers will find it difficult to visualize some knowledge components or technical innovations that have been confined inside the local space only. Of course, these inventions and innovations do exist; empirically, we may identify them through some outcomes: scientific articles written in national languages and that are not cited outside their own country; patent applications within national offices that are not extended abroad; and, perhaps more importantly, forms of tacit knowledge that serve specific local purposes. As first approximation, we can identify this knowledge as experiments but not particularly fruitful ones since, if successful, it is likely that their diffusion would also contaminate other parts of the world. Recently, there has been an increasing interest for knowledge specific to local communities, a sort of anthropology of knowledge able to bring to the fore the knowledge of indigenous communities (see Agrawal 1995). This would include, for example, the therapeutic properties of plants and flowers

known to indigenous communities but not yet codified. An attempt to explore and exploit this knowledge has also been carried out by profit-seeking agents, often creating tensions concerning the intellectual property.

The second category, **the international dissemination and exploitation of nationally generated knowledge and innovation**, comprises knowledge that is developed within national contexts but with explicit attempts to disseminate it across countries. Both the public and the business sector contribute to this category. On the one hand, this includes activities promoted by the government and by the non-profit sector. The international dissemination is generally free and it occurs through the standard channels used by the academic community such as publications in scientific journals, books, conferences, personal contacts, and others.

On the other hand, the business sector also makes explicit attempts to profit from its innovations overseas. When innovations introduced into the domestic market prove to be successful and to get substantial market shares, companies have strong incentives to exploit them also in foreign markets. We can imagine these knowledge advances when the original focus and its more important elaborations are clearly identified with a national location, which is typically the nation hosting the headquarter of the innovating company. The company, however, makes explicit attempts to profit from the innovations also in foreign markets. The traditional way is through trade, exporting abroad innovative products or processes that are competitive because of the advantages associated to the innovation. But when trade is obstructed by high transport costs or by administrative restrictions, the innovating company may also find it convenient to license the know-how to foreign corporation. A third option may be to exploit the innovation in foreign markets by establishing

production facilities in the host country, especially when labor costs in the host country are lower than in the home country.

The third category is represented by **global scientific and technological collaborations** among separate institutions. These collaborations have operated for centuries within the academic community: sabbatical years, student exchange, joint research programs, are established forms used by scholars to learn and to disseminate their expertise. These collaborations have for long been supported by public policies, for example through scientific academies and other support schemes, under the assumption that exchanges with other communities will make the national scientific base stronger. The key belief behind these long established forms of collaboration is that the knowledge developed is not rival and that the advantages obtained through collaboration are much larger than those provided by isolation.

It is more than 30 years since attention was devoted to explore how similar forms of collaboration also operate in the business sector. Companies are much keener than expected to share their knowledge with actual and potential competitors and to undertake strategic technological agreements to share the costs and risks of innovative projects. The conventional economic model that provides paramount importance to inter-firm competition is not particularly suited to explain the new generation of inter-firm technology agreements that came to the fore in the early 1980s and that is still progressing. It can be said that the business sector has learnt from universities that collaboration is vital to augment the knowledge base and that there is more convenience in sharing know-how with rivals rather than in keeping it secret. The legal controversy between Apple and Samsung concerning smart phones has shown how innovation can be the competitive

edge of a company and that companies use all their muscles to protect their successful know-how. But this is only part of the story: behind such a striking case of commercial rivalry, the courts soon discovered that the two contending firms undertook technological strategic agreements to elaborate selected products together, and that some devices and methods were developed by third companies with whom both of them collaborated.

The fourth and last category is the **global generation of knowledge**. There are cases of important STI activities that cannot be associated to any specific national flag since scientists and engineers from different countries participated in its achievement. In the public sector this happens when genuine transnational laboratories and research centers are established. CERN is one of the best known cases of a genuine global laboratory. The European Union has promoted several other permanent research centers and devotes a substantial part of its budget to scientific and technological activities carried out in collaboration among member countries.

But the public sector has not been the first to use the global generation of knowledge. MNEs have used this form after the Second World War, creating research laboratories and technical centers also in the countries of their subsidiaries. Through intra-firm but international research networks, large MNEs often manage to develop complex products as well as incremental innovations, exploiting the expertise available in each national innovation system. MNEs' introduction of successful products and processes is frequently associated with the effectiveness of their internal networks which explore, examine, and assimilate the scientific and technological opportunities of different continents.

