



The Handbook of Global Science, Technology, and Innovation

Edited by Daniele Archibugi and
Andrea Filippetti

The Handbook of Global Science, Technology, and Innovation

Handbook of Global Policy Series

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Edited by

Daniele Archibugi and Andrea Filippetti

WILEY Blackwell

This edition first published 2015
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Chapter 22 © 2015 Paolo Davide Farah and Riccardo Tremolada

Registered Office

John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

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Library of Congress Cataloging-in-Publication Data

The handbook of global science, technology, and innovation / edited by Daniele Archibugi and Andrea Filippetti.

pages cm. – (Hgp – handbooks of global policy)

Includes bibliographical references and index.

ISBN 978-1-118-73906-8 (hardback)

1. Research–Industrial–Handbooks, manuals, etc.
2. Technology transfer–Handbooks, manuals, etc.
3. Technology and state–Handbooks, manuals, etc.
4. Science and state–Handbooks, manuals, etc.

I. Archibugi, Daniele. II. Filippetti, Andrea, 1977–

T175.H35 2015

338.9'26–dc23

2015004138

A catalogue record for this book is available from the British Library.

Cover image: Computer circuit board © blackred / iStockphoto

Set in 10/12.5pt Sabon by SPi Global, Pondicherry, India

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

Daniele Archibugi and Andrea Filippetti

“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.

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

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

<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
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

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

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 head-quarter 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.

Acknowledgements

Editing a handbook like this one is first and foremost a collective venture. Therefore our gratitude goes in the first place to the enthusiastic and professional participation of all the authors. We are also indebted to Ben Thatcher from Wiley-Blackwell for his relentless and professional support. Daniele would like to acknowledge a grant from the School of Business, Economics and Informatics, Birkbeck College, University of London, which initially supported research on the globalization of intellectual property rights. He would also like to thank his colleagues at the Italian National Research Council, IRPPS, and at the Department of Management, Birkbeck, for their continuous support. Andrea would like to acknowledge that this project has been supported by a Marie Curie Intra-European Fellowship project under the EC Grant Agreement No. PIEF-GA-2011-298167, carried out at the Department of Geography and Environment of the London School of Economics and Political Science. He would like to thank the Department for its support, and to express a particular gratitude to his supervisor, Simona Iammarino. Part of this work has been carried out during his pleasant visiting period at the Department of Political Science at the University of Columbia, New York. Finally, he would also like to thank his colleagues at the Italian National Research Council, ISSiRFA, and particularly Stelio Mangiameli, for their continuous support.

Rome and New York, December 2014

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).

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