In the presentation of [Table 0.1](#), we have preferred to keep separate the public and the business sectors. This might be useful analytically, but it ignores another important form of collaboration that has gained greater importance in the last two decades, namely the collaborations between the public and the business sectors in STI. These collaborations are often national, where companies collaborate effectively with the governments and the universities of their home country. But also these forms of public/private partnership are less and less confined to national boundaries, and integrate universities with companies of host countries.

Can the four categories singled out above also be considered diachronic? Not entirely, since all the four forms can be traced even in ancient times. But their relative relevance has been modified over time, and the later categories have grown in importance at the expense of the previous ones. The first category, nationally confined knowledge development, seems today residual and certainly unable to describe the most significant knowledge progresses of our age. The second category, international dissemination and exploitation of nationally generated knowledge and innovation, is probably quantitatively still the most important, but it is losing ground since both public and business players engage in transnational collaborations not only for the exploitation and dissemination of their knowledge, but also for its generation. Global techno-scientific collaborations are becoming increasingly important in both the public and the business sectors. But what will probably become the distinctive modality of the twenty-first century is the global generation of knowledge, at least for what concerns the most relevant scientific and technological advances.

An Overview of the Book

The impact of globalization on STI is first explored in terms of the ongoing trends in [Part I](#) of the book (“Global Trends”). The chapters in this part show that STI is less a domain of the most advanced countries. Until a few decades ago, North America, Europe, and Japan – haughtily self-labeled the Triad – accounted for the dominant share in the production of science and technological advancements and countries outside these regions were, at most, extras, often relying on the knowledge developed elsewhere. Measures such as R&D expenditure, scientific articles, and patents, reflected the dominance of the Triad in the generation of STI. These chapters show instead that a process of convergence in science and technological capabilities is taking place at a global scale. Technological capabilities are increasingly spreading in emerging economies; the production of science shows a tendency to move to the East. This is also mirrored in the rise of first-class universities outside Western countries and in the distribution of key technical infrastructures for basic science like supercomputers. We have also to deal with how the concept itself of innovation is evolving in an increasingly post-industrial society. While for many years it was understood mainly as “technological,” it is now largely accepted that other forms of innovations, including aesthetic changes, may be of crucial importance for economic competitiveness.

[Part II](#) (“The Globalization of Technology and Innovation”) reports a wealth of analyses on how these activities are carried out. Transnational corporations continue to be leading players and often create important *inter*-national but *intra*-firm networks, integrating, through a variety of channels, also emerging and developing countries. Through international R&D alliances and capital and technology flows, companies manage to exploit and to assimilate knowledge and technological expertise developed

elsewhere. The service sector is no longer a passive spectator and absorber of the innovations developed in manufacturing, as it was for most of the twentieth century, but is also generating its expertise through more complex cross-border interactions. This Part also has a chapter devoted to crowdfunding, a rising form to finance innovative projects. To what extent will this form be able to overcome the traditional difficulties of financing innovation?

[Part II](#) also addresses the changing ways of organizing STI in developing countries. In the past decades we have witnessed a reverse of the international cycle of technology as traditionally set out in Vernon's (1966) early works, shifting from a scenario where innovation was only developed in advanced economies to one where global innovation also stems from inputs from emerging economies. Large firms in developing countries acquire technology through outward foreign investment, typically through acquisitions of firms with a portfolio of technology products. The rise of large markets, such as China and India, has led foreign companies to internationalize their R&D activities there. Western MNEs are more and more focusing on how the Chinese market, as well as other emerging markets, could provide these companies with new sources of innovation, a phenomenon called *innovation in reverse*. Geographical agglomerations prove to be very important also in developing countries. Clusters emerge as a viable strategy for catching up in emerging areas or even for becoming global technological leaders.

[Part III](#) ("Spaces and Flows of Knowledge") discusses the role of geography in the globalization of STI, and the importance of transnational collaboration and mobility as drivers of knowledge flows. Globalization has extended the importance of spatial agglomeration across the globe. This natural tendency of innovative activity to cluster spatially

becomes a major concern for policymakers since it may lead to the exclusion or the marginalization of vast areas. When policies try to pursue economic development through innovation it becomes fundamental to understand what makes locations more or less attractive.

In the current phase of economic globalization, geography and space are increasingly important for both public and business organizations. The rise of city-regions as knowledge sources have led to increasingly differentiated geographies across all parts of the world. But locations have to interact with people: they may be more or less knowledge-friendly and innovative also according to how they support actual and prospective residents. To this, one has to add the new dimension of *creativity*. More than anything, creativity has become the key attribute for successful, sustainable, regional economic growth. A new creative class, more mobile than other population groups, is often leading economic, social, and cultural progress. Its geography, however, is profoundly uneven, not just across but within nations. The way in which companies and public institutions, research labs, and universities manage human resources becomes crucial not only for their performance but also for the economic environment in which they operate.

A great driver of knowledge flows has always been human interaction. In fact, it has been argued that the rise of the information communications technologies (ICT) have increased, rather than reduced, the need for face-to-face interaction: "Face-to-face contacts are particularly important in environments where information is imperfect, rapidly changing, and not easily codified, key features of many creative activities" (Storper and Venables 2004). This Part addresses various mechanisms by which this can occur, such as global collaboration in scientific projects,

international mobility often leading to brain drain, and interpersonal ties of scholars.

[Part IV](#) (“Global Institutions and Intellectual Property Rights”) addresses the importance of institutions and international regimes for the globalization of STI. The international economic landscape is periodically rattled by controversies concerning intellectual property rights (IPRs). Recent cases of the so-called smart phone war or anti-HIV drugs are just a few examples. These controversies reflect the fact that in the current global economy, knowledge and intangibles have become increasingly important both as production factors and as consumption goods. While previously IPRs were mostly a matter of nation states, they became more relevant at a global scale after the introduction of a global regime of protection of intellectual property with the establishment of the “Trade Related Aspects of Intellectual Property Rights” (TRIPS) within the World Trade Organization in 1994. This Part reframes the debate regarding the globalization of IPRs by discussing how the generation, transmission, and diffusion of knowledge is a complex phenomenon and that what IPRs can do and what they cannot do to reward inventors and innovators and to prevent imitators is limited. It then addresses the key issue of how, within this context, least affluent citizens can obtain the benefits of modern pharmaceutical therapy at affordable prices. Finally, it discusses the relationship between intangible cultural heritage protection, intellectual property rights regime, and the Information Society.

The final [Part V](#) (“The Global Governance of Science and Technology”) addresses some more general questions about governance. The first relates to the importance of where knowledge is generated and how it gets diffused worldwide, and whether there is the need of some kind of governance or not. This recalls the classic case for public

intervention in the case of public goods, which has also been made about knowledge since the early studies by Nelson (1959) and Arrow (1962). In addition, today, governments release governmental data that were previously hidden from the public. This democratization of governmental open data aims to increase transparency but also fuels innovation. Indeed, the release of governmental open data is a global trend, which has evolved into governmental open innovation, a new perspective on technology and innovation policy that has so far received very scant attention.

[Part V](#) then touches upon other relevant issues that are at stake. Two chapters discuss the risks associated with scientific and technological developments, for instance environmental disasters, from philosophical and economic standpoints respectively. Another chapter takes an epistemological perspective and discusses the role of serendipity and chance in scientific and technological discovery, examining the implications for the individual researcher and the policy implications for the funding and organization of research in a global society. Finally, the last chapter challenges the view of international economic integration as being necessarily *global*, by claiming that regional economic integration – in the sense of subcontinental mega-regions such as Europe and China – is likely to eclipse global integration in coming decades.

Efforts and Ambitions

The realm of knowledge is already one of the most important spaces of our society and it is an easy forecast that it will become even more important in the future. We need to get the appropriate tools to understand how it is working, how it is transforming the global landscape and, in return, how globalization is also shaping the STI

community. The chapters collected in this volume provide a substantial amount of tools and make a brave attempt to identify geographical, economic, and social similarities and differences in the phenomena observed. We hope very much that this handbook will be helpful for the community of scholars working in the economics of innovation, in social studies of science and technology, economic geography, global studies, and in science and technology policy studies. We made a special effort in providing chapters that could be useful for teachers as well as for their students. Our ambition, however, is to be able to involve in this fascinating area also scholars outside the traditional boundaries of the discipline. Scientists and engineers, university researchers and company technicians, are the leading protagonists of inventions and innovations that nurture our society and that allow progress. We hope that some of them will find it useful to read the analyses here presented that ultimately try to make sense of what they do.

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Notes

¹ Statistics available at <http://www.nsf.gov/statistics/seind12/c0/c0s7.htm> (accessed December 17, 2014).

² See data and various annual reports from the WIPO at <http://www.wipo.int/ipstats/en/statistics/patents/>

(accessed December 17, 2014).

Part I

Global Trends

Chapter 1

The Convergence Paradox: The Global Evolution of National Innovation Systems

Fulvio Castellacci and Jose Miguel Natera

Introduction

The investigation of the reasons behind cross-country differences in the creation and international diffusion of advanced knowledge constitutes, in a nutshell, the main interest of the national innovation systems (NIS) approach (Lundvall 1992; Nelson 1993; Edquist 1997). Studies in this tradition have become increasingly popular in the last two decades, and have greatly enriched our understanding of the functioning and evolution of nations' capabilities and competencies. In addition to the great variety of theoretical insights that the systemic perspective has made it possible to achieve, several empirically oriented studies have also tried to operationalize the approach by measuring different aspects of the process of knowledge creation and dissemination in a large sample of countries, and by investigating the extent of cross-country differences (Archibugi and Coco 2004).

Several empirical studies in this tradition are rooted in the traditional literature on technology and convergence (Abramovitz 1986; Verspagen 1991; Fagerberg 1994). Following a technology-gap Schumpeterian approach, applied econometric studies have focused on a few key variables that explain cross-country differences in the innovation ability of countries as well as their different capabilities to imitate foreign advanced knowledge, and analyzed the empirical relationship between innovation and imitation factors and cross-country differences in GDP per capita growth (Fagerberg and Verspagen 2002; Fagerberg, Srholec, and Knell 2007; Castellacci 2008; Castellacci and Archibugi 2008).

Most of this empirical research, however, has so far focused on the cross-country comparative aspect ("why growth rates differ") and mostly neglected the time series dimension and the analysis of the dynamics of the technological catch-up and economic growth process over time. Further, an exceptional amount of research has been devoted to the study of the determinants of GDP and income per capita growth. By contrast, only a limited number of studies have empirically investigated the dynamics of innovative capability and absorptive capacity over time and the main factors that may explain their long-run evolution (Castellacci 2011; Filippetti and Peyrache 2011; Castellacci and Natera 2013). Thirdly, applied research in this field has so far provided a rather stylized view and highly simplified operationalization of the multidimensional concept of innovation systems, typically focusing on a few key variables (e.g., R&D, patents, human capital) and neglecting several other potentially relevant factors. In short, the existing literature provides only limited insights on the global evolution of national systems of innovation and the mechanisms that may explain their evolution and growth over time. This is a crucial task for future research in this field, and the present chapter intends to take a step in this direction.

Motivated by this background, this chapter presents an empirical analysis of the global evolution of national innovation systems. The objective is to carry out a general and comprehensive study aimed at describing the cross-country distribution of a large number of technological, economic, and social factors that broadly contribute to define national systems of innovation, and how these factors have evolved during the period 1980–2008. The work focuses on six main dimensions characterizing NIS, three of which are related to the techno-economic domain (innovation and technological capabilities, openness, and

infrastructures), while the other three define countries' socio-institutional system (education, political institutions, and social cohesion). We adopt a large number of statistical indicators to measure these six conceptual dimensions. These indicators are from the CANA database, a newly released dataset that provides a rich set of information on a large number of countries worldwide for the last three-decade period, and enables a dynamic cross-country analysis of national systems, growth, and development (Castellacci and Natera 2011).

The results of our empirical analysis, in short, point out a contrasting pattern that we call the *convergence paradox*. On the one hand, the three dimensions defining the socio-institutional system – basic education, political institutions, and social cohesion – have experienced a process of worldwide convergence. On the other hand, however, the three dimensions related to the techno-economic system have experienced a marked divergent dynamics with increasing polarization between rich and poor country groups. The paradox we outline is therefore that national systems have progressively become more similar in terms of their socio-institutional frameworks while at the same time diverging and becoming more different with respect to their techno-economic pillars.

Admittedly, the objective and nature of this work is descriptive rather than analytic. The chapter does not intend to analyze the interactions and complex coevolutionary process that links together the techno-economic and socio-institutional variables that define national systems. Rather, as other contributions in this volume, we seek to provide a comprehensive and empirically founded overview of a key issue in the study of global science, technology, and innovation systems.

Literature and Conceptual Framework

Empirical Studies on National Innovation Systems (NIS)

NIS are key drivers of economic growth and competitiveness. The NIS perspective originally developed during the 1990s to understand the broad set of factors shaping the innovation and imitation ability of countries, and how these factors could contribute to explain cross-country differences in economic growth and competitiveness (Lundvall 1992; Edquist 1997). The study of NIS focuses on the main components of the system, such as private firms and public organizations, and investigates their mutual interactions as well as their relationships with the social and institutional framework in which the system is embedded (Freeman 1995; Lundvall 2007). Empirical studies in this tradition initially focused mostly on advanced economies in the OECD area (Nelson 1993), although the NIS literature has recently shifted the focus toward the study of innovation systems within the context of developing and less developed economies (Lundvall et al. 2009).¹

NIS empirical literature has traditionally devoted substantial attention to the process of international knowledge diffusion and investigated the set of factors that affect the extent to which a national system is able to grow and catch up with the technological frontier by means of international learning and imitation activities. This approach was originally inspired by the work of authors such as List, Landes, Gerschenkron, and Abramovitz, which, by focusing on historical case studies of the technological catch-up process, pointed out that international knowledge diffusion is a complex and demanding process, and investigated the set of factors that are necessary for imitation-based technological development, so-called *absorptive capacity* of a country (Abramovitz 1986).

More recently, a strand of empirical research made an effort to measure some of the relevant dimensions composing a national system through aggregate data and statistical indicators, and carried out applied econometric investigations of the relationships between these dimensions, on the one hand, and income per capita dynamics, on the other. However, a well-known challenge for applied research in this field is how to

operationalize the innovation system view in empirical studies and, relatedly, how to measure the complex and multifaceted concept of NIS and its relationship to countries' economic performance. Quantitative applied studies of NIS and development have so far made use of two different (albeit complementary) approaches.

The first approach is rooted in the traditional literature on technology and convergence (Abramovitz 1986; Verspagen 1991; Fagerberg 1994). Following a technology-gap Schumpeterian approach, recent econometric studies have focused on a few key variables that explain (or summarize) cross-country differences in the innovation ability of countries as well as their different capabilities to imitate foreign advanced knowledge, and analyzed the empirical relationship between these innovation and imitation factors and cross-country differences in GDP per capita growth (Fagerberg and Verspagen 2002; Castellacci 2004; Castellacci 2008; Castellacci 2011; Fagerberg et al. 2007). Since one main motivation of this type of studies is to analyze the dynamics and evolution of national systems in a long-run perspective, they typically consider a relatively long time span (e.g., from the 1970s or 1980s onward), but must for this reason focus on a more restricted sample of countries (e.g., between 70 and 90 countries). Due to the lack of statistical data for a sufficiently long period of time, therefore, a great number of developing economies and the vast majority of less developed countries are often neglected by these cross-country studies.

The second approach is based on the construction and descriptive analysis of composite indicators. In a nutshell, this approach recognizes the complex and multidimensional nature of national systems of innovation and tries to measure some of their most important characteristics by considering a large set of variables representing distinct dimensions of national systems and capabilities, and then combining them together into a single composite indicator – which may be interpreted as a rough summary measure of a country's relative position vis-à-vis other national systems. Desai et al. (2002) and Archibugi and Coco (2004) have firstly proposed composite indicators based on a simple aggregation (simple or weighted averages) of a number of technology variables. Godinho, Mendonça, and Pereira (2005), Castellacci and Archibugi (2008), and Fagerberg and Srholec (2008) have then considered a larger number of innovation system dimensions and analyzed them by means of factor and cluster analysis techniques. As compared to the first approach, the composite indicator approach has a more explicit focus on the comparison across a larger number of countries. Consequently, due to the lack of data availability on less developed countries for a sufficiently long period of time, these studies typically focus on a relatively short time span, giving a cross-section description of the sample in one point in time (e.g., the 1990s and/or the 2000s).

Most of this empirical research, however, has so far focused on the cross-country comparative aspect (“why growth rates differ”) and mostly neglected the time series dimension and the analysis of the dynamics of the technological catch-up and economic growth process over time. Further, an exceptional amount of research has been devoted to the study of the determinants of GDP and income per capita growth. By contrast, only a limited number of studies have empirically investigated the dynamics of innovative capability and absorptive capacity over time and the main factors that may explain their long-run evolution (Filippetti and Peyrache 2011; Castellacci and Natera 2013). This is a crucial task for future research in this field, and the present chapter intends to take a step in this direction.

Conceptual Framework and Dimensions

Although the concept of national system was originally intended to comprise a broad and multidimensional set of capabilities, modeling and empirical exercises have often provided a stylized and simplified operationalization of it. As recently argued by Archibugi and Coco (2004), Godinho et al. (2005), and Fagerberg and Srholec (2008), it is indeed

important to adopt a multifaceted description and measurement of the various factors that contribute to shape the innovative capability and absorptive capacity of nations.

Given that the concept of national systems is complex, multifaceted, and comprises a great number of relevant factors interacting with each other, our empirical analysis adopts a broad and multidimensional operationalization of it. Our stylized view, broadly in line with the previous literature, is presented in [Figure 1.1](#).² The diagram provides a stylized representation of the main aggregate dimensions that define the dynamics of a national system. Specifically, we represent NIS as composed of six main dimensions: (1) Innovation and technological capabilities; (2) Openness; (3) Infrastructures; (4) Education and human capital; (5) Political institutions; (6) Social cohesion.

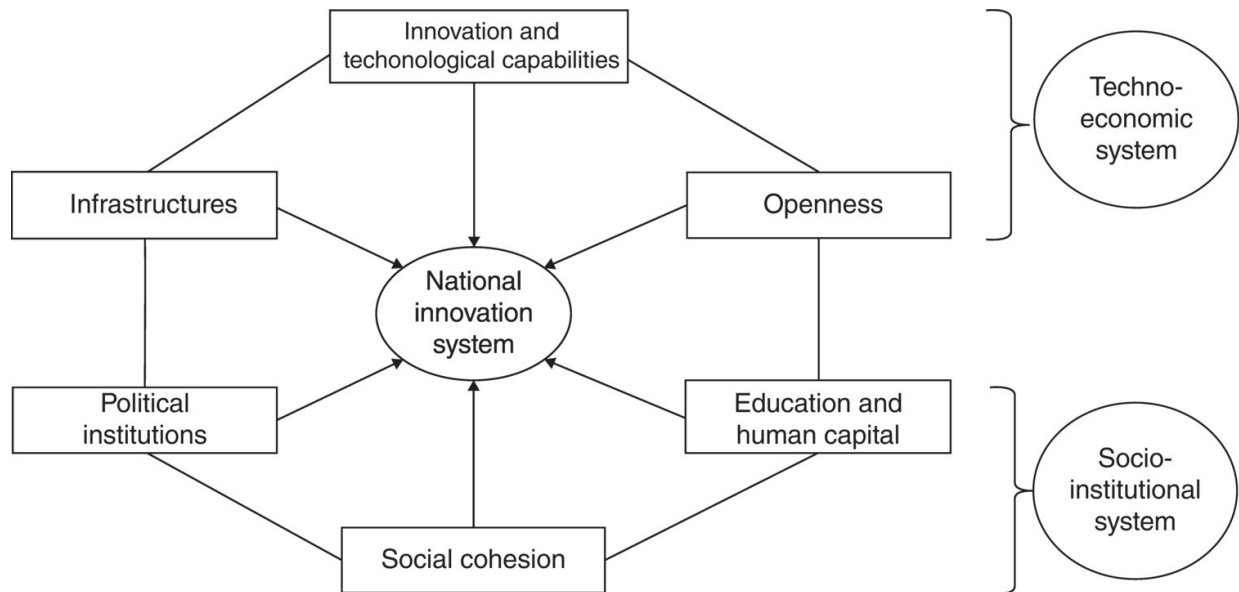


Figure 1.1 National innovation system: a stylized framework.

The first three dimensions are broadly related to a host of technological and economic factors, which classical neo-Schumpeterian work by Chris Freeman (1987) summarized under the heading *techno-economic system*. The next three dimensions refer instead to a heterogeneous set of social and institutional factors that may be combined together under the label *socio-institutional system* (see also Freeman and Louça 2001; Castellacci 2004). The underlying idea motivating this framework is that the dynamics and complex interactions between these six dimensions represent the driving force of national systems' social and economic development, and it is therefore crucial for empirical analyses in this field to have statistical information available for a large number of indicators and country-year observations, and to study how each of these dimensions evolve in the long run.³

Dimension 1: Innovation and Technological Capabilities

This is one of the crucial dimension on which empirical literature in this field has so far focused. Three related aspects contribute to shape each country's innovative capability. Innovative inputs represent the total efforts and investments carried out by a country for R&D and innovative activities, that is, its innovation intensity. Its scientific output denotes the result of research and innovation activities carried out by the public scientific and technical system, for example, scientific and technical publications. The technological output refers to the total output of technological and innovative activities carried out by private firms, such as in particular patents, the commercialization and export of new products.

Dimension 2: Openness

This represents the openness of the national system, a proxy of the potential for exchanging knowledge and technical information with other nations and hence imitating and absorbing foreign advanced technologies. The more open the system, the more capable it is to imitate internationally available advanced knowledge (Fagerberg 1994).

Dimension 3: Infrastructures

A greater level and quality of infrastructures (e.g., network, transportation, distribution) increases the country's capability to absorb, adopt, and implement foreign advanced technologies (Freeman 2004).

Dimension 4: Education and Human Capital

This is the key absorptive capacity variable typically emphasized by technology-gap models, according to which countries' ability to imitate foreign advanced technologies does to a large extent depend on their workforce's human capital (Verspagen 1991).

Dimension 5: Political Institutions

A better and more efficient governance system and institutional quality tends to increase the country's commitment to technological upgrading as well as its imitation capability (Fagerberg and Srholec 2008).

Dimension 6: Social Cohesion

A national system with a greater level of social cohesion and within-country income equality is in general characterized by a higher degree of trust and knowledge sharing, hence supporting the pace of diffusion and adoption of advanced knowledge within the country (Arocena and Sutz 2003).

National Specificities and Cross-Country Heterogeneity

This stylized framework intends to provide a general background for our empirical analysis of the global evolution of national innovation systems. Nevertheless, it is important to emphasize that, although these six conceptual dimensions are arguably important for all countries, the way in which they combine and interact with each other greatly differs among national economies. In particular, the specific trajectory followed by distinct national systems of innovation and the specific set of key factors driving the dynamics of the system may differ across country groups characterized by different levels of development. To illustrate this, consider for instance some of the main differences between advanced (high-income), middle-income, and less developed economies, as often depicted in the literature.

Advanced countries are usually rich in terms of both absorptive capacity (infrastructures, openness, and human capital) and innovative capability. In particular, private R&D capabilities become a more central engine of growth as compared to less advanced national systems, and they are also more closely related to the development of public scientific activities. This is one of the central points made by historically oriented studies on the emergence of new world leaders such as Imperial Germany (Veblen), the United States (Abramovitz), and Japan (Freeman), as well as the seminal studies on national systems of innovation in advanced economies (Nelson 1993). Therefore, this group of countries is typically characterized by an intense and complex web of relationships among the key variables driving the system, and in particular a two-way process of coevolution between innovative capability and absorptive capacity.

Compared to the advanced group, middle-income countries often lack the innovative capability that is required to become a world technological leader. However, they have in

general a well-developed absorptive capacity and may then exploit the international diffusion of advanced technologies. For instance, previous studies of East Asian innovation systems have pointed out their rapidly increasing levels of human capital, ICT infrastructures, and export specialization and competitiveness (Edquist and Hommen 2008). Compared to the East Asian group, Latin American economies are instead characterized by lower levels of human capital and technical training, as well as a more traditional (resource-based) export specialization profile (Nelson 1993; Alcorta and Peres 1998). Finally, former Soviet countries in Eurasia, in spite of their high levels of human capital, have in general lower private R&D capabilities and weak scientific and technical interactions, which can be explained as the historical heritage these countries have received from the Soviet innovation system and its heavy reliance on publicly funded defense R&D (Freeman 1987; Nelson 1993). All in all, within the broad (and heterogeneous) group of middle-income economies, we normally find weaker interactions among the innovative capability variables, because of the less central role of R&D in the national system and, for the same reason, weaker interactions between innovative capability and absorptive capacity.

Finally, in less developed countries, national systems do not only lack strong innovative and R&D capabilities, but are also characterized by a more limited absorptive capacity, for example, in terms of lower levels of human capital and technical training, infrastructural investments, and ability to reap benefits from international trade activities (Fagerberg et al. 2007; Castellacci 2008; Lundvall et al. 2009). As a consequence, for this group of countries most of the dynamic interactions and coevolution patterns among the six conceptual dimensions noted above are likely to be weaker or non-existent. Below a threshold level of development, innovative capabilities and absorptive capacity are low, and their interaction is therefore not expected to be a key driver of the economic system.

Data, Indicators and Descriptive Evidence

Our empirical analysis makes use of the CANA database, a newly released cross-country panel dataset containing a large number of indicators for the period 1980–2008 (Castellacci and Natera 2011). The novelty of the database is that it provides full information for the whole set of country-year observations, and so it contains no missing value. The dataset has been constructed by combining together indicators available from a number of existing cross-country data sources, and then applying the method of multiple imputation recently proposed by Honaker and King (2010).⁴

The CANA dataset is an attempt to provide a broad, comprehensive, and widely accessible database of a large number of indicators measuring countries' technological, social, and economic characteristics. In particular, the CANA dataset enables us to measure some of the main characteristics of national systems of innovation and carry out a cross-country comparative analysis of their differences and long-run dynamics. Based on the theoretical framework outlined in the previous section, we use this database to obtain four indicators for each of the six dimensions of NIS (see [Figure 1.1](#)).

Dimension 1: Innovation and Technological Capabilities

- R&D: R&D expenditures as a percentage of GDP (source: UNESCO, OECD).
- Scientific articles: Number of scientific articles per million people (source: NSF).
- High-tech products: Export of high-tech products as a share of manufacturing exports (source: World Bank).
- Patents: Number of patents registered at the US Patent and Trademark Office per million people (source: USPTO).

Dimension 2: Openness

- Inward FDI: Inward FDI flow, share of GDP (source: World Bank).
- Import: Imports of goods and services as a share of GDP (source: UNCTAD).
- Export: Export of goods and services as a share of GDP (source: UNCTAD).
- Openness: (Export + Import) / GDP (source: UNCTAD).

Dimension 3: Infrastructures

- Electricity: Kilowatts of electricity consumed per hour per capita (source: World Bank).
- Telephony: Sum of telephone mainlines and mobile phones per 1000 people (source: ITU, UNDP, World Bank).
- Carrier departures: Domestic takeoffs and takeoffs abroad of air carriers registered in the country, per 1000 inhabitants (source: World Bank).
- Paved roads: Paved roads as a percentage of the whole road length of the country (source: World Bank).

Dimension 4: Education and Human Capital

- Primary enrollment ratio: Share of primary students (source: UNDP, World Bank).
- Secondary enrollment ratio: Share of secondary students (source: UNDP, World Bank).
- Mean years of schooling: Average number of years of school completed in the population over 14 (Barro and Lee 2001; UNDP, World Bank).
- Tertiary enrollment ratio: Share of tertiary students in science and engineering in the population of that age group (source: UNDP, World Bank).

Dimension 5: Political Institutions⁵

- Political rights: People's free participation in the political process. It ranges from -7 (low freedom) to -1 (total freedom) (source: Freedom House).
- Civil liberties: People's basic freedoms without interference from the state. It ranges from -7 (low freedom) to -1 (total freedom) (source: Freedom House).
- Freedom of press: It reflects the degree of freedom that journalists and news organizations enjoy in each country, and the efforts made by the authorities to respect and ensure respect for this freedom. Index from -115 (no freedom) to 0 (high freedom) (source: Reporters Without Borders).
- Freedom of speech: Extent to which freedoms of speech and press are affected by government censorship, including ownership of media outlets. Index from 0 (Government censorship) to 2 (No Government Censorship) (source: Cingranelli and Richards 2008).

Dimension 6: Social Cohesion

- Corruption: Corruption Perception Index, ranging from 0 (High Corruption) to 10 (Low Corruption) (source: Transparency International).
- Inequalities: Gini index (within-country income inequalities).
- Trust: Percentage of respondents who agree with the statement "Most people can be trusted" (source: World Value Survey).